

Piezoelectric devices for energy harvesting in building structures

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INTRODUCTION

Devices that convert vibration energy into electricity and are capable of its accumulation (energy harvesting) are very promising both in mechanical engineering (damping oscillations with the conversion of excess energy into electricity) and in electronics and the environment (systems for energy storage and replenishment). That systems convert extra motion of engineering devises into electrical energy used for their autonomous operation or for power supply of other devices [1]. Another application is portable electronics, where energy storage devices can power or charge mobile phones or other devices. When energy sources are limited, energy harvesting plays an important role in the environment.

Energy harvesting as a separate direction began to develop in the 1990s. Human, bicycle, water flow, low-frequency oscillations in mechanisms, etc. can be used as sources of mechanical energy for the piezoelectric transducer. Usually, due to steady oscillations, piezoelectric elements produce alternating electric current, showing the greatest efficiency at resonant frequencies. Most piezoelectric power sources produce power of the order of milliwatts, which is small enough for system use but sufficient for portable devices. Piezoelectric systems can convert the movement of the human body, such as the movement of legs and arms, shocks and blood pressure to obtain energy from implanted or portable sensors. Piezoelectric elements are built into running and walking roads, shoes, pavement, etc. One of the priority areas of research is the development of autonomous wireless sensors that receive energy from the measured signal, or use other ways to obtain mechanical energy. Their use becomes relevant in atypical tasks –

measuring oscillations in hard-to-reach places of rotating mechanisms, seismic sensors and so on. Smart roads can play an important role in electricity generation. The incorporation of piezoelectric material into the road can convert the pressure exerted by moving cars into voltage and current.

STRUCTURE OF ENERGY HARVESTING SYSTEMS

For energy harvesting usually are used sensors and motors of cantilever beam structure, consisting of a membrane lower electrode, film, piezoelectric film and the upper electrode (bimorphs and multilayer elements). PZT thin films are used for force sensors, accelerometers, gyroscope motors, micropumps [2].

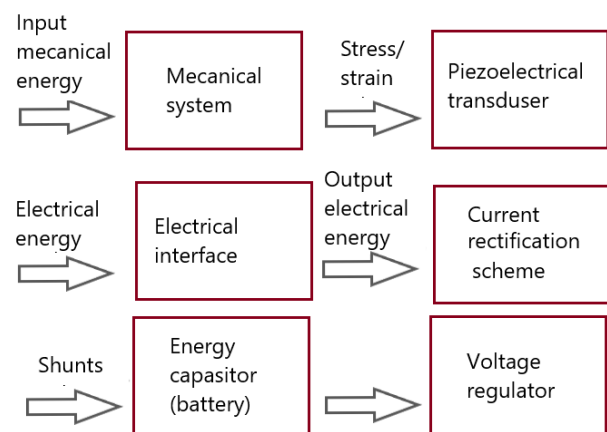


Fig. 1. Structure of energy harvesting devices

The connection between the piezoelectric elements is provided by a shunt chain [3]. In Fig. 1 it is presented as a rectification scheme. In the case of passive damping, due to the piezoelectric effect, part of the mechanical energy of the oscillations of the structure is converted

into electrical and is removed or collected by means of a shunt circuit.

For active damping, actuators oscillating in antiphase with undesired design frequencies are also introduced into the circuit. The mode of operation of the actuators is determined from the data obtained from sensors that read and transmit to the controller the existing electromechanical or acoustic state of the element. Resonant shunt circuits are able to adjust to the frequency to be damped, due to the presence of an inductor and a resistor. The piezoelectric element in the electrical circuit works as a capacitor.

The obtained electricity is stored in a capacitor, supercapacitor or battery (energy storage on Fig. 2). Capacitors are used for possible large voltage spikes. Batteries are used when the device requires a steady flow of energy. Supercapacitors have virtually unlimited charge-discharge cycles, but are much less accessible than capacitors.

piezoelectric element during vibration can get significant deformation. The manufacture of piezoelectric consoles is relatively simple and inexpensive. The main bend frequency of the console is much lower than other modes of vibration of the piezoelectric element. Most developed piezoelectric devices use a unimorph (one layer of piezoelectric material attached to a non-piezoelectric layer) or a bimorph (two layers of piezoelectric material attached to a non-piezoelectric layer). The bimorph structure doubles the energy given off, so it is used more often than the unimorph one. To adjust the resonant frequency of the console, an additional mass is attached to the free end.

Non-resonant energy transducers are usually in the form of a plate or a multilayer piezoelectric element (stacks) [5]. The structure of the transducers in the form of plates enhances the mechanical impact used to improve the output power of energy harvesting.

In stack architecture, piezoelectric materials are used in the mode of longitudinal oscillations, which have a higher conversion factor than the transverse mode. Since the first natural frequency of piezoelectric stacks usually exceeds 1 kHz, while the natural oscillations of the structure usually occur in the range of 10 Hz - 100 Hz, such piezoelectric elements are used out of resonance. Plates and stacks have low vibration sensitivity with low amplitude, but can withstand much higher mechanical loads (especially stacks) than cantilever energy collectors.

Matching elastic or viscoelastic layers are used in the stacks to match the resonant frequencies of the transducer with the oscillating frequencies of the structure [6]. To determine the real oscillations amplitudes of elements at resonant frequencies, energy dissipation is taken into account [7].

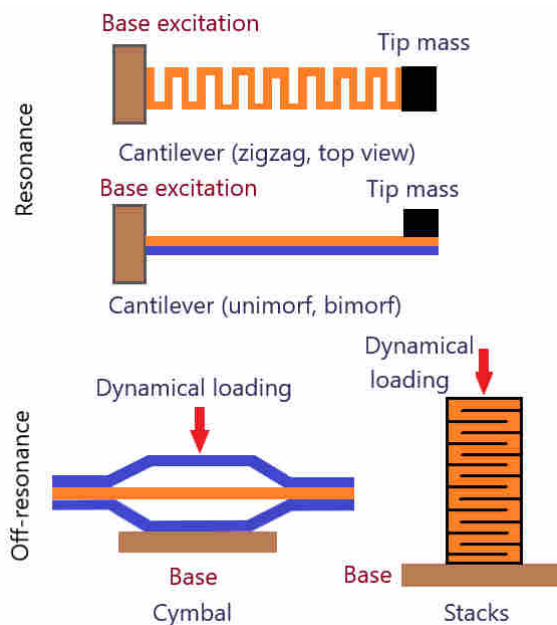


Fig. 2. Piezoelectrical elements for harvesting of energy

TYPICAL PIEZOELEMENTS FOR HARVESTING OF ENERGY

The cantilever rod is one of the most widely used forms of piezoelectric energy harvesters [4], especially for mechanical energy collection from vibrations, because of the piezoelec-

MATHEMATICAL EQUATIONS

Full system of piezoceramic body vibrations includes equation of continuous medium motion $\sigma_{ij,j} = \rho \ddot{u}_i$; quasi-static approximation of Maxwell's equations $D_{i,i} = 0$, $E_i = -\phi_{,j}$; piezoeffect physical relations in form $\sigma_{ij} = c_{ijkl}^E \epsilon_{kl} - e_{kij} E_k$, $D_i = e_{ikl} \epsilon_{kl} + \epsilon_{ik}^S E_k$, or in

equivalent form
 $\varepsilon_{ij} = s_{ijkl}^E \varepsilon_{kl} + d_{kij} E_k$, $D_i = d_{ikl} \sigma_{kl} + \varepsilon_{ik}^T E_k$; and
 geometric Cauchy relations
 $\varepsilon_{ij} = (u_{i,j} + u_{j,i})/2$, which are written using
 the notation accepted in tensor algebra. In this
 relations $\sigma_{ij}, \varepsilon_{ij}$ - components of tensors of
 mechanical stresses and strains; u_i, D_i, E_i -
 components of vectors of mechanical dis-
 placements, electrical induction and electric
 field strength; φ - electrical potential; ρ -
 medium density; $c_{ijkl}^E (s_{ijkl}^E)$, $e_{kij} (d_{kij})$,
 $\varepsilon_{ik}^S (\varepsilon_{ik}^T)$ - elastic, piezoelectric and dielectric
 constants for piezoceramic. For elastic induc-
 tive elements of system there are used the
 same relations with zero piezoelectrical con-
 stants. Differential equations are closed with
 boundary conditions. At mechanical loading
 on open electrodes appears difference in po-
 tentials, what can be found from condition
 $\int_{\Omega_i} \dot{D}_i n_i d\Omega = 0$. For bodies of simple geometry
 (cantilever beam or round disk) the problem
 can be reduced to one-dimensional equations,
 what can be simply solved.

CONCLUSIONS AND RECOMMENDATIONS

Energy harvesting using piezoelectric transducers is a promising and rapidly evolving area in engineering. The application of the proposed technologies allows to convert unnecessary oscillations into electrical energy and accumulate it for further autonomous operation of the device. The geometry of typical piezoelectric elements used in energy collection is quite simple and allows to reduce the problem to one-dimensional equations that can be solved analytically or by simple numerical means.

The reaction of the piezoelectric element on mechanical perturbation in the nonstationary

mode requires multimode analysis. But perturbations propagating in elements in other directions can cause undesirable effects at certain frequencies.

Therefore, for a clear understanding of the operating conditions of the device, it is necessary to conduct additional analysis with three-dimensional theory using numerical methods, taking into account the influence of the environment and matching viscoelastic layers.

Keywords: energy harvesting, piezoceramic sensor, transduction of energy, accumulating of energy, autonomous devices, resonance and off-resonance modes.

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