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ME128, Fall 2010 **Liwei Lin**

Final Project #3

Design of an Energy Harvester

“Energy or power harvesting” is the process of acquiring energy from surrounding and converting it into usable electrical energy. This area of research has emerged in recent years as the technology of wireless communications and wireless sensing become mature while long-term energy source becomes an issue. This project aims to design an energy harvester by using piezoelectric bimorph (two-layer bender with metal shim) as power source for the purpose to replace battery or as semi-permanent energy generator. A bimorph mounted as a cantilever beam with a proof mass placed on the free end is essentially the basic structure of harvester (Figure 1). First, for a given vibration (force input), the cantilever configuration results in the strain accumulated along the beam and the power output is closely related to the average strain developed in the bender. Second, the proper design of the cantilever with end mass can result in lowest resonant frequency for the target application at low frequency vibration sources.

Part A

The following parameters are fixed and not adjustable for you:

Maximum volume of device ≤ $50000mm^3$
Maximum Cross Sectional Area (viewing from the top) ≤ $2500mm^2$
Acceleration of vibration source ≤0.2g
1mm ≤ Width of any structure
0.1mm ≤ Thickness of piezo-layer, t ≤ 1mm
0.1mm ≤ Thickness of metal shim ≤ 1mm

The following are the engineering goals you must meet:

Minimum power output ≥ 2.5mW
Maximum allowable stress in piezoelectric material ≤ 25MPa
The housing material should be inexpensive and plastics is preferred
The natural frequency of the harvester is preferred between 100 ~ 200Hz

The actual power output of the piezoelectric harvester is rather complicated and is closely related to the matching of electrical circuit as well as resonant frequency and the driving frequency provided by the environment. One can design the harvester in terms of geometry, piezoelectric properties, proof mass, anticipated acceleration magnitude and anticipated driving frequency of the environmental vibration source etc. You are welcome to adopt more advanced models or FEM to evaluate the power output more accurately.

Further assumptions:

You can consider piezoelectric material as isotropic (which is generally not true). The typical piezoelectric material PZT-5H has dielectric constant (ε_{33}):3500x8.85x10^{-12} F/m, and piezoelectric transverse constant (e_{31}): 6.62281 C/m^2. You can use the follow material properties:

Piezo: equivalent to P5A~P5H
E_{11}= 6.3×10^{10} N/m^2
ρ= 7800 kg/m^3
Poisson ration: 0.31

Shim metal: copper
E= 11.7×10^{10} N/m^2
ρ= 8900 kg/m^3
Poisson ration: 0.34

Plastics: ABS
E= 1.8×10^9 N/m^2
ρ= 1040 kg/m^3
Poisson ration: 0.35~0.42

The power generated from piezoelectric harvester can be estimated by a simplified analytical model [1]. In order to use this model, you design must have the cantilever shape as illustrated in Figure 1 with a mass at the end and the piezoelectric material thickness is very thin as compared with the metal shim thickness. In analyzing the deflection amplitude, A, at the end of the free end (the beginning of the mass), we only consider force vibration for conservative estimation.

Simplified analytical model [1]
Power = $\dfrac{\omega^2 b^2 h^2 e_{31}{}^2 A^2}{4(1+bL\varepsilon_{33}\omega R/t)^2} R$
ω:driving frequency(Hz) A: strain at the fix end of the cantilever (see [1]) h: metal shim thickness(m) R: matching external electrical resistance(ohm) L, b ,t are length, width and thickness (in meter) of bimorph respectively e_{31}:piezoelectric transverse constant (C/m^2) ε_{33}: dielectric constant (F/m)

Please complete the design by constructing the structure so that your design meets all the constraints and goals. If you can't meet all the constraints and goals, then attempt to meet them as much as possible and explain why you feel your choice of parameters is the best. For the report, please follow the format given on the website and be sure to explicitly state the values of:

1. Plot the figure of output power versus matching resistance R and determine the optimal R and the magnitude of power generation for your design.
2. All chosen geometry and dimensions for your design.

3. If you cannot find a solution under these constraints, what are the things would you change in order to meet most of the requirements?

In the theory section of the report, please be sure to clearly state your decision logic in choosing the values of the dimensions you select. "I just made guesses," "I gave up after 2 hours of trying" or similar characterizations are not acceptable statements of the decision logic. You can use Matlab or other environment to do the computations and use the FEM analysis to verify your design results.

[1] F Lu et. al., "Modeling and Analysis of Micro Piezoelectric Power Generators for Micro-electromechanical-systems Applications", Smart Mater. Struct. 13(2004) 57-63.

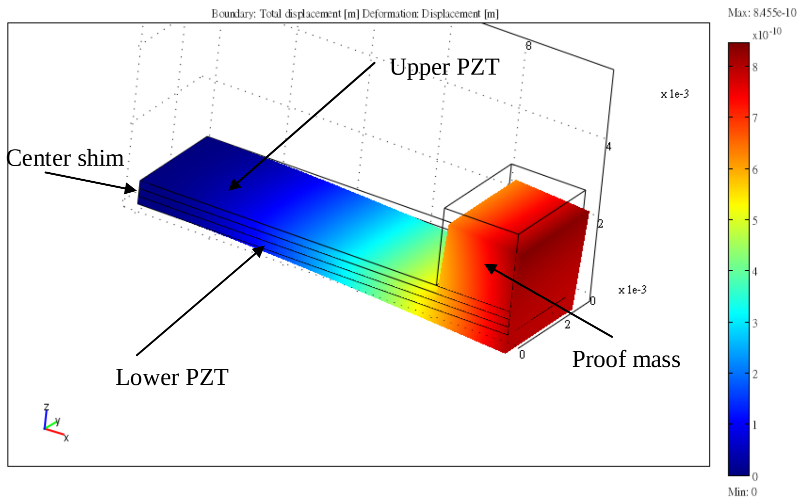

Figure 1, A design example showing the core of the harvester based on cantilever/mass.

Part B

It was assumed that your energy harvester structure has fixed shape in part A of the project such that you can use the simplified formula. You will get your full credit by working on Part A only. You are welcome to work on one or several of Part B only if you have finished Part A and would like to get extra challenge and credits. This part of the project considers several issues that were neglected in Part A of the project.

1. re-derive the formula that will include various effects such as the material differences of piezo-layer and metal shim layer, the effect of the end mass to the moment of inertia and other things …
2. what if the width of the cantilever is not a constant but different shapes?
3. what if multiple layer of piezo materials can be used?
4. can we get better estimation by using FEM models on the accumulated strain of the structure instead of using the simplified formula?