Comparison of different beam shapes for piezoelectric vibration energy harvesting

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This paper reports the comparison of different beam shapes of piezoelectric harvesters in regards to their stress level and power harvestable. We proved that trapezoid and circular shapes allow to reduce the stress level in the material for a low decrease of the power harvested at a given resonance frequency, which increases the reliability of the device.

There is nowadays a huge interest for wireless sensor networks in industrial or natural environment. A way to improve these networks is to replace batteries at each network's nodes by piezoelectric ambient energy harvesters ([1], [2]), to have energy sources with an important lifetime. As a consequence, an important issue of these scavengers is reliability, and in particular their tolerance to high acceleration input. The tolerance of the device to high acceleration can be improved by reducing the maximum stress level in the device.

Usually, the piezoelectric energy scavenger structure is a clamped free beam, with a piezoelectric thin layer deposited on top, and a seismic mass at the end of the beam to reduce the resonance frequency. We can see on figure 1 that the maximum of stress in the rectangular beam is located near the clamping. To reduce this maximum, we have to widen the beam at the clamping, and to thin down the beam far from the clamping to keep the same resonance frequency. Two structures have been proposed to reduce the maximum of stress: trapezoid shaped-beam [3] and circularly fittered beam [4] (figure 2), but their efficiencies were not compared. In this paper, we will compare the stress reduction and the power harvested of both kinds of beams.

We have done some Finite Elements Modelling (FEM) with Ansys™ to compare the behaviours of the beams. We proved that triangle and curved shaped beams reduce the stress level by spreading the maximum of stress spatially (figure 3). As a consequence, trapezoid-shaped and circularly filleted beams can support higher acceleration than rectangular beams. We compared the performance of trapezoid-shaped and circularly filleted beam, for a given resonance frequency of 200Hz and a fixed acceleration of 0.25g, with given beam length and mass dimensions. For each simulation we changed the non-rectangular length to beam length ratio (L_c/L_b), but we kept the same resonance frequency by changing the beam width. We can see on figure 4 that the stress reduction is very important compared to the power reduction. Trapezoid-shaped beams showed the best stress reduction with 61% of reduction, but with 18% of power reduction, as circularly filleted beams showed 59% of stress reduction for 7% of power reduction. Therefore, both structures are promising structures for stress reduction and improvement of reliability.

Home-made MEMS devices have been fabricated, with a thin piezoelectric layer of aluminium nitride, which has a CMOS compatible deposit process. Different devices are being fabricated, including rectangular, trapezoidal and circularly filleted clamped-free beams. Fabrication results and the first characterisation results of these devices will be presented. Simulation and experimental results will be compared in term of power harvested.

Word count: 498

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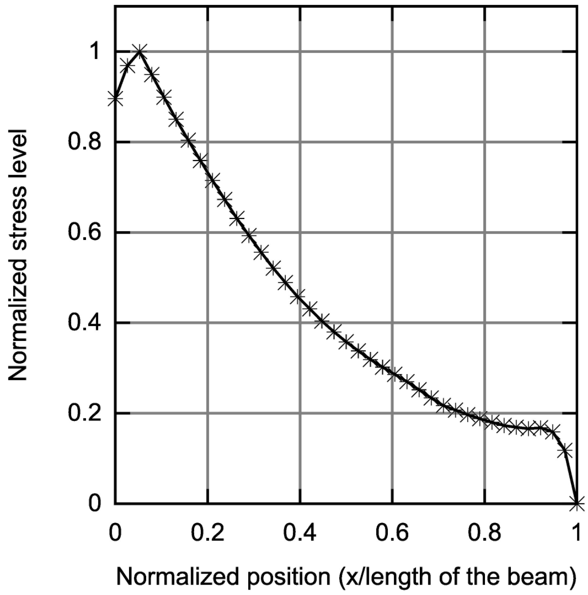

Figure 1. Stress level in a rectangular beam depending on position (0 is the clamping).

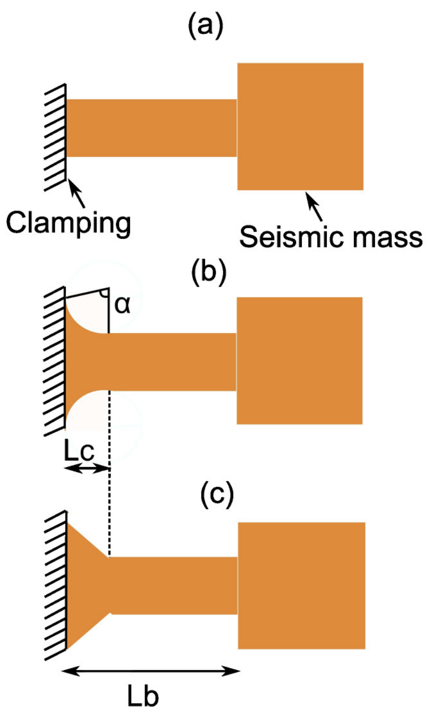

Figure 2. Top view of: (a) Rectangular-shaped beam, (b) circularly filleted beam and (c) trapezoid-shaped beam. L_c is the non-rectangular length.

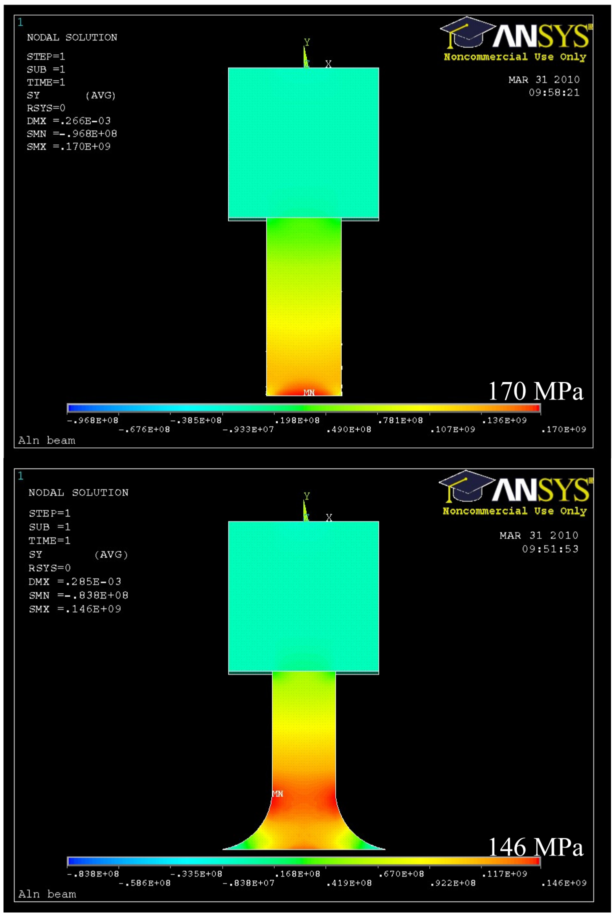

Figure 3. Stress distribution in a rectangular-shaped beam (top) and in a circularly filleted beam (down).

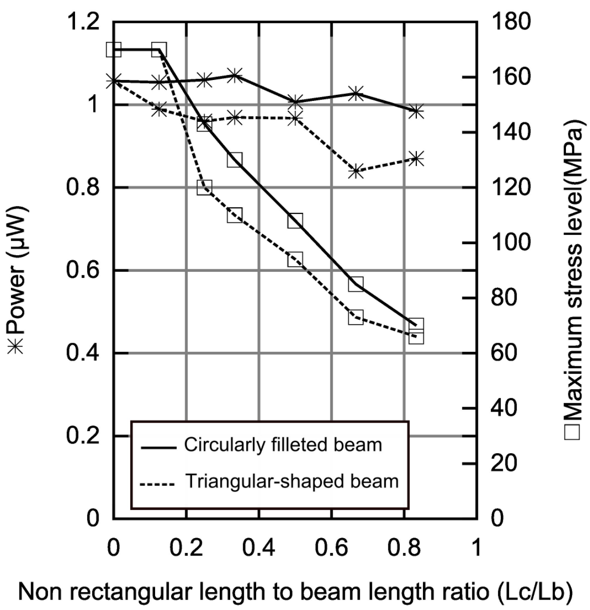

Figure 4. Comparison between stress reduction and power harvested for trapezoid-shaped beam and circularly filleted beam for different non rectangular to beam length ratio (L_c/L_b) at a given resonance frequency of 200Hz and a fixed acceleration of 0.25g.