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INNOVATIVE ENERGY HARVESTER DESIGN USING BISTABLE MECHANISM WITH COMPENSATIONAL SPRINGS IN GRAVITY FIELD

Bogdan Vysotskyi[1,2], Fabien Parrain[1], Denis Aubry[2], Philippe Gaucher[2] and Elie Lefeuvre[1]

[1]Centre for Nanoscience and Nanotechnology (C2N) – Site d'Orsay, Univ. Paris-Sud, Université Paris-Saclay, Bât. 220, Rue Ampère, 91405 Orsay, France

[2]Laboratoire Mécanique des Sols, Structures et Matériaux, CentraleSupélec, Université Paris-Saclay, Châtenay-Malabry F-92295, France

E-mail: bogdan.vysotskyi@c2n.universite-paris-saclay.fr

Abstract. The purpose of the presented work is to introduce the novel design of electrostatic energy harvester using bistable mechanism with compensational springs in gravity field capable of providing the output of several µW under the excitation of extremely small amplitude (up to 0.2g) and low frequency (10-100Hz). Presented energy harvester uses the bistable hysteresis modification to achieve low-frequency low-amplitude sensibility. It was demonstrated with finite element modelling (FEM) that hysteresis width produced by bistability is changing with a constant linear coefficient as a function of a compensational spring stiffness and thus a device sensitivity could be adjusted to the minimum point for the amplitude of external excitation. Further, highly non-linear bistable double curved beam mechanism assures the high sensitivity in frequencial domain due to the non-defined bandwidth. The equivalent circuit technique is used for simulating the device performance.

1. Introduction

Today energy harvesting aims towards offering the solutions for supplying the variety of standalone devices with the electricity. The possible applications for compact self-recharging sources of energy are immense: from structures health monitors and tire pressure sensors to biomedical devices.

Creation of the energy harvester that will be able to replace a conventional battery in task of powering the pacemaker had been considered as one of the major challenges in energy harvesting domain during the last several years. Typical requirements for such a device is relatively small size (volume <1cm^3), long lifetime (more than 20 years) and the power output delivering 1-10µW. In this paper we propose a concept, design and simulations of the device that is expected to meet the required characteristics.

The bistable mechanism had been chosen for such a device in order to achieve high bandwidth in low frequency domain. It is explained by the fact that the switching between stable positions depends only on the value of the force applied, and frequency dependence is significantly suppressed due to the presence of strong non-linearity.

Another innovation of the offered mechanism is the use of a gravitational effect. Generally, in MEMS domain gravitational offset is either neglected due to the low masses involved [1], either is meant to be perpendicular to the operational plane of the device [2]. In this case, when the device is aligned with gravitational force it is not expected to be functional. However, proposed energy harvester needs to be placed into gravity field in order to achieve its full sensibility.

Movement of a seismic mass is achieved by switching between stable positions of bistable hysteresis modified by the compensational springs, in contrast to previously reported hysteresis shift [3].

2. Design of the energy harvester

Presented energy harvester consists of bistable double curved beam mechanism [4], compensational springs, seismic mass and transducer part. The schematic representation of the device is shown on the Fig. 1. With the external excitation, the inertial force is acting upon the seismic mass, which leads to the switching between stable positions of bistable mechanism. However, due to the presence of the compensational springs and accurate choice of the mass, the required switching force is significantly lowered in comparison to non-compensated bistable system. It happens due to bistable hysteresis modification with linear spring. For the variable capacitance, an overlap geometry had been chosen in order to make use of all displacement amplitude of the seismic mass.

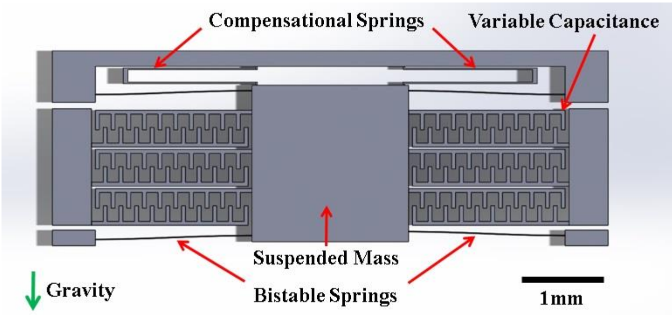

Figure 1. Schematic representation of the device using bistable mechanism and compensational springs in gravity field for energy harvesting.

Parameter	Value
Curved beam length, mm	2
Capacitive finger length, µm	120
Number of fingers	2688
Seismic mass, g	0.5
Compensational spring stiffness, N/m	60
Inter-finger distance, µm	5
Cmax, pF	35
Cmin, pF	239

Table 1. Summary of designed parameters.

2.1. Bistable hysteresis modification

A finite element modelling (FEM) with ANSYS© had been performed on the double curved beam bistable mechanism with linear compensational springs attached. It had revealed that a usual bistable hysteresis is significantly modified in the presence of the linear spring.

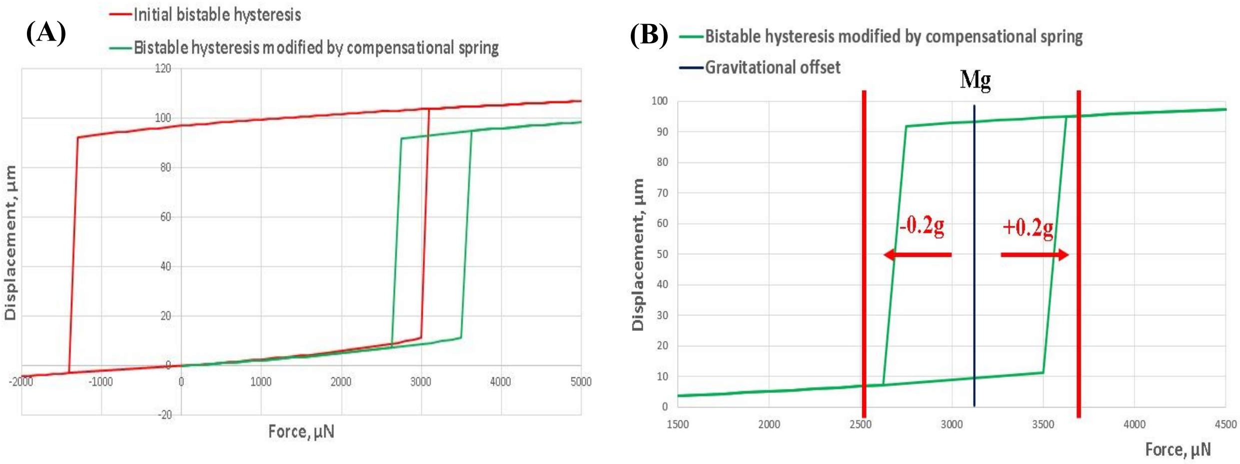

Figure 2. (A) Comparison of initial bistable hysteresis shape with bistable hysteresis modified by compensational spring with k=50N/m. Modified hysteresis becomes narrower and is pushed to a higher forces of switching; (B) Image showing the movement available with the sinusoidal excitation at 0.2g amplitude. With the chosen mass system is placed in the center of modified bistable hysteresis, making the seismic mass unstable and, thus, sensible to the small excitations.

As it could be seen on the Fig. 2 (A), compensational spring makes it harder to push the bistable system to another stable position, but the return into initial state is easier due to the pulling from the linear spring.

2.2. Use of gravitational offset
Hysteresis modification phenomenon could be used along with gravitational offset to achieve the high device sensibility in terms of acceleration. If the mass is chosen carefully, it will be possible to put the system in a highly unstable state by applying a gravity field (typical example is given on Fig. 2 (B)). Due to the positioning in the centre of hysteresis, even a small external acceleration (considerably less than 1g) could produce a switching of states in bistable mechanism.

3. Spice model

3.1. Mechanical part
For the simulation of the device performance a classical approach of building an equivalent circuit is used. Linear part of the harvester is simulated with RLC oscillator, whereas all other forces are included into the voltage behavioral source. Thus, additional external source takes into account the non-linearity that comes from the bistable system, force of gravity, electrostatic attraction inside the variable capacitance and the restoring force of the linear compensational springs. A sinusoidal source is used to simulate the external acceleration of a variable frequency and amplitude. The schematics of the equivalent circuit is shown on the Fig. 3. The resulting displacement over time is calculated. It is shown on the Fig. 4: switching is followed by near stable position vibration. With the lower amplitude of excitation the system behaves mainly in chaotic way, whereas when the amplitude is increased the movement reaches higher periodicity, up to the point of total following the excitation near the cut-off frequency.

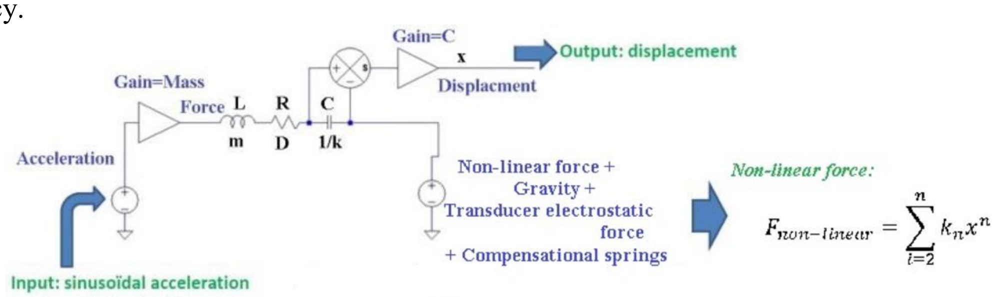

Figure 3. Equivalent circuit schematics of the energy harvester using bistable mechanism and compensational springs in gravity field.

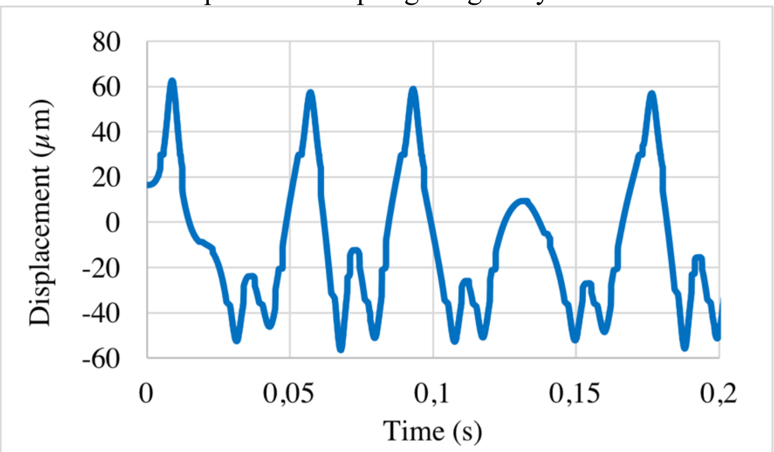

Figure 4. Spice simulation revealing the displacement of the seismic mass over time under 20Hz, 0.2g sinusoidal excitation.

3.2. Power output

To simulate a power output of the energy harvester, an interface circuit have to be chosen. For this work, we had taken the simplest one proposed by Lefeuvre et al. [5] in order to check the device performance.

Several simulations under different conditions had been performed. The excitation frequency of sinusoidal excitation and its amplitude had been varied in order to obtain the power output dependence (Fig. 5). It could be seen that harvested power is proportional to the excitation frequency. However, input acceleration affects only the bandwidth, keeping only the small impact on the amount of energy harvested. It could be easily explained by the fact that the movement is achieved by the switching of the bistable mechanism, whose design imposes almost constant displacement magnitude. Thus, the input excitation could either produce the switching which will lead to the power generation or not. Dependence of the bandwidth on the input acceleration comes from the strong non-linearity present in the system.

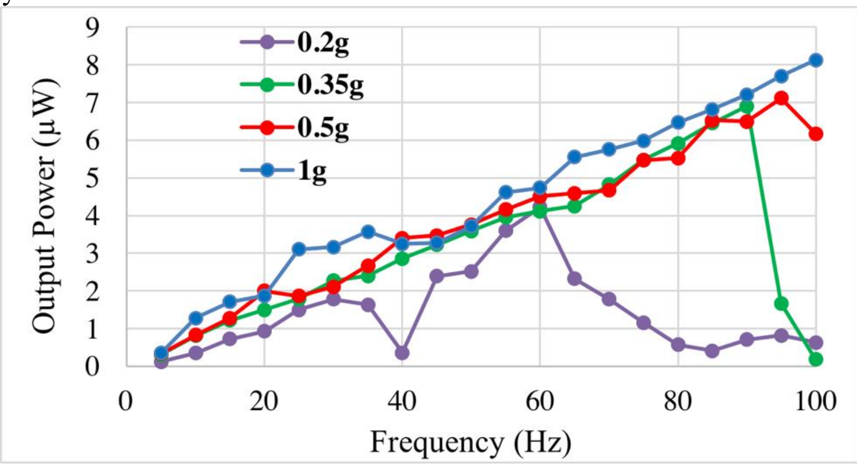

Figure 5. Simulated power output as a function of sinusoidal excitation amplitude and frequency. Note the changes in the bandwidth with the excitation amplitude whereas the power output is maintained.

4. Conclusions and future perspectives

In this work a novel technique of using the bistable hysteresis modification by compensational spring is employed in order to achieve extremely low values of harvestable accelerations (>0.2g) and frequencies (10-100Hz). Simulated power output lies in the range of several µW depending on the given excitation.

In the nearest future the device is going to be fabricated in Silicon with classical MEMS technologies and then characterized.

Acknowledgements

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