A wideband piezoelectric vibration energy harvester

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***Abstract* — This paper focuses on the design of the bistable energy harvester based on a patented solution invented by the SYMME / USMB laboratory and using Amplified Piezoelectric Actuator (APA®) technology. A preliminary prototype is developed considering the lifetime and mechanical limitations. Experimental results are also given for swept sine and random vibration.**

I. INTRODUCTION

The development of embedded and autonomous sensing solution is increasing in several industrial applications. The major constraints for the development of such devices is the availability of energy/power supply. Especially for applications implying a high cost for maintaining the function such as transport network (over cities, countries…). For these applications, solutions based on batteries have a lifetime limitation and wires supply are not adapted due to the accessibility and difficulty of installation.

The development of energy harvester solutions is increasing in the same way with the autonomous senor. Several solutions are already available on the market and on laboratories.

The most answered solution uses a linear oscillator tuned to match the excitation vibration. The narrow band solutions exploit a high mechanical quality factor at the frequency resonance of the linear oscillator. Contrariwise, these solutions are sensitive to any variation of the excitation vibration. On other hand, the environmental excitations have an energy dispersed over a frequency spectrum. A large bandwidth harvesting solutions are in this case required.

As a solution, bistable oscillators were proposed in the literature for energy harvesting as they offer a large bandwidth behaviour. Bistability is usually obtained thanks to either magnetic attraction/repulsion [1], either buckling effect [2]. This paper proposes a solution based on mechanical buckling effect.

II. EXCITATION SIGNAL

The preliminary design of any energy harvester requires an analysis of the excitation vibration signals and to know dispersion of the energy according to the vibration records. The performed analysis allow to have the mean representative signal. The mean signal shows an acceleration level of 3.5 g and two frequencies 110 and 180 Hz.

III. THE BISTABLE REPRESENTATION

A. The modeling

For the modeling, the architecture of the bistable energy harvester is simplified as given hereafter (FIGURE 1).

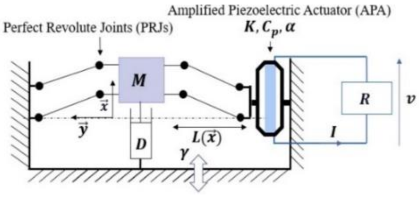

FIGURE 1. BISTABLE REPRESENTATION

The equation of motion and the current expression are provided in (1) from [2, 3]. K, C_p and α are the stiffness, the capacitance and coupling constant of APA respectively. The APA120 S was considered for this study. M, D and R are the equivalent mass, the damping coefficient, and the resistive load restive load respectively. γ is the base acceleration, x is the proof mass displacement and L is the beams length. x_0 is the buckling level and corresponds to the equilibrium position.

$$\begin{cases} M\gamma = M\ddot{x} - 2K\dfrac{x_0^2}{L^2}x + 2\dfrac{K}{L^2}x^3 + D\dot{x} + \dfrac{2\alpha}{L}xv \\ i = \dfrac{2\alpha}{L}x\dot{x} - C_P\dot{v} \end{cases} \tag{1}$$

B. The bistable response

The bistable response in terms of power and displacement was computed (the mean signal § II). Various values of M, L and x_0 were tested. In order maximize the harvested power while considering boundaries such as volume limitations and preliminary feasibility criterions (e.g., minimal x_0 physically feasible). As an illustration, the Figure 2 represents the expected power as a function of x_0 and M for L =35 mm. The red points correspond to the realizable configurations.

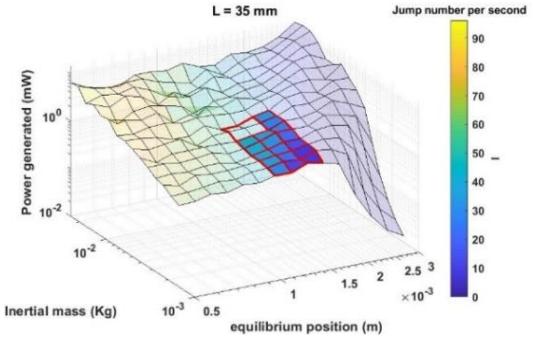

FIGURE 2. EXPRECTED POWER AND JUMP BETWEEN THE EQUILIBRIUM POSITIONS AS REPONSE

The dimensional parameter of the optimal design corresponds to $L = 35\,mm$, $M = 5\,g$ and $x_0 = 0.85\,mm$.

IV.

IV. MECHANICAL DESIGN

A. *The amplified piezoelectric actuator constraint*

The APA® consist of piezoelectric material installed inside a metallic shell for an amplification and preload purpose. Two limitations are considered: the dismounting of the piezoelectric material and the stress on the metallic shell. These limitations imposed a displacement limitation at 50 µm in compression and 480 µm in tensile.

B. *The beam thickness*

The beam width was fixed at 10 mm. The beam thickness had to be selected considering the limitations as it has a strong influence. The thickness must be limited to around 400 µm and 350 µm to not exceed the yield stress and APA® compression limits respectively. A thickness of 200 µm was considered for our prototype which correspond to 50 %of the yield stress.

V. PROTOTYPING AND EXPERIMENTS

A. *Prototyping*

The prototype is design and manufactured (FIGURE 3) according the optimal design (§ 0). The prototype allows the integration of different size of APA®.

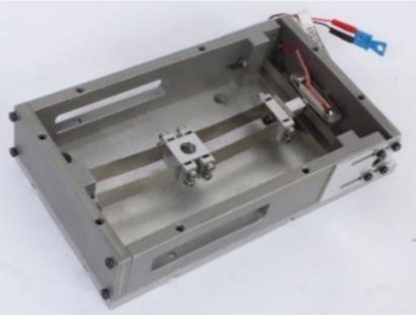

FIGURE 3. PROTOTYPE OF BISTABLE ENERGY HARVESTER

B. *Experimentation*

1) *Swept sine vibration*

The first evaluation is performed upon resistive load set at 1500 Ohm. The excitation vibration corresponds to swept sine vibration from 35 to 175 Hz at 3.5 g acceleration.

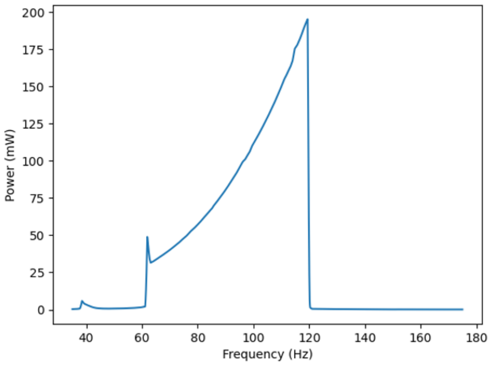

FIGURE 4. THE EXTRACTED POWER ON THE RESISTIVE LOAD

The minimum dissipated power upon the resistive load is about 30 mW at frequency 90 Hz ± 60% (Figure 4). The power raises the 190 mW at 120 Hz.

2) *Random vibration*

In random vibration test campaign, two profiles of vibration are used. The first profile (PSD1) includes two peaks at 110 and 178 Hz. The second profile (PSD2) include only one peak at 110 Hz. The comparison between two profile is given below (Figure 5).

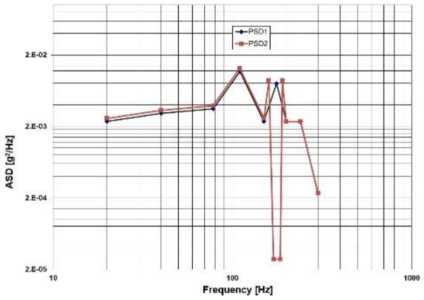

FIGURE 5. THE PROFILE OF PSD1 AND PSD2 VIBRATION

The power / energy extracted from the bistable energy harvester are measured (Figure 6). The level of acceleration is 3 grms and the duration is about 3 minutes.

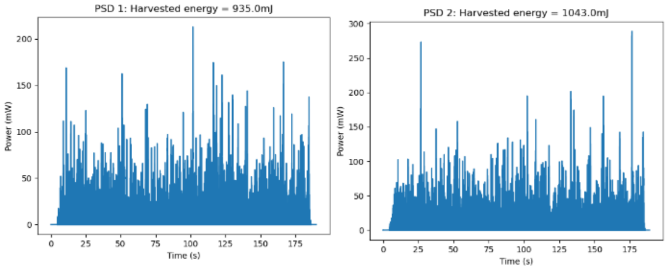

FIGURE 6. POWER / ENERGY EXTRACTED FROM BISTABLE HARVESTER WITH PSD1 AND PSD2 VIBRATION

The measurement shows a stability of the extracted energy even if there is a variation of the excitation signal.

VI. CONCLUSION

The broadband piezoelectric harvester has been presented in this document. The preliminary results show an available power of 30 mW at frequency 90 Hz ± 60% and 3.5 g acceleration. The random vibration test demonstrates a low sensitivity of the bistable energy harvester to two different PSD.

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