Energy Harvesting for Sensors in Infrastructure Monitoring and Maintenance

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Summary

Infrastructure monitoring and maintenance needs various kinds of sensors; all these sensors are expected to have long lifetime and self- maintenance and not be replaced. For non-destructive infrastructure monitoring, these sensors should be wireless, however, wireless sensors have an inherent problem on energy efficiency and energy consumption. Thus, how to power sensors efficiently or how to design a self-powered sensor is a key issue to this problem. Energy harvesting technique emerges as a new direction on getting power from environment. Piezoelectric and electromagnetic harvesting methods on vibration are analysed in this paper, and a low cost self-powered conversion circuit is modelled and simulated. Other kinds of energy harvesting are also briefly compared with those two methods; the solar-electric, vibration-electric, thermal-electric and electromagnetic-electric energy harvesting methods are briefly compared in this paper.

Keywords: Energy harvesting, Wireless sensor, Power efficiency converter, Low Voltage Multiplier, Structural Health Monitoring.

1. Vibration Model

The natural frequencies of the bridge include axial modes, lateral modes and longitudinal modes. But, the longitudinal bending modes are the most significant modes, as they contribute the most to the harvesting potential. Hence, the vibrations may be assumed as 1-D in the longitudinal direction.

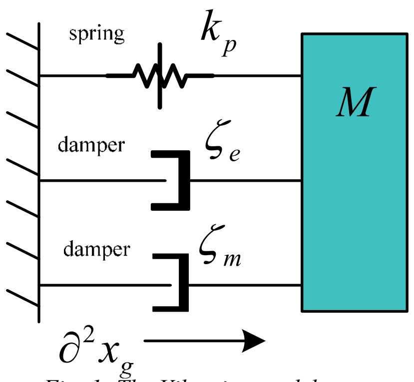

Fig. 1: The Vibration model

The energy harvesting unit (it can be Piezoelectric or electromagnetic) is placed on an cantilever which is connected with an additional mass with a stiffness factor k_p ,where the k_p has spring effect on the vibration mass [6]. Two equivalent dampers are assumed with mechanical damping factor ζ_m and electrical damping factor ζ_e , the x gives the real-time displacement of the mass and the ∂x give the speed of the movement, and the $\partial^2 x$ gives the acceleration, here x_g is the prescribed ground displacement.

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2. Vibration Based Magnetic Energy Harvesting

The magnetic based energy harvester can be employed in many configurations; the simplest model uses a static permanent magnet with one vibration coil which can be modeled as a wire coil attached to a seismic mass. The electricity is generated when the mass vibrates.

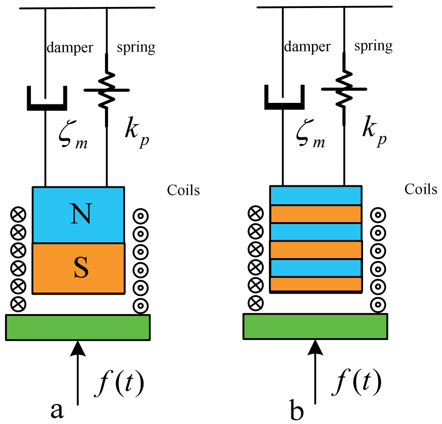

Fig. 2: The magnetic energy harvesting

$$V_i = n\frac{\partial\Phi}{\partial t} = n\frac{\partial\Phi}{\partial x}\frac{\partial x}{\partial t} = (n)\left(\frac{\partial\Phi}{\partial x}\right)(x') \quad (1)$$

Where the symbol Φ is the magnetic flux per coil per turn, and n is the number of the turns, and x is the displacement of the vibration magnet. For the case of Fig.2, the vibration model in Fig.1 can be rewritten with the real electrical damping factor; so the equation (1) can be rewritten with the electrical damping factor ζ_e as well as the voltage and current, according to the energy reservation law, the whole equation can be derived as

$$F_{ed} \times \partial x = (\zeta_e \partial x)\partial x = V_i \times i \quad (2)$$

3. Vibration to Electrical Energy Converter

The vibration energy either converted from PZT or magnetic coil is actually quite weak in terms of voltage and current. In order to use such energy properly, the voltage from the energy harvester has to be regulated. All the sensor circuits and the energy storage circuits involve certain number of transistors or diode, the typical threshold voltage for a diode is around 500~700mV, for transistor, at least 900mV voltage is required to power the circuit. However, the energy harvester usually provides 200mV voltage, so the conversion circuit should be able to provide such conversion ability. Fig.3 gives the final output voltage Simulated from the proposed voltage converter; we can see that after 200 seconds, the output voltage can reach 1.007 V. which is sufficient to power the transistor.

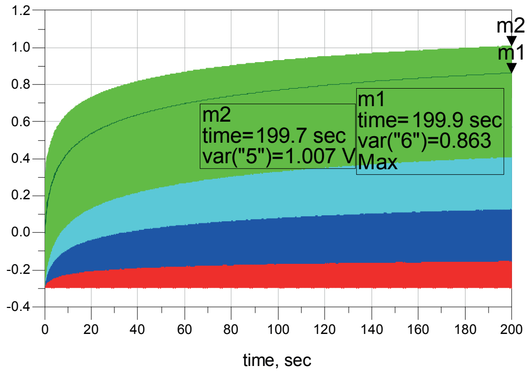

Fig. 3: Output Voltage of the Converter

A comparison between several energy harvesting techniques is given in the paper. It can be seen that the highest efficiency (power density) is given by the solar cell, however, the solar cell as its limitations during night time, the RF wave and thermal energy harvesting gives the lowest performance. Among the vibration based energy harvesting methods, the magnetic method is much higher than the piezoelectric method.

So for bridge monitoring or structural health monitoring, the vibration energy harvesting is proposed for all time energy collection (day and night), among the vibration energy harvesting method, the magnetic micro generator is proposed for high efficiency energy harvesting.