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Analysis and Optimization of a Piezoelectric Harvester on a Car Damper

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Abstract

Low power levels obtained from piezoelectric conversion of ambient vibrations appear to be a promising solution to supply wireless sensors embedded inside automotive suspension. However such a solution requires overall an optimum power extraction from the piezoelectric power harvester. This leads to the use of a sufficiently accurate and flexible modelling method to find the optimal characterics and configuration of the harvester. To this end, an innovative bond graph model of the piezoelectric harvester embedded in the quarter vehicle system is proposed for providing the harvested power when a car travels a road with a speed bump at 30km/h. Results show that around of 0.5 milliwatt electrical power is harvested when varying key parameters like the location and characteristics of the piezoelectric device.

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Keywords: Vehicule suspension, Energy harvesting, Piezoelectric vibration harvester, Bond graph modelling

1. Introduction

With the increasing use of remote sensors embedded in the vehicles, one of the primary challenges is to propose potential clean sources for powering them. In this study, the aim is to design and analyze piezoelectric vibrations harvesters located in a vehicle suspension for powering standalone systems, such as wireless transducers [1]. Considering the wireless character of sensors it is not recommended to supply it with the car battery. The main advantage of using ambient energy converted by piezoelectric materials instead of batteries is to decrease the system installation price. Furthermore, ambient vibrations energy that will be harvested is dissipated in the mechanical parts

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of the automobile. As the piezoelectric conversion level according to the mechanical excitation is around some milliwatts for a piezoelectric transducer bonded onto the structure, the development of an associated low power electronics adapted to the piezoelectric characteristics is essential for the power harvesting. To obtain optimal configurations of our generators, an innovative approach based on Bond Graph modeling of the piezoelectric vibration harvester inside the vehicle suspension is presented.

2. Evaluation of the power in the quarter vehicle system

To know how the power is distributed in the system, it is necessary to make a power balance. This leads to the use of the bond graph modeling which is well adapted to simulate power exchanges inside a multiphysics system. Such a study allows inferring the most interesting areas for power recovery. The mechanical model reference is the quarter car modeled by a dual-mass model [2-3]. The parameters are deduced from golden car suspension parameters. The model consists of a sprung mass of m_2, and an un-sprung mass of m_1 connected in series combination by a suspension spring with a stiffness of K_2 and a damper with a damping coefficient of C_2. The wheel is modeled with a spring stiffness coefficient K_1.The solicitation depends on random rough road with a motion function $y(t)$ as seen in Fig 1a.

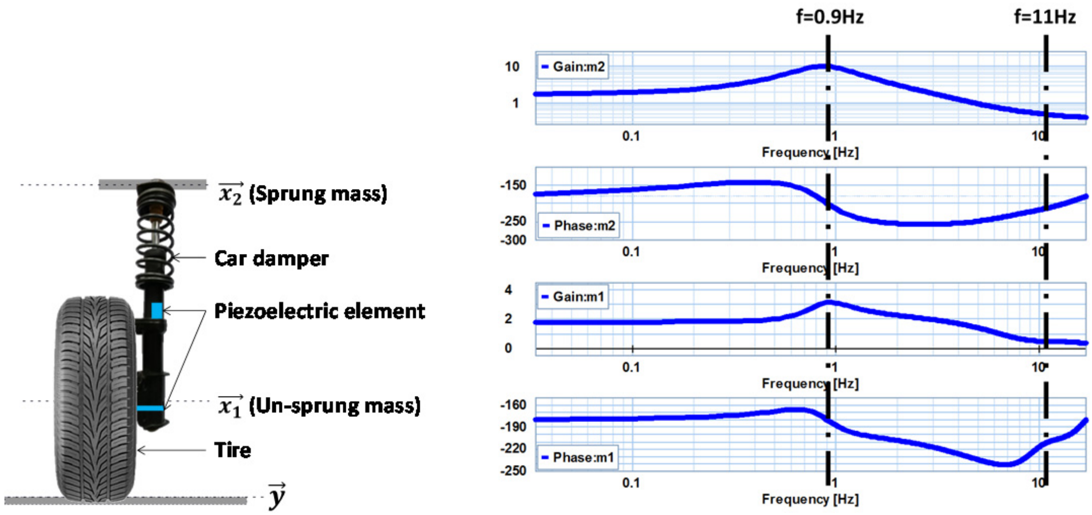

Fig. 1. (a) Quarter car system, (b) Frequency response of the system

The governing differential equations of a dual-mass system are expressed below according to the Newton second law (1), where $x_1, x_2, \dot{x}_1, \dot{x}_2, \ddot{x}_1, \ddot{x}_2$ denotes the displacement, speed and acceleration of the un-sprung mass and sprung mass respectively, and $y(t)$, $\dot{y}\ (t)$ corresponding to the transverse motion and speed function of the road surface. We can deduce the frequency response and the resonances of the system from Fig 1b.

$$\begin{cases} m_2\ddot{x}_2(t) + K_2(x_2(t) - x_1(t)) + C_2(\dot{x}_2(t) - \dot{x}_1(t)) = 0 \\ m_1\ddot{x}_1(t) + K_1(x_1(t) - x_0(t)) + K_2(x_1(t) - x_2(t)) + C_2(\dot{x}_1(t) - \dot{x}_2(t)) = 0 \end{cases} \tag{1}$$

Fig. 2 illustrates the power evolution simulated by the bond graph model when the car travels a road with a speed bump at 30km/h. The bond graph storage elements C and I, the dissipative element R and the modulated flow source (MSf) represent the elasticity, the mass, the mechanical damping and the speed input of the road surface respectively. The 1 junction results directly from the Newton Euler equations whereas the 0 junction reflects the velocity difference. The result shows that a priori sufficient power in the car damper could be harvested with a mechanical-electrical convertor.

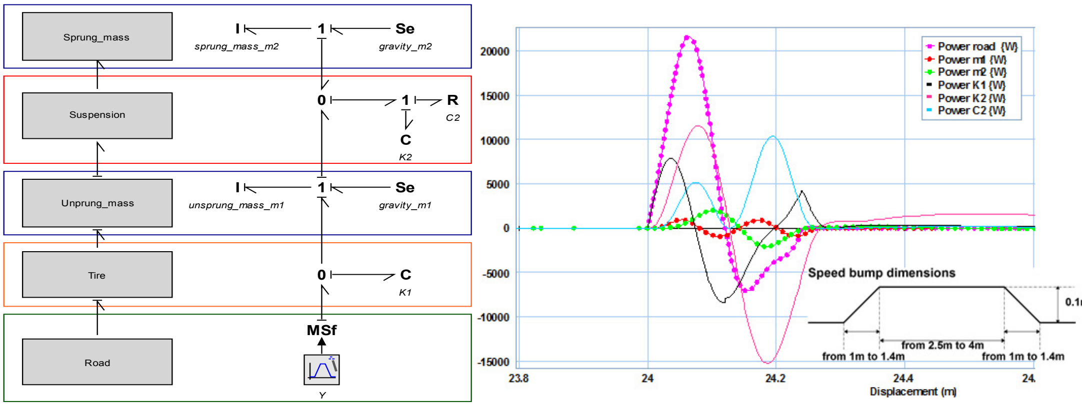

Fig. 2. (a) Quarter car bond graph model, (b) Evolution of the power in the system

3. Bond graph modeling and simulation of the power harvesting system embedded in the car damper

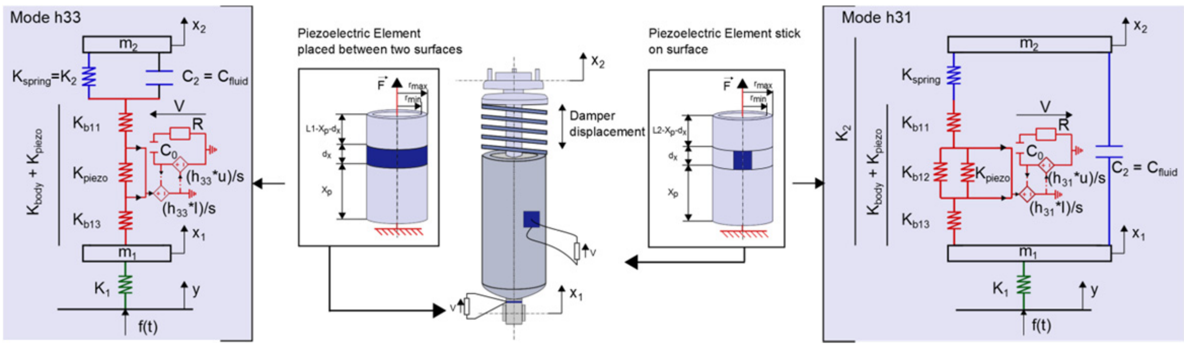

Fig. 3. Damper representation with two possibilities: piezoelectric element located (on the left) between two surfaces and bounded (on the right) on the car damper surface

According to Fig. 3, the piezoelectric could be located between two surfaces (on the left) or bounded onto the damper's surface (on the right). To simulate the influence of the location on the power conversion across to the piezoelectric element behavior, the car damper is dividing in several parts using the finite difference method. We assume that the piezoelectric element works in quasi static state i.e. that masses and coefficient damping are negligible. In the first case (on the left of Fig.3), the upper part and the bottom part are directly in contact with the piezoelectric element. The stiffness expressions can be written as:

$$K_{b11} = \frac{ES}{X_p}; \quad K_{b13} = \frac{ES}{L1 - X_p - \Delta x} \tag{2}$$

In the second case, the stiffness coefficient of the cylinder is decomposed in three parts with K_{b11}corresponding to the upper part below the spring of damper, K_{b12} for the middle part including cylinder's infinitesimal deformation where the piezoelectric element is sticked and K_{b13} for the bottom part above the sprung mass m_1. Their expression can be written as:

$$K_{b11} = \frac{ES}{X_p}; \quad K_{b12} = \frac{ES}{\Delta x}; \quad K_{b13} = \frac{ES}{L2 - X_p - \Delta x} \tag{3}$$

The piezoelectric coupling is represented by Leach model [4]. The piezoelectric power harvester used to generate electricity is a PZT5H (Lead Zirconate Titanate). The piezoelectric capacitance C_0 is 0.15nF. The mechanical-electrical conversion depends on the configuration, but is doing with effort source according to the expression: $V = \int h * u dt$. The bond graph model of the car system with the piezoelectric harvester is directly deduced from the mass-spring and electrical circuit system configurations from Fig. 3 using the same approach than those presented in Fig. 2. The electrical circuit is here represented by a modulated source of effort (MSe) and the piezoelectric capacity by a storage C element whereas the electric components are simulated with R and I elements. Fig. 4 shows the bond graph results for several values of loads [5] with a resistor R and an inductance L. The value of inductance L is adapted with respect to the resonance frequencies of the quarter car system. The optimal configuration is in using piezoelectric element in mode h33, since it allows to harvest around 6mW, but the other configuration with piezoelectric bounded onto structure gives around 3mW.

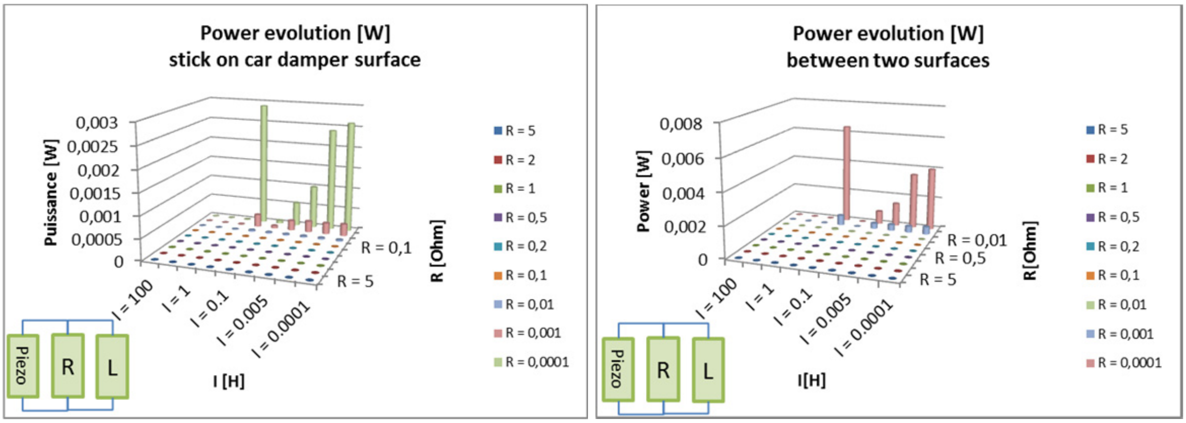

Fig. 4. Power evolution according to values of loads (R and L)

4. Conclusion

To conclude, this innovative bond graph model gives an estimation of power harvesting around 0.5mW which is promising since a sufficient power to use new miniaturized microcontroller generation is around 100µW. With less power level the data treatment between different smart systems on the suspension is permitted. In the future works, the numbers of piezoelectric devices could be extended for increase the capacity of power harvesting. Here, the simulation results are presented only for two locations but could be easily extended for all locations. Future work is currently in progress in order to optimize the conditioning circuit.

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