OPTIMIZATION OF CAR'S ELECTRIC POWER CONSUMPTION USING PIEZOELECTRIC SYSTEM

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Abstract— This article presents a mechatronics modeling of a driver's seat suspension in order to exploit the vertical vibrations transmitted by the road to the profile of the driver's suspension to harvest an electric power. This paper aims to reduce the vehicle's power consumption due to long driving hours, so, the suspension of the vehicle seats must be extremely producer. The proposed mode will be first of all studied by a mechatronic methodology which is the bond graph modeling for a seat suspension model comprising a vehicle chassis suspension, a seat suspension and a body model. The variation of the conductor mass and the road profile are also taken into account in the proposed model. Finally, the simulation shows a large amount of power during the car's motion.

Keywords— Driver Body, Bond Graph, Chassis Suspension, piezoelectric, Energy harvesting

1. INTRODUCTION

The piezoelectric beam is allowed to oscillate freely in response to vibration normal to the flat surface of the beam, in order to converter these vibrations to in-plane material strain. However, the car seat suspension has been commonly accepted in commercial vehicles for industrial of tire rolling resistance generated [1], agricultural and other transport purposes a lot of research [1-2-3] are focused to driver ride comfort, to reduce driver fatigue due to long hour driving or exposure to severe working environment such as rough road condition, so to improve the driver safety and health [3-4]. The study on reducing vertical vibration has been an active topic for decades [5]. But for us, it is interesting to use lost energy like vibrations and to recover the electrical energy. This study mainly focuses on passive seat suspension in order to optimize the driver's seat parameter such as the spring stiffness and the damping coefficient, this proposed model of seat suspension has provided a variable damping [6-7] force with less power consumption.

This work focused on the road vibration on a vehicle, which could be harvested by a piezoelectric system in longitudinal and transvers directions [8], as well as around the vertical axis (yaw rotation) within the limits imposed by the physical laws and the surfaces interaction through model adherence. The transverse and yaw movement are very well harvested. In the vertical direction the movement of the vehicle follows the roadway, including all the movement, without any perturbation on the driver's seat. For comfort and a safety driving. To simulate this energy harvesting system, we have decided to adapt and widen existing models published in the literature [9-10] and modeling them

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with the Bond Graph (BG) language [11-12]. While the traditional methods [13] like block diagrams [14] would give equivalent results than with the Bond Graph method, but in this case the BG method was chosen due to its unified language and graphical representation of power exchanges and causality relations. Furthermore, the BGe method is usually more agreeable and less complex than pure circuit models and block diagrams which consider only signal flows [15]. Moreover, the BG model gives us a possibility to simulate the power exchanges in the whole system. Because of its a strong approach it is especially suitable to optimize and forecast the whole power stored into the power storage circuit and restitution system. It has already proved its use in piezoelectric energy conversion modeling [16-17] and BG model for piezoelectric beam has been developed in a recent paper [15]. Consequently, this model could also deal the nonlinear phenomena [18]. Therefore, another advantage to use this method is that this multidisciplinary junction could be easily to adapted with nonlinear energy harvesters. In the literature, several overall car BG models less complex are done with the basic suspension components (wheels, suspension and chassis) and add device such as brake and steering [19-20] or transmission and engine [20]. Silva et al. presented an electric vehicle model [21-22] with integrated motors and electromechanical interaction (ABS, regenerative brake and so on) with the probability of variables evolution during risky situations [23-24]. The mainly goal of this paper is to modeled a piezoelectric device to convert vibration mechanical energy to electrical energy, as a low power energy source. In the mechatronics field it is possible to use this principle for energy harvesting to supply electricity for wireless sensor and car accessory, and in some type of sensors. At the same time, they give the information about the system speed, it is possible to use the range of voltage generated for supplying the control the integrated application. The proposed method is to modeled the car's seat suspension system using Bond Graph, which takes into account all system interactions to predict electrical power based on driver's seat vibration on the condition of the c class road. The simulation is applied at a speed of 60 km / h, we were able to harvest a power of 49 μ W which is a source of electrical energy adapted to the environment.

2. MODELING OF THE PIEZOELECTRIC INTEGRATED ON SEAT SUSPENSION

2.1. INTEGRATED VEHICLE SEAT SUSPENSION MODEL

It is supposed that in this paper only the vertical motion of vehicle is concerned, and we neglected both pitching and rolling motions. The integrated piezoelectric beam in the driver's seat is exposed to vibration is a sophisticated dynamic system whit complex mechanical property. We deduce the equation of motion of the model, without neglected the effect of the actuator dynamics this mode is assumed to be an ideal force generator the vertical motion of the system give us the motion equations for the quarter-car whit the complete seat suspension, and driver body are modeled with mass, spring and damper in the Bond Graph model. The piezoelectric materials used in the proposed system lead zirconated ate, undergo a structural phase transition as its temperature drops through the so-called Curie temperature. The dynamic motion equations are as follows:

$$\begin{aligned} m_u \ddot{z}_u &= -k_t(z_u - z_r) - c_t(\dot{z}_u - \dot{z}_r) + k_s(z_s - z_u) + c_s(\dot{z}_s - \dot{z}_u) \\ m_s \ddot{z}_s &= -k_s(z_s - z_u) - c_s(\dot{z}_s - \dot{z}_u) + k_{ss}(z_f - z_s) + c_{ss}(\dot{z}_f - \dot{z}_s) + u \quad (1) \\ m_f \ddot{z}_f &= -k_{ss}(z_f - z_s) - c_{ss}(\dot{z}_f - \dot{z}_s) + k_c(z_c - z_f) + c_c(\dot{z}_c - \dot{z}_f) - u \\ m_b \ddot{z}_b &= -k_c(z_c - z_f) - c_c(\dot{z}_c - \dot{z}_f) \end{aligned}$$

The bond graph modeling of the tire forces requires special attention and care especially when along with the stationary behavior which has to be covered. In micro- and Nano positioning applications the typical comportment of PEAs concerned include hysteresis, creep, and vibration dynamics. Hysteresis is the nonlinear dependence of a system not only on its current input but also on its past input. In PEAs, hysteresis exists in both the electric field (voltage)-polarization relationship and the strain (deformation or displacement) relationship caused by the nonlinearities in the converse piezoelectric effect [20]. According to the proposed model the relationship between the actuating force exerted on the PEA and the resulting displacement of the PEA is linear. In order to represent the piezoelectric cantilever beam conversion, we have chosen to improve the work done by Erturk et al. [21]. Even if the general equations of energy conversion use a distributed approach [20], thanks to the bond graph modeling we could solve the state equations easily. Regarding the excitation frequency range, it has been decided to operate with only the first piezoelectric cantilever beam resonance for practical purpose with the driver's body [22].

2.2. BOND GRAPH MODEL OF THE PIEZOELECTRIC INTEGRATED ON SEAT SUSPENSION

We are based on the relationship between average strain and maximum deflection for homogeneous cantilevers with an applied point load in $x = L$, whereas the representation tool used here is the bond graph modeling method and its associated state equations.

Fig. 1 The system bond graph modeling, and the Mason model for a Piezo electric's

The improved model is based on spring-mass-damper system decomposition for each mode, yielding a multiple degree of freedom system. Resonance frequencies are the most critical working points not only from the standpoint of comfort and safety but also for the design of the actuator power and force values. However, the use of the Bond graph modeling assures the mastery of the suspension resonance frequencies. The piezoelectric beam parameters for the analyzed case are deduced from the bond graph language. Simulation results of the harvesting power are presented in Fig. 5, 6.

To achieve controller performing adequately for a wide range of road disturbances this model gives a good ride comfort and make the gain between the road disturbance input w and the control output z , which is modeled in the fig.3. Our proposed method is modeling the car seat suspension system using the Bond Graph which takes into account all the interactions of the systems to predict well the electric power according to the vibrations applied to the driver on a road with 40km / h speed the power is order of 48Uw. In this work two electrically isolated piezoelectric elements were used, whether

independently or bridged for increased voltage (series configuration) or current output (parallel configuration).

Set connection will double the open circuit voltage collect to a single element, and the effective capacitance will be 1/2 of the single capacitance.

Fig. 2 Car Suspension and piezoelectric beam bond graph modeling

The Bond Graph model, which can describe the relationship between the input and output, enable one to understand the behavior of the system, Figure 2 shows general principles of bond graph modeling. The purpose of this bond graph model in this paper is to obtain a state equation representation of the driver's seat suspension model. In this paper the suspension system is modeled as a nonlinear suspension system. The state variable can be represented as a vertical movement of the car body, chassis and a vertical movement of the wheels. In order to obtain linear model, roll and pitch angles are assume to be small.

The option was to use the parallel connection in order to increase the power harvesting capability because the parallel connection will double the current compared to a single element configuration, and doubling the effective capacitance. However, the single element configuration was also tested and the results are presented as a reference for analyses facility. In wide band applications where both hysteresis and vibration dynamics are signified, the rate-independent hysteresis models need either to be combined with vibration dynamics models or to be modified into rate-dependent hysteresis models to represent the behaviors of the PEA. To model both the major loops and the minor loops in the hysteresis of PEAs without concerning the influence of the rate of change of the input, in other words, to model the rate-independent hysteresis of PEAs, both existing and newly developed rate independent hysteresis models have been adopted. The simplicity of the proposed solution presents an advantage in terms of internal power consumption. From equations given by the BG modeling, it can be derived the appropriate dimensions of the structure and its elastic and piezoelectric properties.

It is recommended a small length and a large width and thickness. This bond graph modeling is sufficient for the simulation of driving, because the excitation frequencies are well below the eigenfrequencies of the road vibration. With this approach problems can't arise, when a large number of influencing variables have to be taken into account, because in this model a considerable characteristic curve must be saved and evaluated.

3. ENERGY HARVESTING WITH THE WHOLE SYSTEM: NUMERICAL SIMULATIONS

Numerical simulations are conducted in this section to show the effectiveness of the proposed integrated seat suspension model and stockage strategy for reducing power consumption. The parameters used in the simulations, also the quarter-car suspension parameters have been optimized in terms of driver body acceleration. The fast estimation check implementation of the simplification, and obtaining a reduced model with physical reality makes this approach quite interesting in order to harvester more electric energy from the vibration. With the bond graph modeling we can have an overview the driver seat suspension system over the transient, harmonic responses using the random road profiles respectively Fig 3.

Fig. 3 The input signals: Gauss white noise with zero mean value

To study the efficiency of piezoelectric energy harvesting from the road vibrations we improve the driver's seat by integrated the piezoelectric beam system in the seat suspension. The vibration levels which are set in our analyze terms of RMS acceleration values that extend equal "fatigue-decreased proficiency." In most situations, exceeding the specified exposure causes noticeable driver fatigue and may be a cause of a large number of automobile perturbation.

This main objective is to reduce driver fatigue and replace conventional systems such as batteries, which are the power supply of cars, with autonomous systems generating energy from vibrations. The proposed solution is promising to harvested more and more power when the vehicle's mass is bigger. This method ensures the quantity of energy necessary to electrically power the car's device during the motion without using the battery.

Fig. 4 The vehicle speeds

In order to be able to assess the possibilities and limits of the proposed systems we have used this mechatronics techniques which has proven a great value. By means of a suitable reduction of the model, the computing time and interpretability of the results can be optimized.

Fig. 5 The voltage output Variation with versus resistance load

To ensure the reliability of the results we used two piezoelectric with different dimensions and similar connections, so, the results are presented in the Figures 4.5.

The motions are with a maximum amplitude of 0.03 m, 0.06 m and 0.207 m, respectively. Accordingly, three relative displacements, with maximum amplitudes of 0.042 m, 0.062 m, and 0.099 m, of the sprung mass and un-sprung mass excited by the random road transversal motions in Figures 4.5 are provided. we can notice that the harvested power is a growing function that is to say when the load of the car increases one has an increase of the power this is to mark for the two types of PZT chosen in our

case of simulations, figs 4.5 shown clearly this relationship between charges and power, then from these simulations we deduce that piezoelectric systems are the most common vibratory energy recovery systems to provide a permanent source of electrical energy. In this investigation, the aim was to reduce the electric power for a vehicle consumption and improve the dynamic performance factors indulging ride quality and road handling. Furthermore, a bond graph modeling has been developed including suspension design parameters and driving operational conditions. The piezoelectric beam is treated as a Bernoulli-Euler function, which is sufficient to capture vibration in the first few transverse bending modes, for which frequencies are not high enough.

Despite the conflict between potential power and dynamic responses, even for the desired dynamic responses regions, there is a sufficient amount of suspension power loss that is worth to be harvested.

Fig. 6 The power output Variation with versus resistance load

The present contribution intends to characterize a piezoelectric device as a solution to increase the energy sustainability and performance of instrumentation systems with wireless communication capabilities. The determination of the reciprocal system and its associated matrix is simplified. The value for whole-body vibration is given in terms of a frequency-weighted acceleration, and so is applicable to vibration at frequencies from 1 to 80 Hz. In these circumstances, the simulation of piezoelectric response to potentially life-threatening dynamic forces and accelerations are desired. They are also used in the development of vehicle seats and, in the case of hand arm models, of powered hand-held tools, the value of the energy is given in Figs 5, 6 in terms of the vehicle's velocity in a range of 10 m/s to 35 m/s on a road of classes B, C, and D, is demonstrated. Evaluation of the electric power for the vehicle seat suspension is based on the examination of the specific frequency domain and the suspension deflection between the cabin floor and seat frame. These simulations adopt the same geometry and material parameters with previous simulations. It is found in Figs. 4. 5 that the electric voltage linearly increases with an increase in the velocity of vehicles. The observation is interpreted by the fact that the transversal motions and velocities of the road surface and the relative displacements and velocities of the sprung mass and un-sprung mass are all proportional to the square root of the velocity of vehicles. It is seen from these two figures that the magnitudes for the body accelerations are significantly increased. While adding the withe noise signal to the harmonic and random road profiles, time settlement of sprung driver's seat acceleration is reduced by 67.70 %, 40% and electric power has increased by 45%, 80% over the road profiles class A.

These simulations confirm the effectiveness of the importance of using this solution to harvest electrical energy. In particular, the increasing acceleration indicates that the recovery of electrical energy is important to improve driving comfort. The results show that the electrical energy increases respectively from 19 W to 39 W, from 60 W to 159 W and from 280 W to 642 W, when the speed of the vehicle increases from 10 to 35 m/s. In this work, the results were obtained for an established frequency of 80Hz. We also confirmed that under these conditions, the voltage level and, consequently, the energy recovery were extremely high. The piezoelectric beam using in our system given us the energy recovering necessary to just see the dimensions suitable for the manufacture and the realization of such system then it is necessary to note that we defined the need in energy to consume by the sensors.

4. CONCLUSION

The main purpose of this article is to improve a piezoelectric system built into the car seat to measure and capture mechanical vibrations of equipment and road vibrations, as well as other sources and converter them to electric power. This study performed taking into account the power supply capabilities of the piezoelectric devices as a function of the amplitude and the frequency of the vibration, as well as the electrical characteristics of the charging circuit. The simulation show that the electrical energy increases respectively from 19 W to 39 W, from 60 W to 158 W and from 280 W to 642 W. The models for the piezoelectric system, chassis and suspension components could be improved due to the simulation condition and the time of testing experiments, in order to harvest the power quantity request for the vehicle accessory use.

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- [3] Bellekom S, Benders R, Pelgrom S, Moll H. Electric cars and wind energy: two € problems, one solution? A study to combine wind energy and electric cars in 2020 in The Netherlands. *Energy* 2012;45(1):859e66. Fig. 6. Displacements and RMS of electric power on a road of class D based on a certain Gauss white noise. (a) Gauss white noise with zero mean value, (b) Transverse displacement of road surface, (c) Relative displacement of sprung mass and unsprung mass, and (d) RMS of electric power versus speed of vehicle. X.D. Xie, Q. Wang / *Energy xxx* (2015) 1e8 7
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