Statistical Analysis of Piezoelectric Energy Harvesting in Bridge Systems

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1- Introduction

In recent years, application of low power electricity sensors and wireless communication systems has increased in various industries such as Structural Health Monitoring (SHM). Health monitoring of the traffic induced bridges is an essential requirement for life safety and also for prevention of economic losses. One of the effective methods for bridge structural health monitoring is the utilization of wireless sensors. Energy Supplying for wireless sensors with separate sources such as batteries is undesirable for many reasons, e.g., they are quite bulky, have a limited life and include a finite quantity of energy .

Nowadays, progresses in compact circuit technologies such as sensors and wireless systems have made it possible to use autonomous systems. These systems do not require an independent source for supplying the required energy and acquire it from environmental energy resources such as solar energy, wind energy and thermal gradients. However, each of the above mentioned environmental resources has its own problems. For example, in the case of solar energy, insufficient light is one of the disadvantages of this kind of energy source. Thus, another sources of energy should be considered. It is for these reasons that several researchers have proposed new methods of supplying energy which can convert mechanical vibration to electrical power. Among the various mechanisms which are used to convert vibrational energy to electrical energy, such as electromagnetic, piezoelectric and electrostatic, the method of implementing piezoelectric material has been noticed more than the others, due to the simple structure and convenient usage.

A comprehensive review of the other scientific articles in this field has been done and this review has revealed that a statistical analysis of the voltage output from bridge-energy harvester system under general uncertain parameters (such as mass, stiffness, damping, suspension, speed and dimensions of crossing vehicles) with different road surface roughness have not been simultaneously carried out. Therefore, in this study, all of the uncertainties related to the crossing vehicles have been considered in a pervasive model and a detailed statistical analysis has been carried out for the mentioned power. Also, the effect of the uncertain parameter associated with the class of the vehicle has been carefully investigated.

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The mentioned classes are divided into light, medium and heavy crossing vehicles which have been defined with proper random parameters in the simulation. Moreover, the bridge has been modeled as a simply supported Euler-Bernoulli beam for the mentioned purpose, and the finite element method has been applied for discretization. It should be noted that in the modeling and simulation section of this study, the vehicle has been considered as a four degree of freedom mass-spring system and the ISO standard has been used for road surface roughness simulation. Finally, the mean and variance values and confidence interval of the deflection along with velocity, acceleration and voltage of the piezoelectric harvester in a point with random characteristics and classifications have been obtained by the Monte-Carlo simulation method. This simulation has been carried out by a program developed in MATLAB. Then, the harvested power from these vibrations has been calculated.

2- Simulation of the bridge-vehicle and harvester system

In this paper, the dynamic response of the assumed node on the bridge has been obtained by considering the uncertainty effects of the passing vehicle and by applying the Newmark-Beta method for numerical solution. In addition, the Monte-Carlo method has been used for simulation and then the output voltage of the piezoelectric harvester has been calculated. For this purpose, a program has been written in MATLAB and also the main data associated with several classes of vehicles have been extracted from the database of CarSim software. The vehicles have been classified into three classes based on their variables. The equation of motion of the bridge-vehicle system has been solved using the Newmark-Beta method in which, β and γ have been assumed to be 0.25 and 0.5, respectively.
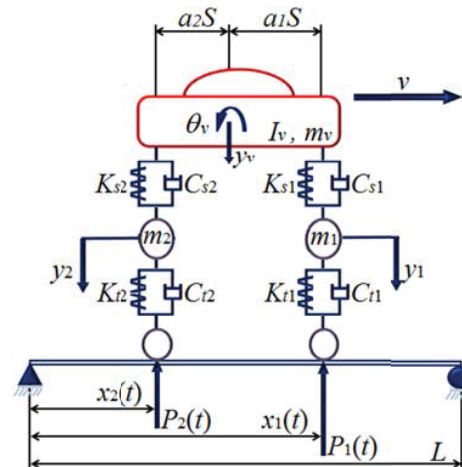

Fig. 1. Bridge-vehicle system model

3- Results and Discussions

In this section, vibration (upper and lower limits for the mean values of deflection, velocity and acceleration) of the bridge mid-span has been obtained by using Monte-

Carlo for simulation and Newmark-Beta method for the solving process. This acceleration has been considered as the input excitation for the base of the energy harvester beam. By obtaining the mentioned acceleration and also by considering the specifications of the energy harvester beam, harvester equations have been solved. Then, the output voltage has been acquired. So, calculation of acceleration for the attaching point of the energy harvester (bridge mid-span) has been carried out for five different classes of road surface roughness and for passing of 100 vehicles with various random specifications in this study. The road surface qualities has been considered as very poor, poor, average, good and very good. Also, the confidence interval is considered to be 95%.

Fig. 2. Statistical results for dynamic response of bridge mid-span point and output voltage associated with very good surface quality of the road

Fig. 3. Statistical results for dynamic response of bridge mid-span point and output voltage associated with very poor surface quality of the road

By considering these Figures, it can be seen that increasing the road surface roughness causes a growth in the amplitude of acceleration. As a result, by increasing the (excitation) acceleration amplitude, the mean value of the output voltage increases. On the other hand, it can be seen from variance diagrams that increasing of the surface roughness also causes growth in output voltage variance. This point leads to a low level of reliability for the output voltage.

4- Conclusion

Nowadays, the application of low power electricity sensors and wireless communication systems has increased in various industrial applications such as Structural Health Monitoring (SHM). One of the new methods of powering these low-power electronic devices is applying energy harvesting systems. In this paper, after the modeling of bridge-vehicles and harvester systems, a statistical analysis of the energy harvester power output has been carried out by considering all possible uncertainties that are effective in the dynamic response of the bridge. In this analysis, the Mount-Carlo method has been used for the simulation of the stochastic system with the energy harvester attached to the mid-span point of the bridge. Then, the main statistical parameters such as mean and variance values of deflection, velocity, acceleration and energy harvester voltage output have been calculated. It should be noted that the important result is the effect of road surface roughness in power production. The results of this section have shown that by increasing surface roughness, more power has been harvested from bridge vibration energy. However, a reduction has been observed in 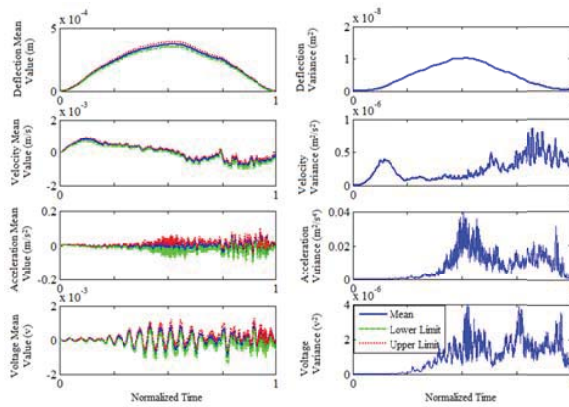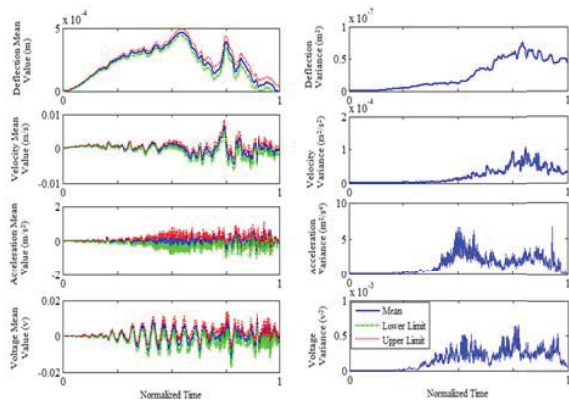reliability of the harvested power at the same time.