Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 54(12) (2023) 555-558
DOI: 10.22060/mej.2023.21412.7444

Designing an Optimal Non-Linear Controller for an Active Vehicle Suspension System and Investigating its Effect on Electrical Energy Harvesting

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ABSTRACT: One of the most important challenges in using active vehicle suspension systems is the high energy consumption of these types of systems. The use of the energy harvesting system is one of the ways to reduce energy consumption in active suspension. In this paper, by designing a new optimal controller of the vehicle's active suspension system and the energy harvesting system, their interaction with them has been investigated. The active control loop calculates the required force to realize the desired mechanical performance. The method is based on the constrained nonlinear predictive control algorithm obtained from the continuous model of the system. Also, the mechanical indices of the suspension system, including travel comfort and road-holding, are managed by the weight coefficients defined in the active control algorithm. The effect of the weight coefficients on the maximum harvesting of energy, while achieving the desired mechanical performance is another issue that has been addressed in this article. The simulation results for two types of the road show that the proper use of the active control algorithm leads to the realization of the desired mechanical performance along with the maximum harvesting of energy. Also, the external energy consumption of the active control system is significantly reduced.

Review History:

Received: May, 23, 2022
Revised: Oct. 02, 2022
Accepted: Dec. 27, 2022
Available Online: Jan, 11, 2023

Keywords:

Vehicle suspension system
Active vibration control
Energy harvesting
Constrained nonlinear control.

1- Introduction

The active suspension system is designed to isolate the vehicle body from rod roughness while keeping good contact between the tire and the road. In designing an active suspension system, the control algorithm plays a significant role to provide the conflicting objectives, simultaneously [1, 2]. One of the most important challenges of the active suspension system is the high external energy consumed by the external actuator. For this purpose, energy harvesting mechanisms are used [3]. Investigating the interaction of the active suspension and the energy harvesting systems has been very important for researchers [4, 5].

In the current paper, the model of an active vehicle suspension system with a nonlinear spring and damper is introduced. Also, the energy harvesting mechanism which includes a linear permanent magnet generator, a full-wave rectifier, and a storage source is applied to the system. The predictive optimal constrained controller has been designed for the active suspension system. By adjusting the weighting coefficients in the optimal control algorithm, different strategies can be applied to the system. Simulation is carried out for various weighting factors of the optimal controller to choose the proper one considering both mechanical performance and energy efficiency. The rest of the simulations are performed with the chosen weighting factors for various excitations.

2- Proposed System Model

The quarter model of an active suspension system with an energy harvesting mechanism is shown in Fig. 1. The dynamic equations of the model are as follows:

$$m_s \ddot{x}_s = -f_s - f_d - f_{em} + f_a \tag{1}$$

$$m_{us} \ddot{x}_{us} = f_s + f_d + f_{em} - f_{st} - f_{dt} - f_a \tag{2}$$

where $f_{em} = KI$ and I is the electrical current in the generator.

Also, the electrical circuit for the energy harvesting system is depicted in Fig. 2. The governing equation of the electrical circuit is as follows:

$$E - V_s = \left(R_a + R_s\right) I + L_a \frac{dI}{dt} \tag{3}$$

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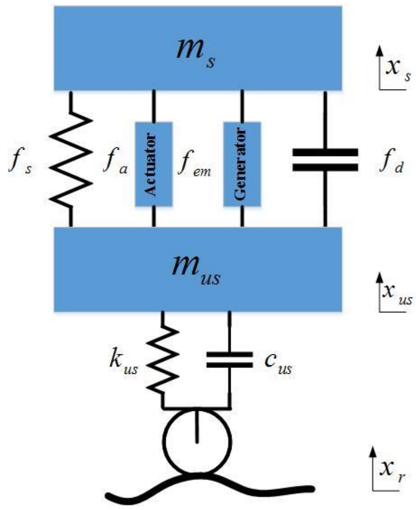

Fig. 1. Quarter model of active suspension system with an energy harvesting system

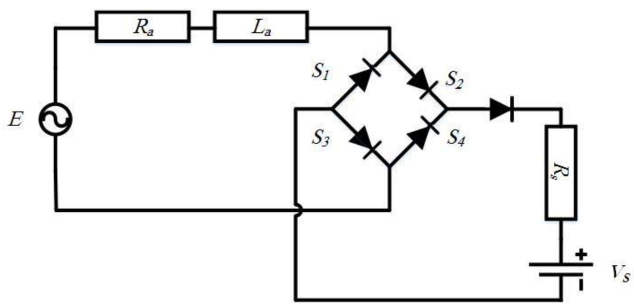

Fig. 2. Electrical circuit of energy harvesting system

3- Controller Design

The optimal control force is obtained as follows:

$$f_a = \begin{cases} f_{a-\max}; & if\ :\ g_1 \geq 0, g_2 \leq 0 \\ f_{a-optimum}; & if\ :\ g_1 \leq 0, g_2 \leq 0 \\ -f_{a-\max}; & if\ :\ g_1 \leq 0, g_2 \geq 0 \end{cases} \quad (4)$$

where

$$f_{a-optimum} = -\frac{\sum_{i=1}^{3} L_i \rho_i b_i}{\sum_{i=1}^{3} \rho_i b_i^2} \quad (5)$$

4- Results and Discussion

The consumed power in the active control and the electrical power saved in the harvesting system for the three control strategies is shown in Fig. 3. It is clear that the harvested electrical power is the highest in AC1 and it is the lowest in AC3. Also, the performance indices in three control logics are reported in Table 1.

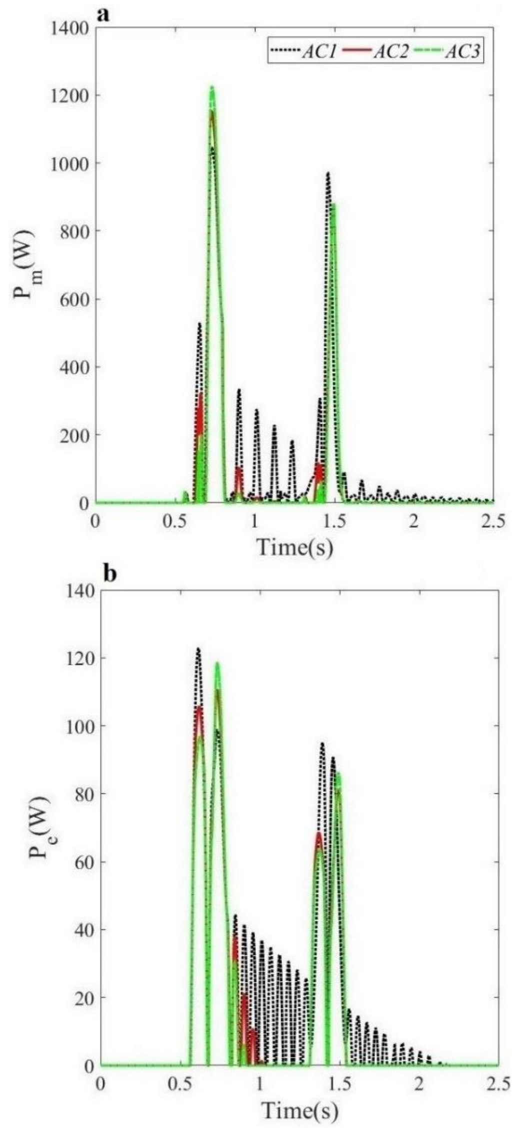

Fig. 3. Active suspension system powers, a- consumed power in the active control, b- electrical power saved in the harvesting system

5- Conclusion

In this research, the interaction of active control and energy harvesting systems was studied. The effect of adjusting the weight coefficients of active control on both mechanical indices and energy harvesting was investigated. As a result, the most suitable combination for controlling mechanical indices with minimum energy consumption was introduced. In order to clarify the importance of using the energy harvesting system in active suspension, the power

Table 1. Control performance with different combinations of weighting factors in double bump excitation

Control logics / Index	AC1	AC2	AC3
RMS of m_s acc	0.21	0.424	0.81
Consumed energy	209.5	153.5	141.4
Harvested energy	40.21	30.98	29.66
Net consumed energy	169.3	122.5	111.8

consumed in the active control, stored power in the energy harvesting system, and net consumed power were presented. The proposed active control law provides the ability to achieve the optimal mechanical indices of the suspension with less energy consumption.

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HOW TO CITE THIS ARTICLE

R. Azmi, M. Mirzaei, A. Habibzade-Sharif, Designing an Optimal Non-Linear Controller for an Active Vehicle Suspension System and Investigating its Effect on Electrical Energy Harvesting, Amirkabir J. Mech Eng., 54(12) (2023) 555-558.

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