Modeling and Implementation of LQR controller for Efficient EV Suspension Energy Harvesting

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1. Introduction

In recent years, the application of vibration-based energy harvesters as an alternative energy source for many applications has gained significant growth [1-4].

The gradual phaseout of internal combustion engines to hybrid/EVs has created a growing interest in alternative energy harvesting methods that allows energy rather wasted in vehicle's suspension system to be converted to electrical energy through different transduction mechanisms.

A major challenge that energy harvesting from a vehicle's suspension poses is that the suspension system is resonant in nature and maximum power can only be extracted when the excitation frequency coincide with the spring's resonance frequency. [5].

Although many researchers have studied energy harvesting from vehicle suspension[6,7], there still exist a gap in designing an efficient energy harvester that not only consumes less than generated but generate maximum power at frequencies outside the spring's resonant frequency.

2. Research aim and objectives

The aim of this research is to model and implement an efficient low power consumption EV energy harvesting device.

Objectives:

- To investigate the application of electromagnetic theory in energy harvesting from an EV suspension system.
- To investigate varying spring stiffness to consequently vary the resonance frequency of the spring.
- To model the EM energy harvester.
- To model and implement LQR controller for efficient EV suspension energy harvesting.
- Finally, compare with other models to show efficient energy harvesting and controller response time..

3. System description

A two degree of freedom quarter car model is considered for this research, as shown in Figure 1 . The inputs to the model are the vehicles' speed, road disturbance and the actuator force controlled by the controller. A set of kinetic equations was formulated, and the system was analyzed without control.

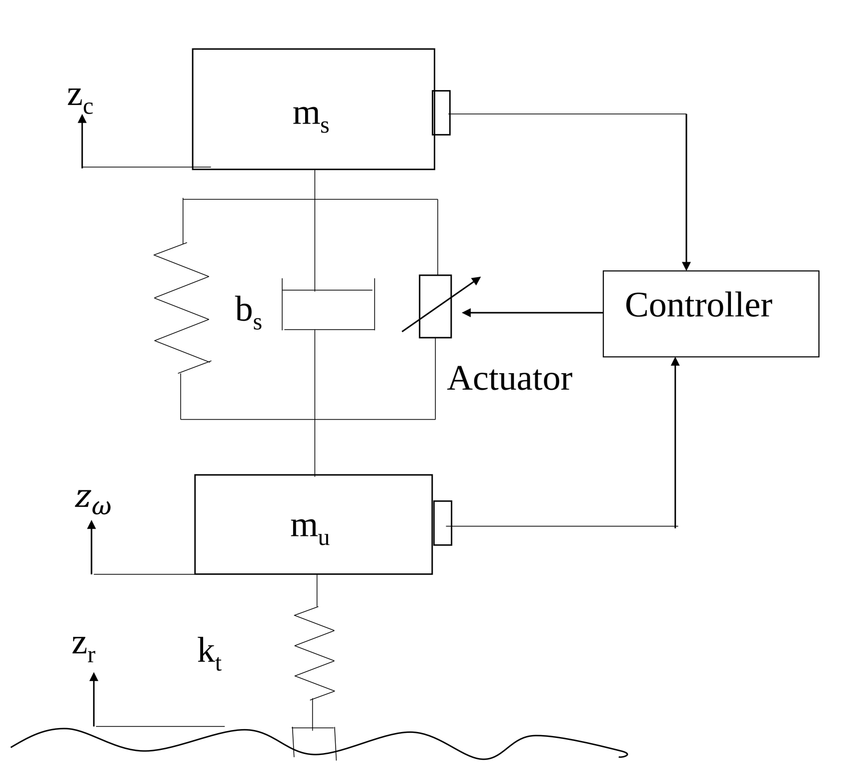

Fig1: Quarter car suspension system model [8]

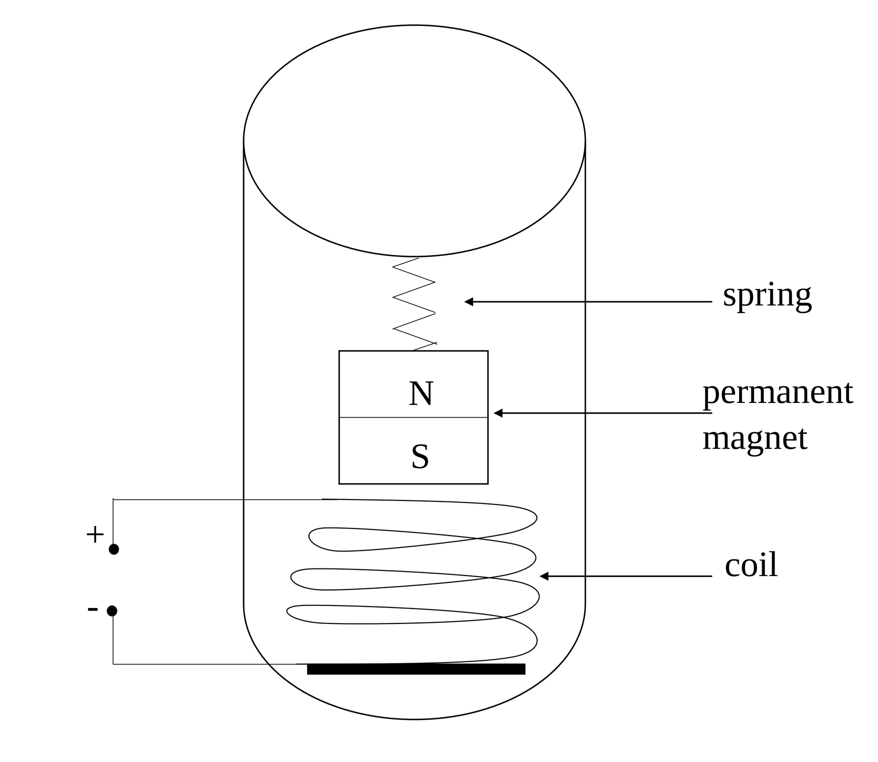

Fig2: Electromagnetic power converter model [8]

An electromagnetic power converter model was used in this research as shown in figure 2; consisting of a magnet connected to a spring while the other end of the spring is attached to the suspension spring.
As the magnet moves through the coil as it vibrates, voltage is induced in the coil by an amount determined by Faraday's law.

4. Model Equations

$x_1 = z_c\,;\; x_2 = \frac{dz_c}{dt} = \dot{z}_c\,;\; x_3 = z_\omega\,;\; x_4 = \frac{dZw}{dt} = \dot{z}_\omega$

$$\dot{x}_1 = x_2$$

$$\dot{x}_2 = \frac{1}{m_s}\left[k_s(x_1 - x_3) + b_s(x_2 - x_4) - u\right]$$

$$\dot{x}_3 = x_4$$

$$\dot{x}_4 = \frac{1}{m_u}\left[k_s(x_1 - x_3) + b_s(x_2 - x_4) - k_t(x_3 - z_r) - u\right]$$

$$Z_r = A\sin\left(\frac{5\pi st}{9\lambda}\right);\; V = -N\frac{d\phi}{dx};\, V_{oc} = NBLv;\; P_e = \frac{V_{oc}}{R};\, P_e = \frac{(NBLv)^2}{R}$$

5. Results

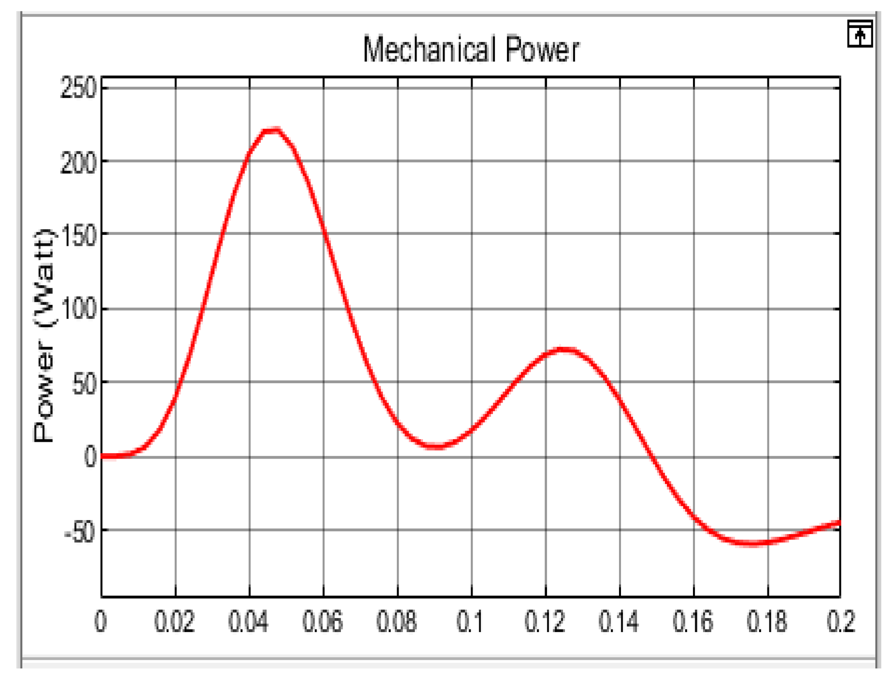

Fig 3: Mechanical power generated at 15 mph

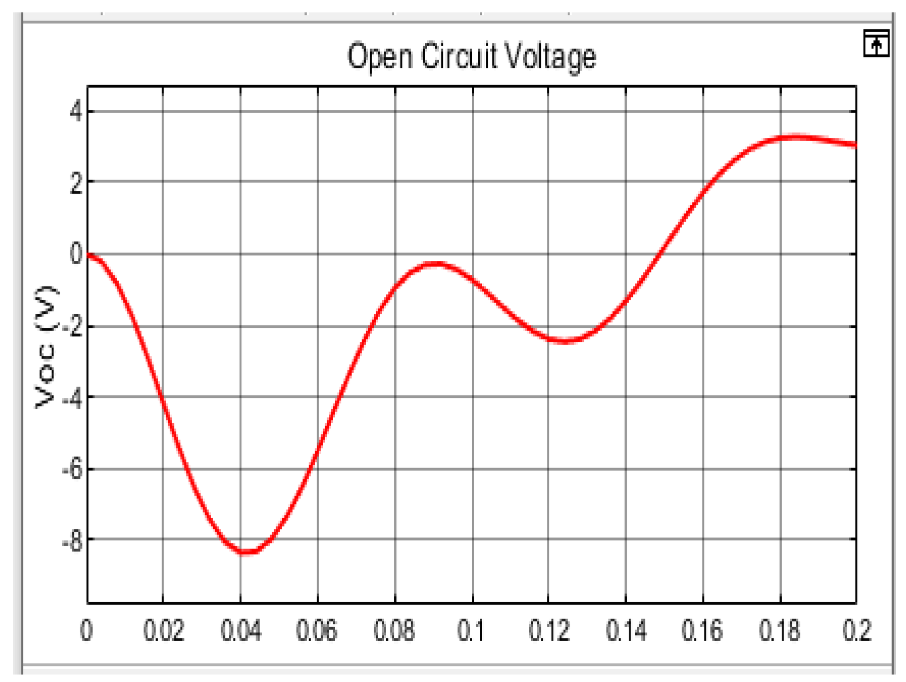

Fig 6: Open circuit voltage induced at 15 mph

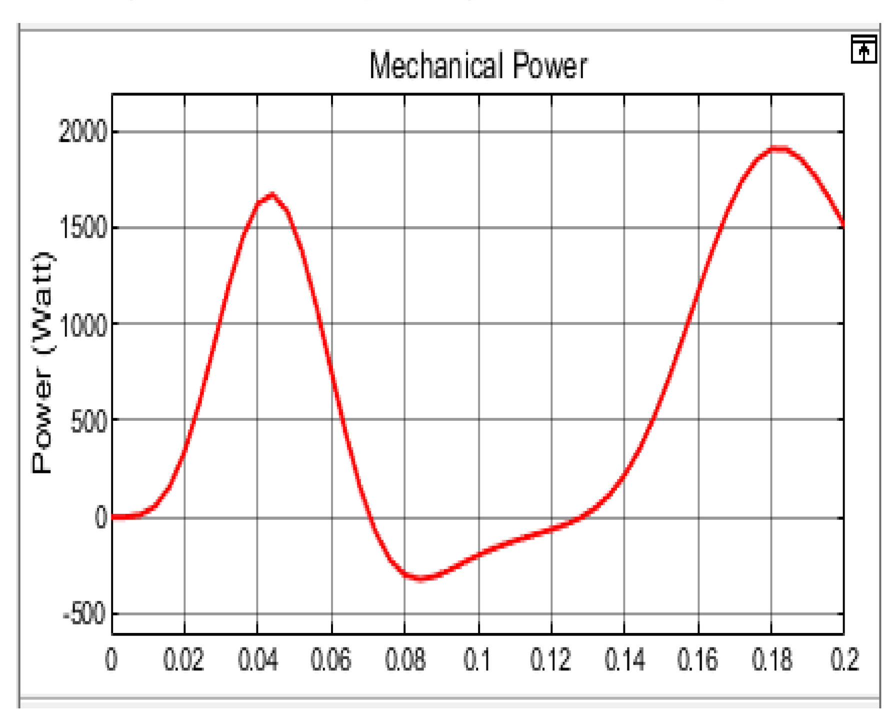

Fig 4: Mechanical power generated at 45 mph

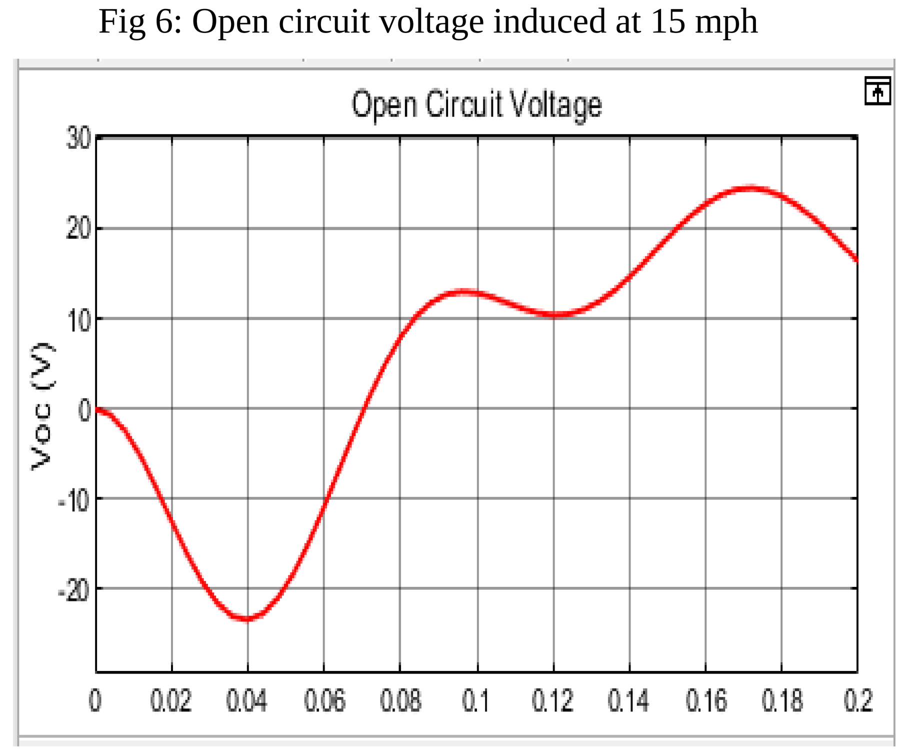

Fig 7: Open circuit voltage induced at 45 mph

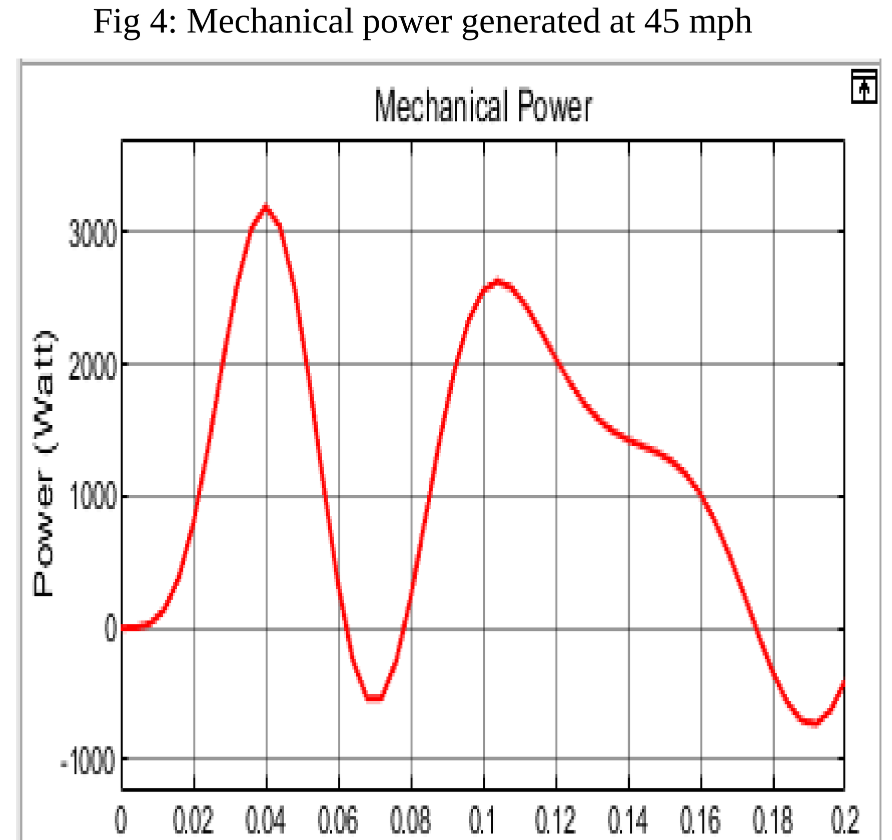

Fig 5: Mechanical power generated at 70 mph

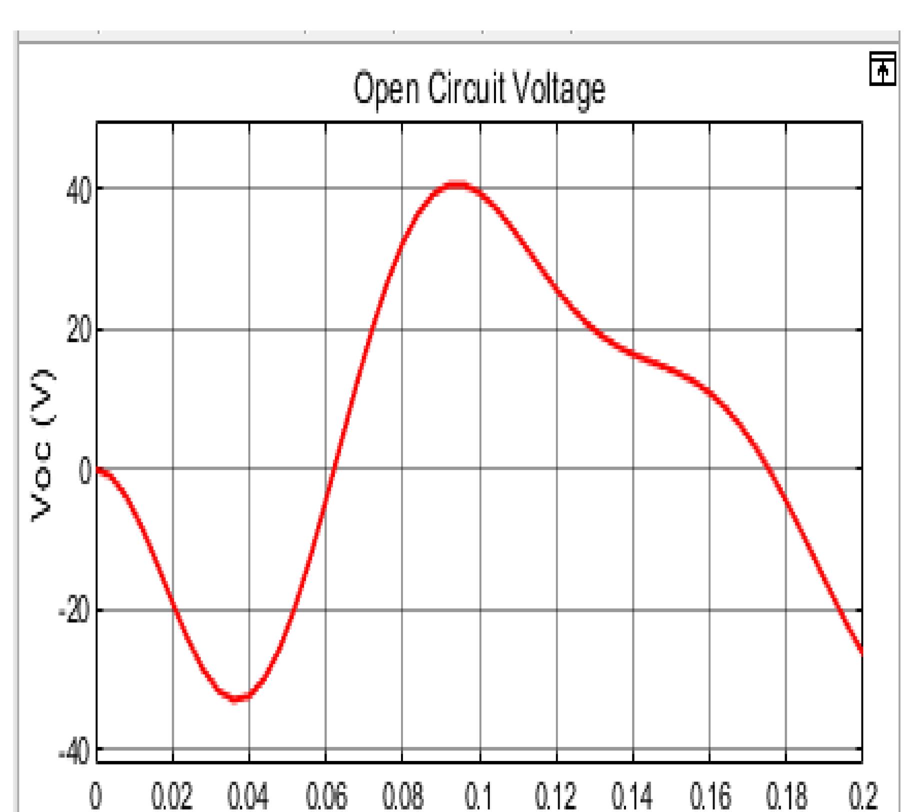

Fig 8: Open circuit voltage induced at 70 mph

6. Result Discussion

Using the following parameters $m_s = 290\,kg, m_u = 40\,kg\,, k_s = 23500\,N/m\,, k_t = 190000\,N/m\,, b_s = 700\,N/m$ [8] the results in figures 3-8 are presented and MATLAB codes were developed to solve the model equations.

The results presented in figures 3-5 are the ideal harvested powers at various speeds of 15 mph, 45 mph and 70 mph respectively. These results show that increase in vehicle speed leads to more suspension spring vibration thus leading to higher acceleration and velocity and consequently, more power is harvested.

The open circuit voltages are shown in figures 6-8 at various speeds. As expected from Faraday's law, more voltage is induced at higher vehicle speeds due to increased vibrations.

7. Conclusion and Future Work

In concluding, it can be deduced from the results that wasted energy in a vehicles suspension system can be harvested through application of electromagnetic theory.

The results show that an average of 1.5kW of mechanical power can be harvested from the model when evaluated at 70 mph of vehicle speed.

However, not all the objectives of this research have been met. Research is ongoing to design and model the electromagnetic power converter using Ansys electromagnetic software.

Also, to incorporate the proposed controller to the system model for efficient resonance tracking and energy harvesting and consequently implement the entire system

8. References

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9. Acknowledgement

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