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# Modelling and Control of Air Bellow based Active Suspension System

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# Modelling and Control of Air Bellow based Active Suspension System

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**Abstract**. This paper presents a complete design and simulation of active suspension actuated using pneumatic air bellow. The electronic controlled active suspension will control all vertical force acting from road surface by regulating the air mass of bellow. Quarter car active suspension is modelled and analysed using Matlab-Simulink. The output of designed active suspension system is simulated under standard road input that gives the response of the suspension to varied roughness of road surface. From the results it is evident that proposed active suspension system can suppress more than 60% than standard passive suspension system.

## 1. Introduction

The suspension system is essential for the realization of comfort, stability and safety. The function of the suspension is to absorb and separate body of vehicle from longitudinal ground force and to maintain frictional contact between the tire and the road. Passive suspension systems can only offer fixed rates of spring and damping. Thus, affecting vehicle handling capability and result in reduced passenger comfort due to excess body vibrations.

Active suspension is setup of system which controls the vertical movement of the wheel with onboard control system. Active suspensions are typically composed of a varying coefficient of spring and damping achieved by some type of force actuator. Pneumatic air bellows, have long been used as vibration isolation and levelling devices. They are typically used where it is desired to have a higher spring rate.

Need for this system is to have a complete control of suspension which alter its working parameter as per suitable requirement by itself. Electronic controller takes control over the system. Controller should be capable of performing various function which all enhances the vehicle vibration isolation. The system control should be capable of resulting in better dynamic control of vehicle and comfort.

The principle of active pressure control represents a research on effectiveness of PID-control algorithm and suggested an algorithm for achieving reasonable. Using bellow as suspension will result in no bending stiffness it only has deformation due to compressibility will be an advantage for this proposed suspension [1].

Mathematical modelling of quarter car active air suspension was suggested us with by controlling mass flow rate makes it possible to dynamically change the characteristics of the air suspension corresponding to road input [2], [3]. Pressure drops between pressure feed system, pneumatic bellows and outer space. Valve used for this system should incorporate at optimal point between the bore and response time. Using these type of servo valves will result in quick response, thus effectively increases the damping force. Moreover, the efficiency the system relies on size of the orifice area and response time of the servo valve. The PID controller should be incorporated with integral closed loop [4].

Considering the velocity of the fluid flow as laminar large damping force can be obtained huge variation in displacement of valve [5]. Developed air suspension system prototype can be adapted easily to existing vehicle suspension configuration. Air suspension system gives improved ride performance over default vehicle suspension system. Ride performance can be optimally balanced for laden and unladen behavior of vehicle through pressure setting of air springs [6]. The efficiency of the system will decrease at the point where the suspension stiffness was increased near to a resonant frequency of a vehicle, for surpassing this counter effect your system should be designed with multi-degree of freedom considering the all resonant source element [7]. These type of proposal with pneumatic system would show good performance properties, but the concern of energy consumption and the space required for this setup should be optimized precisely [8]. The energy consumption will be based on our specification of compressor and other energy sink in this system is controller.

The control should need the level of adaptation such like it has to change according to road input. The control can be either linear and non-linear or switch between them [9],[10]. The complexity having the both type of control can be minimized by a concentrating on establishing the relation between flow rate and pressure drop this type of relationship would enable us to have overall control with linearized model [11].

These switching between controls requires different feedback, this paper would suggest a controller in common which can work as both control with same feedback elements, thus making the control part less complex. The pneumatic system for this suspension will have various component related to its function [6]. Simulating this model for input road excitation can be done, various input should be given to the model to obtain its performance for various displacement [12]. An effective tool for designing air suspensions of the type considered, simulating their behavior [13]. The analytical behavior of this suspension can be obtained based on experimental real-time simulations this will give us the overall characteristics of the proposed suspension [14]. When considering the actuator force the design consider should be optical, the optimal design parameter is given from source [15]. The realistic road roughness input is set up and resulted the behavior with non-linear modelling, more detailed modelling of the fluid flows and the electrical system and to corresponding experimental work.

The main objective of this work is to model, simulate and control active suspension system actuated by pneumatic bellows. The mathematical modelling phase involves mechanical model design of both passive and active suspension, were the mechanical system is reduced through force equation and computed. The mathematical equation is developed as a block diagram in Simulink by developing this Simulink model, which can be simulated and test the systems behavior. Controller design involves design of the schematic flow of the controller system and actuator's pneumatic circuit is designed. The designed model is tested with a standard input signal in simulation with standard constant as input parameter referred from the previous research.

## 2. Mathematical Model

Quarter car model is used for dynamic study of suspension system of four-wheel vehicles. Quarter car model by its name suggests that all the 4 suspension of the car are same and only one suspension. The figure 1 and 2 represents the schematic of passive and active suspension systems. The difference between active and passive model is, varying actuator force u acting additional to the system in active suspension system.

For a passive suspension system shown in the figure 1, the force balance equations are given by equations (1) and (2).

$$m_1\ddot{x}_1 + b(\dot{x}_1-\dot{x}_2) + K_1\,(x_1-x_2) = 0 \tag{1}$$

$$m_2\ddot{x}_2 + b(\dot{x}_2-\dot{x}_1) + K_1\,(x_2-x_1) + K_2(x_2-r) = 0 \quad (2)$$

where $m_1$ is sprung mass (kg), $m_2$ is unsprung mass (kg), $K_1$ is suspension stiffness (N/m), $K_2$ is tire stiffness (N/m), $b$ is damping ratio (Ns/m), $x_1$ and $x_2$ are the displacement of the sprung and unsprung masses, $r$ is road displacement.

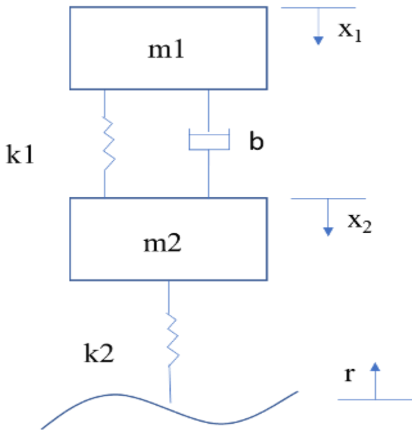


**Figure 1.** Schematic of Passive Suspension System.

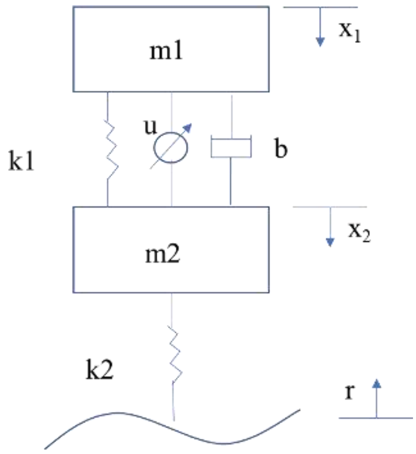


**Figure 2.** Schematic of Active Suspension System.

For an active suspension system shown in the figure 2, the force balance equations are given by equations (3) and (4).

$$m_1\ddot{x}_1 + b(\dot{x}_1-\dot{x}_2) + K_1\,(x_1-x_2) - u = 0 \quad (3)$$

$$m_2\ddot{x}_2 + b(\dot{x}_2-\dot{x}_1) + K_1\,(x_2-x_1) + K_2(x_2-r) = 0 \quad (4)$$

where $u$ is the additional actuation force created by the air bellows.

The mathematical equation is implemented in Simulink. Block is a graphical modelling and simulation environment for dynamic systems. An input output relationship fully characterizes a block.

## 3. Mathematical Model

The overall control system is represented in figure 3. The input force is fed system and the actuator force is given between sprung and unsprung mass. A sensor is placed in top of sprung mass to measure the value of vertical acceleration of mass. The sensor gives the output to a PID controller which is error detector system and give out the required output to eliminate that acceleration. Electronic controller converts its processed value into current signal. The current signal from the controller actuates the solenoid relief valve to the required value as per the input current signal. The pressure relief valve sends required pressure to actuator and actuator give out force opposing the vertical acceleration. This is closed loop system were the value from sensor is used as feedback input the system.

## 4. Simulation and Results

A standard input should be given to system. Any standard ISO 8608:2016 model should be presented with a generic output defining a standardized procedure for transmitting calculated vertical road profile data for either single or multitrack measurements. The standard varies road class is stated in Table 1. The types of road input are given to simulate any automobile system.

. The road classification of longitudinal road profiles based on vertical displacement power spectral density. Power spectral density represented characterized by two parameters of a straight line, an unevenness index and waviness. The Simulink block for PSD road input will generating the standard road profile. The gain value and constants vary for various road class. The road profile is set for vehicle velocity of 20kmph.

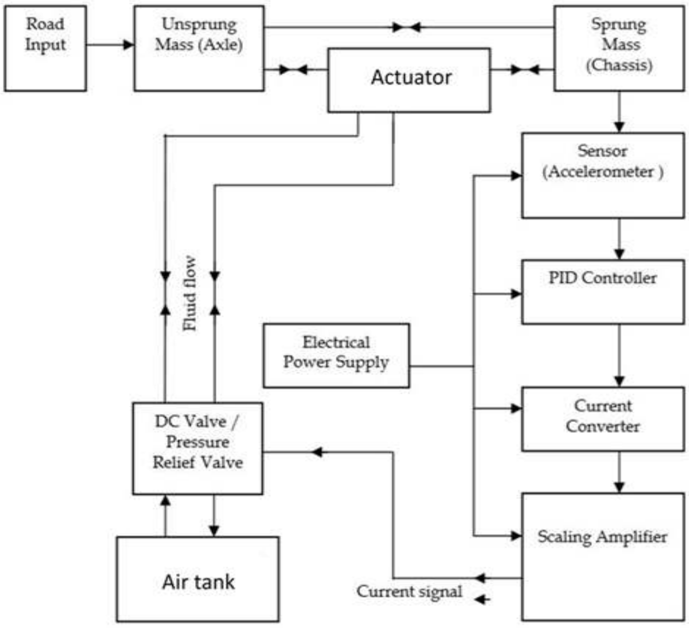


**Figure 3.** Schematic of Overall control system.

**Table 1.** Standard Road profiles

| Class number | Road Class | Type of Road |
|---|---|---|
| 1 | A | Smooth Runway |
| 2 | B | Smooth Highway |
| 3 | C | Highway with Gravel |

The parameter for assumed in the simulation model are appropriate the results of simulation or close to that of actual experimentation are given in Table 2. The results of the simulation may give guidance to understand the response. The suspension parameters used are given in the simulation of the response.

**Table 2.** System parameters values used in simulation

| Parameters | Assigned values |
|---|---|
| $K_1$ | 1190 N/m |
| $K_2$ | 101115 N/m |
| $B$ | 2070 Ns/m |
| $m_1$ | 90 kg |
| $m_2$ | 1900 kg |

The response of passive suspension with respect to sinusoidal input is simulated and traced in figure 4, we could observe the behavior of passive system only reduces the half of the input force. The output response of active suspension system shown in figure 5, nearly damps all input signal, this difference inference us with variations in passive and active suspension system. The PID used in active suspension model is self-tuned with respect to the transfer function and constant given to variables. Response of our active suspension system with respect to various standard road input is taken.

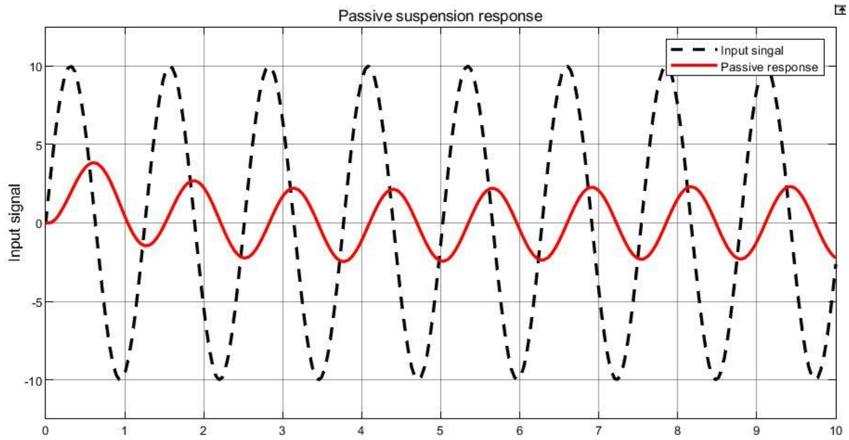


**Figure 4.** Response of Passive suspension to sinusoidal input

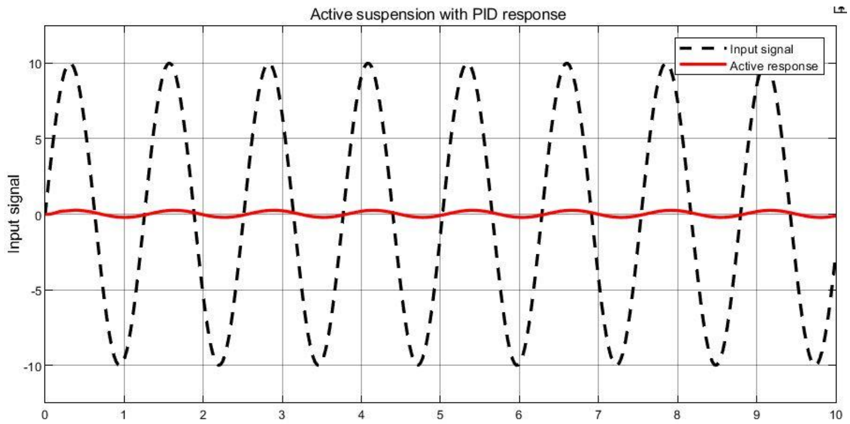


**Figure 5.** Response of Active suspension to sinusoidal input

The response of both passive and active system with respect to class A, B and C type road signals are shown in figure 6, figure 7 and figure 8 respectively. The plots are more evident to that proposed active suspension is more response to the input excitation. Thus, the comparison between passive and proposed active suspension model will give helps us to understand variation in performance between them with respect to different inputs. Table 3 shows the comparison of active and passive suspension systems using the parameters Root Mean Square (RMS) and Maximum displacement.

**Table 3.** Performance Comparison of Active and Passive Suspension in different road types

| Road Class | Input (RMS) ($x10^{-3}$) | Passive Suspension | | Active Suspension | |
|---|---|---|---|---|---|
| | | RMS ($x10^{-3}$) | Maximum displacement ($x10^{-3}$m) | RMS ($x10^{-4}$) | Maximum displacement ($x10^{-4}$m) |
| A | 1.247 | 0.470 | 1.084 | 0.228 | 0.609 |
| B | 5.753 | 2.172 | 5.006 | 1.054 | 2.817 |
| C | 7.145 | 2.698 | 6.218 | 1.309 | 3.499 |

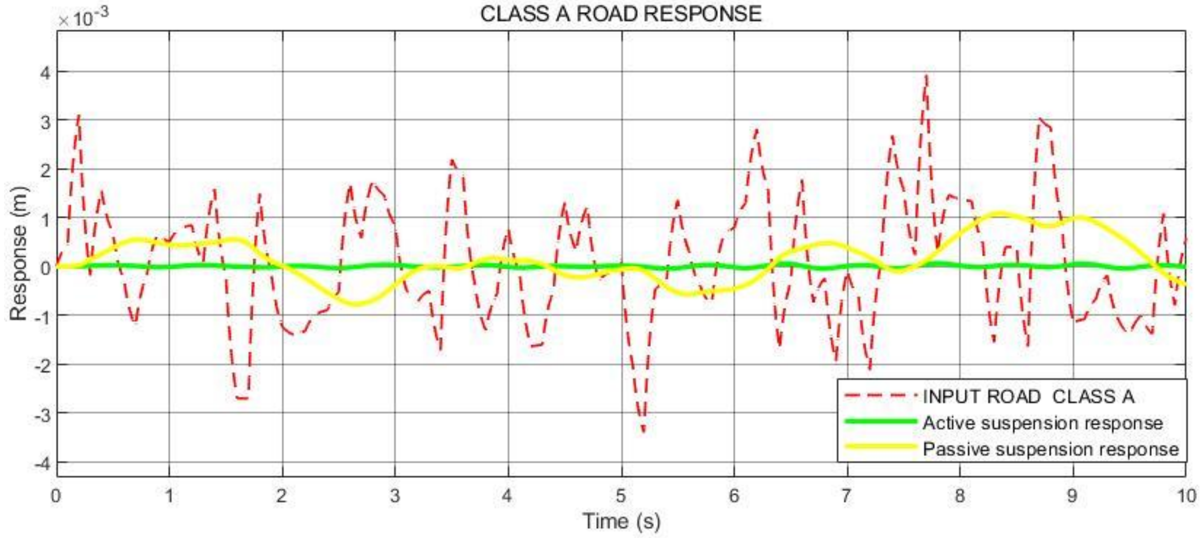


**Figure 6.** Response of Passive and Active suspension to Class A type road input

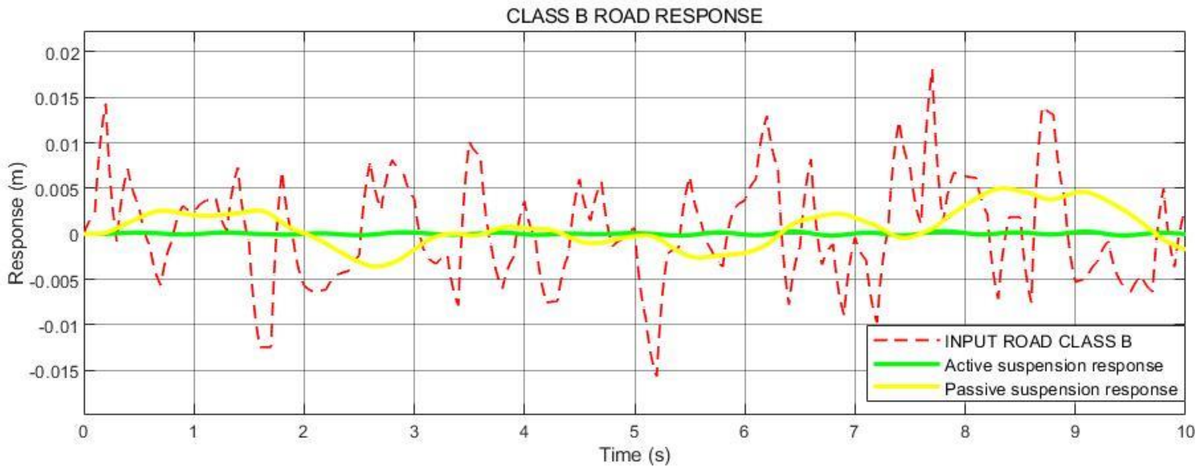


**Figure 7.** Response of Passive and Active suspension to Class B type road input

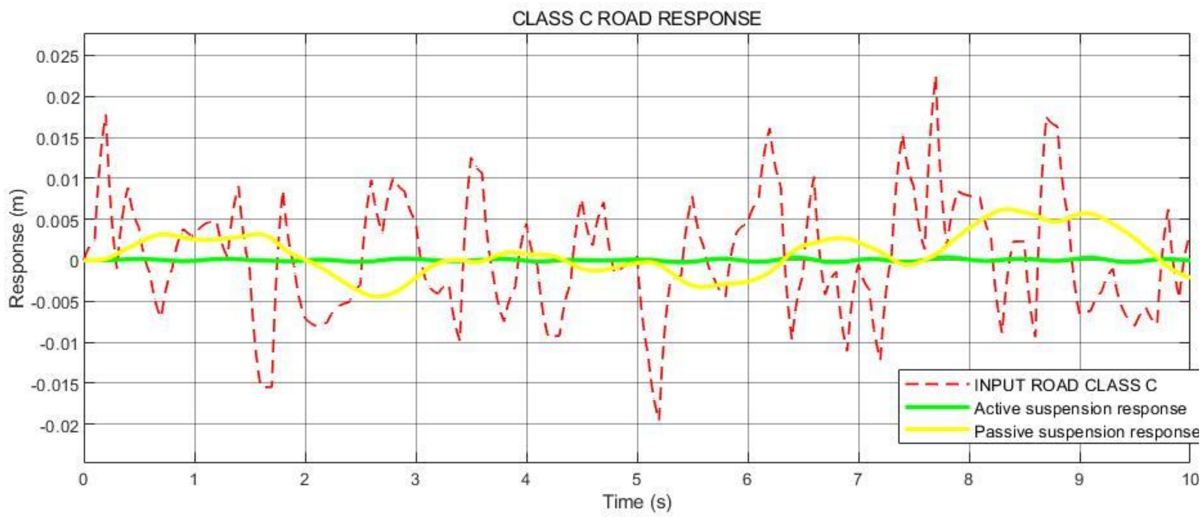


**Figure 8.** Response of Passive and Active suspension to Class C type road input

The response of designed active suspension for various class of standard road input. The simulation of scheme readily produces result which illustrate the performance of active suspension. The above results of active suspensions are based on pneumatic air bellow. Frequency response of our active suspension to various standard road input are plotted in figure 9. The system behavior is better than the conventional passive.

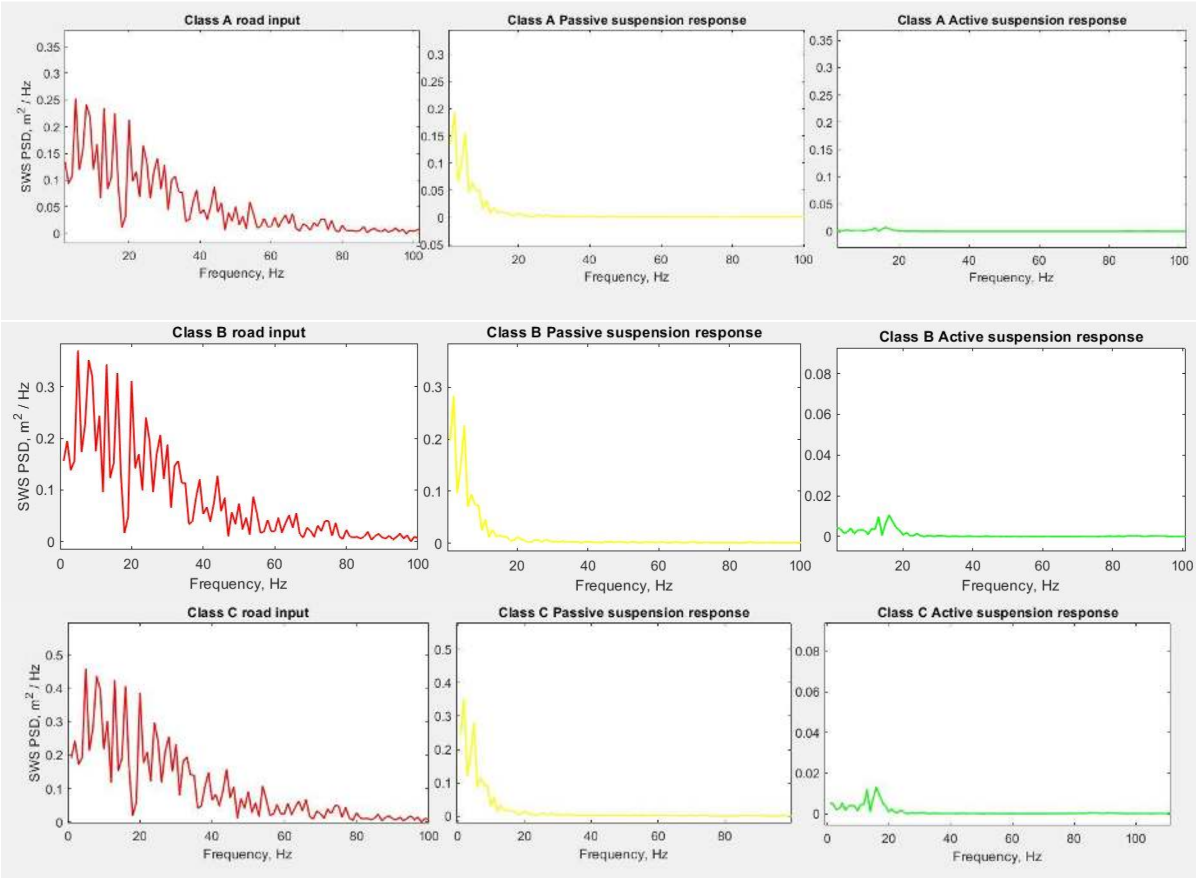


**Figure 9.** Frequency Response of Passive and Active suspension Systems

## 5. Conclusion

In this paper, we had designed the system for passive and active system, simulated them to understand the variation between active suspension and passive suspension and the output of designed active suspension system is simulated under standard road input by generating power spectral density is used to get roughness of road surface in software. From the results, it is evident that the passive suspension system can suppress 60% more vibration than passive suspension system.

## References

[1] Francisco J M Q M, António B P, Alfredo B M 2018 The simulation of an automotive air spring suspension using a pseudo-dynamic procedure *Appl. Sci.* **8** 1049.
[2] Razdan S, Pathak C S, Bhave S Y, Awasare P J 2018 Mathematical modeling and simulation of quarter car model of an active air suspension *Int. J. Acad. Res. Develop.* **3** 63-69.
[3] Priyandoko G, Mailah M, Jamaluddin H 2009 Vehicle active suspension using skyhook adaptive neuro active force control *Mech. sys. sig. process.* **23** 855-868.
[4] Kosenkov P V, Makaryants G M 2017 Control algorithm design of the active pneumatic vibration isolator *Procedia Engg.* **3** 653 – 660.

[5] Teixeira R L, Neto F P L, Ribeiro J F 2006 Modelling and experimental investigation of an active damper *Shock Vib.* **13** 343–354.

[6] Bire S, Pawar P, Saraf M 2017 Integrated approach for development of air suspension system for a SUV category vehicle using analytical and experimental tools *SAE Technical Paper* **26** 0340.

[7] Sekulić D, Dedović V 2011 The effect of stiffness and damping of the suspension System *Int. J. Traf. Transport Engg.* **1** 231–244.

[8] Sharp R S, Hassan J 1988 Performance predictions for a pneumatic active car suspension system *Proc. Inst Mech. Engineers Part D Transport Engg.* **202** 243-250.

[9] Sharkawy A B 2005 Fuzzy and adaptive fuzzy control for the automobiles - active suspension system *Int. J. Veh. Mechanics Mobility* **43** 795-806.

[10] Fialho I, Balas G J 2002 Road adaptive active suspension design using linear parameter-varying gain-scheduling *IEEE Trans. Contr. Sys. Tech.* **10** 43-54.

[11] Quaglia G, Sorli M 2001 Air suspension dimensionless analysis and design procedure *Vech. Sus. Dyn.* **35** 443-475.

[12] Khodadadi H 2018 Self-tuning PID controller design using fuzzy logic for active suspension system *Int. J. Dyn. Contr.* **6** 291-295.

[13] Sreedhar B, Deshmukh C 2013 A simplified model of air suspension for multi body simulation of the commercial passenger vehicle *SAE Technical Paper* **26** 0157.

[14] Nieto A J, Morales A L, González A, Chicharro J M, Pintado P 2008 An analytical model of pneumatic suspension based on an experimental characterization *J. Sound Vib.* **313** 290-307,

[15] Zhu H, Yang J, Zhang Y 2018 Modelling and optimisation for pneumatic pitch-interconnected suspension of a vehicle *J. Sound Vib.* **432** 290-309.