International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Special Issue - AMET-2019

Mathematical model of Active Suspension System Using Noise Cancellation Techniques

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Abstract: The suspension systems currently in use can be classified as passive, semi-active and active. The passive suspension systems are the most commonly used due to their low price and high reliability. However, this system cannot assure the desired performance from a modern suspension system. An important improvement of the suspension performance is achieved by the active systems. Nevertheless, they are only used in a very reduced number of automobile models because they are expensive and complex. Another disadvantage of active systems is the relatively high energy consumption. The use of noise cancellation technique reduces the complexity and cost of the active suspension system. In this paper, a mathematical model of active suspension system is proposed using noise cancellation technique.

Keywords —Active suspensions, Actuator, Noise cancellation, Passive Suspension

I. INTRODUCTION

The primary function of vehicle suspension is to isolate the vehicle body and passengers from the oscillations created by the road irregularities and produce a continuous road-wheel contact.

At present, three types of vehicle suspensions are used: passive, semi-active and active ones. All the systems known as implemented in automobiles are based in hydraulic, pneumatic or electromagnetic operation. However, it is verified that these solutions cannot solve satisfactory the vehicles oscillations problem or they are very expensive and contribute to the increasing of the energy vehicle consumption.

Since 1980s, the evolution occurred in power electronics, permanent magnet materials and microelectronics allowed very important improvements in the electrical drives domain. Dynamic and steady state performance, volume and weight reduction, unconstrained integration with the electronic control system, reliability, cost reduction are very important factors justifying a generalized use of electrical drives.

This evolution justifies the analysis of the possibility of implementing noise cancellation in suspension systems using electromagnetic actuators in order to improve the performance of suspension system without increasing the energy consumption and the costs.

Another point of view is that an active suspension system, which keep the passenger compartment on a flat trajectory as the car wheels bounce over bumps and rough roads is a luxury concept. However, it must be remembered that the vehicle oscillations will decrease the tire-ground contact lowering the riding safety. In fact, the sprung mass vertical oscillations are not only uncomfortable but also dangerous to the human spine healthy condition.

II. SUSPENSION SYSTEMS DESCRIPTION

Passive suspension

Passive suspension is composed of the non-controlled spring and the shock absorbing damper. Both components work mechanically in parallel and are fixed between the wheel supporting structure (unsprung mass) and the vehicle body (sprung mass). The damper is a cylinder filled with hydraulic oil or Compressed gas. Inside the cylinder there is a piston driven by a rod. This fluid or gas flow generates a reaction force that is proportional to the relative speed between sprung and unsprung masses. The damping is achieved by converting the energy of the oscillations in heat.

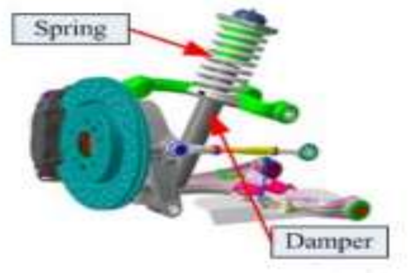

Fig. (1) Representation of passive suspension

Active Suspension

An active suspension system has the ability to store, dissipate and to introduce energy to the system. It may vary its parameters depending upon operating conditions. An active suspension includes an actuator that can supply active force, which is regulated by a control algorithm using data from sensors attached to the vehicle.

An active suspension is composed of an actuator and a mechanical spring, or an actuator, a mechanical spring and a damper. An active suspension controls both the sprung mass and the unsprung mass with the actuator working mechanically in parallel with the spring.

The active suspension is named generally as the hydraulic or pneumatic one if the actuator is selected as the hydraulic or pneumatic actuator, and the active suspension is named generally as the electromagnetic one if the actuator is an electromagnetic actuator. Active suspensions commercially implemented in automobiles today are based on the hydraulic or pneumatic one.

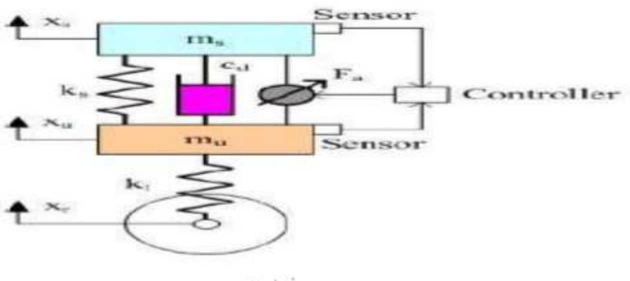

Fig. (2) Representation of active suspension system

NOISE CANCELLATION

Noise: Unwanted frequencies reaching to the suspension is called as noise.

Noise Cancellation: It is a method of reducing unwanted frequency by addition of a second frequency specifically designed to cancel the first. These unwanted frequencies are called as input test signals in control system.

The commonly used test input signals are step functions, ramp functions, acceleration functions, impulse functions, sinusoidal functions and white noise. With these test signals mathematical and experimental analysis of control systems can be carried out easily. Since the signals are very simple functions of time. Once a control system is designed on the basis of test signals the performance of the system in response to actual inputs is generally satisfactory. The use of such test signals enables one to compare the performance of many systems on the same basis.

III. MATHEMATICAL MODEL OF PASSIVE SUSPENSION SYSTEM

Assuming a quarter car model with only two degrees of freedom (DOF), two equations have been formulated for both the DOF's from their respective Free Body Diagrams (FBD). The Quarter car model can be represented as shown in Figure (3), where the road disturbance is in the form of displacements; the other terms are as mentioned. The use of a two DOF model is justified mainly because it suffices our preliminary study and if the Suspension System works satisfactorily for this basic model then if necessary, the model can be further sub-divided for further research.

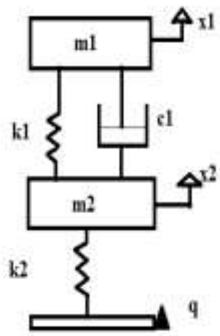

Fig. (3) Mathematical representation of passive suspension

c1: damping coefficient, N s/m
k1: spring coefficient, kN/m
k2: tire stiffness, kN/m
m1: quarter car sprung mass, kg
m2: unsprung mass, kg
x1: sprung mass vertical displacements, m
x2: unsprung mass vertical displacement, m
x1-x2: suspension travel, m
x2-q: tire deflection, m
$\ddot{x}_1 =$ sprung mass acceleration, m/s2

According to Newton's second law and free body diagram approach, the equations of motion for the system are written as,

For spring mass at passenger seat m1,

$$m_1\ddot{x}_1 + c_1(\dot{x}_1 - \dot{x}_2) + k_1(x_1 - x_2) = 0 \quad (1)$$

For unsprung mass at wheel m2,

$$m_2\ddot{x}_2 - c_1(\dot{x}_1 - \dot{x}_2) - k_1(x_1 - x_2) - k_2(q - x_2) = 0 \quad (2)$$

ISSN : 2454-9150 Special Issue - AMET-2019

Simulink Block Diagram

The input signals for mathematical model of passive and active suspension systems are step, impulse, sinusoidal and ramp signal. The Mathematical Model, when opened the window will look as below, which is purely a Simulink Block Diagram of the above Mathematical Equations. The Simulation is run and the results generated can be viewed by opening the respective Scope shown in Figure (4). The 'q' in Equation (2) is the Road disturbances and is simulated using the Signal Builder Block. The Typical Test Signals as used for the Physical Modelling are used in this Mathematical Model too. Also, with the difference that these will be used as inputs which are displacements in meters and in the Physical Model they were used as inputs which were Acceleration or Unit Force in m/s^2.

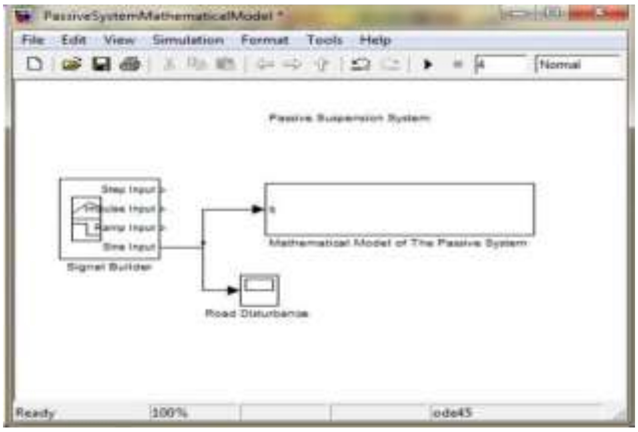

Fig. (4) Simulink block diagram for passive suspension

IV. MATHEMATICAL MODEL OF ACTIVE SUSPENSION SYSTEM

As shown in Figure (5) the active suspension includes an actuator attached in addition to the components of the Passive System, the actuator can supply active force, which is regulated by a control algorithm using data from sensors attached to the vehicle. Apart from applying the Newton's Second Law of Motion, equations need to be formulated using the Kirchoff's Voltage Law and other concepts of Electromagnetism for the actuator.

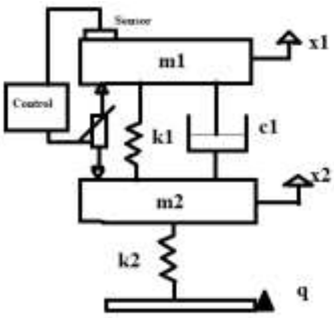

Fig. (5) Mathematical representation of active suspension

Using the variables as defined in the Passive System, here also;

Fe: actuator force,

x: linear displacement of the piston = x1

For active suspension shown in Figure (5), using the Newton's second law of motion and free-body diagram concept, the following equations of motion are derived

For test mass at passenger seat m1,

$$m_1\ddot{x}_1 + c_1(\dot{x}_1 - \dot{x}_2) + k_1(x_1 - x_2) - F_e = 0 \qquad (1)$$

For unsprung mass at wheel m2,

$$m_2\ddot{x}_2 - c_1(\dot{x}_1 - \dot{x}_2) - k_1(x_1 - x_2) - k_2(q - x_2) + F_e = 0 \qquad (2)$$

Simulink block diagram

By translating above equations into block diagrams (by Laplace Transform), a transfer function is found and from that Simulink block diagram for Active suspension system is made

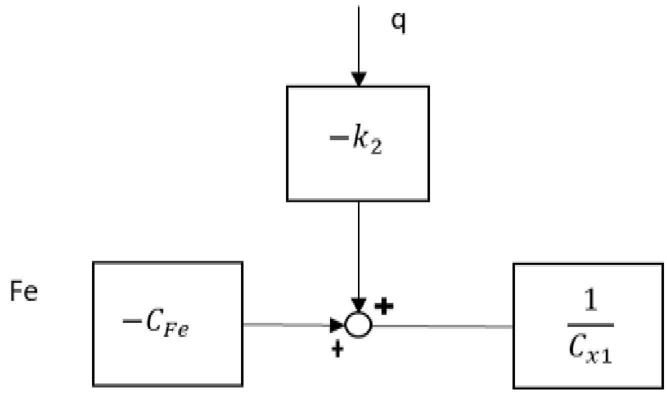

Fig. (6) Basic block diagram of active suspension system

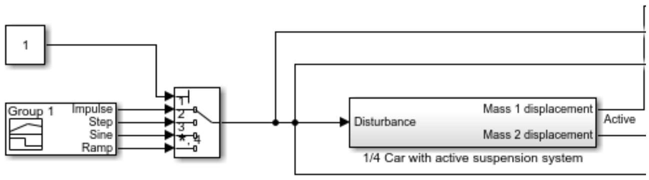

Fig. (7) Simulink block diagram for active suspension

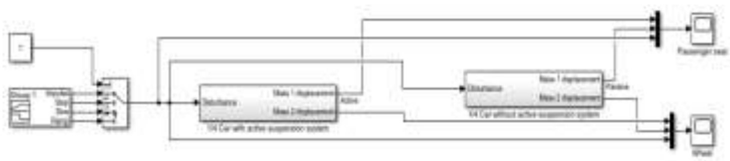

Fig. (8) Complete Suspension System in Simulink

Noise Cancellation model:

A noise cancelation system can be added as below (note that there is a minus signal in front of the block Cancel)

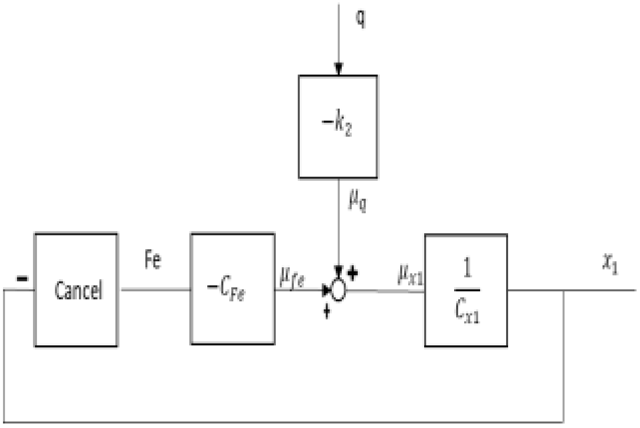

Fig. (9) Block diagram of active suspension using noise cancellation block

This noise cancellation block is added as a negative feedback to the system, which continuously compares desired output and given input. By solving the above block diagram, value of cancel block comes to be,

$$\text{Cancel} = \frac{1}{\left(\frac{1}{C_{x1}}\right).\left(-C_{Fe}\right)}$$

When the subsystem block of active suspension system from the Simulink block diagram is opened, a noise cancellation block is shown in a negative feedback. This is shown in the figure (10) below,

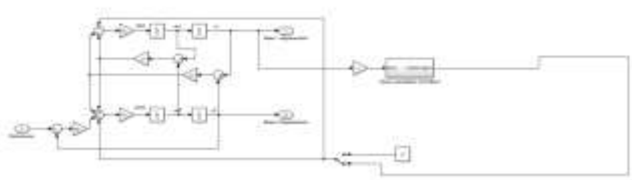

Fig. (10) Simulink block diagram for active suspension using noise cancellation model

When we switch on the key shown in fig (10), noise cancellation block gets activate and we get output at the passenger seat.

V. PARAMETERS

Values for car model for theoretical testing on Simulink:
m1 = 300; % kg
m2 = 60; % kg
c1 = 1000; % N/m/s
k1 = 16000; % N/m
k2 = 190000; % N/m
Verifying the position of poles for the transfer function disturbance to chassis displacement
roots ([m1*m2 m1*c1+m2*c1 k1*m1+k2*m1+m2*k1 k2*c1 k1*k2])

VI. OUTPUTS AT PASSENGER SEAT WITH NOISE CANCELLING MODEL

Fig. (11) Graphical Outputs in Simulink at passenger seat
From fig. (8), when we open the graph at passenger seat, output as fig (11), (12), (13), (14) are shown.
On X-axis, Time in seconds is plotted
On Y-axis, Disturbance in meter is plotted
Red Line- Disturbance at passenger seat without any passive or active system
Blue Line- Disturbance at passenger seat with passive suspension
Yellow Line- Disturbance at passenger seat with active suspension system

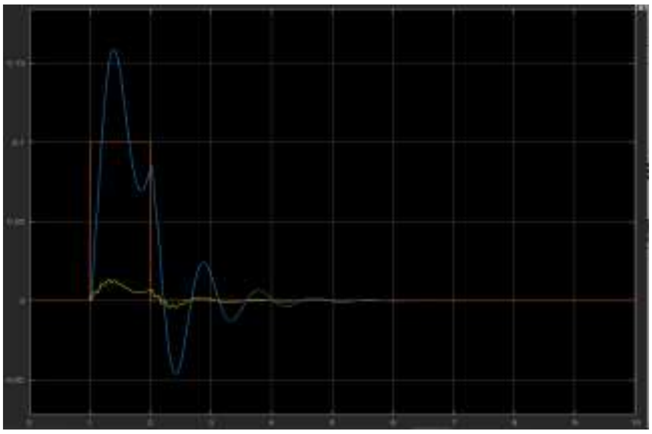

Fig. (11) Output at passenger seat for impulse signal

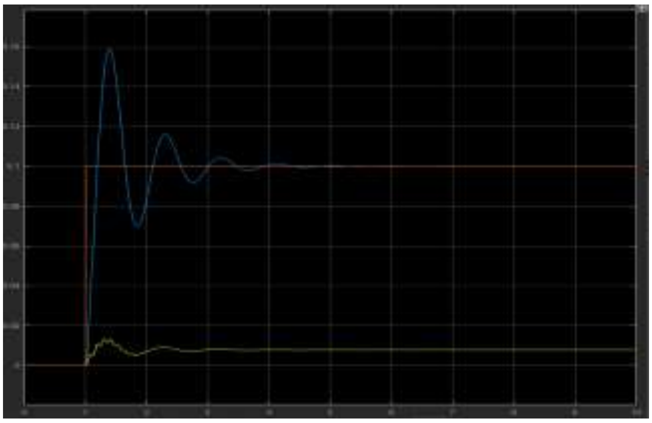

Fig. (12) Output at passenger seat for step signal

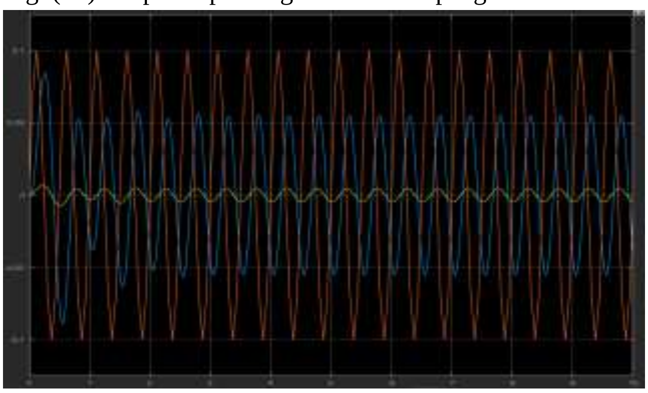

Fig. (13) Output at passenger seat for sinusoidal signal

 DOI : 10.35291/2454-9150.2020.0106

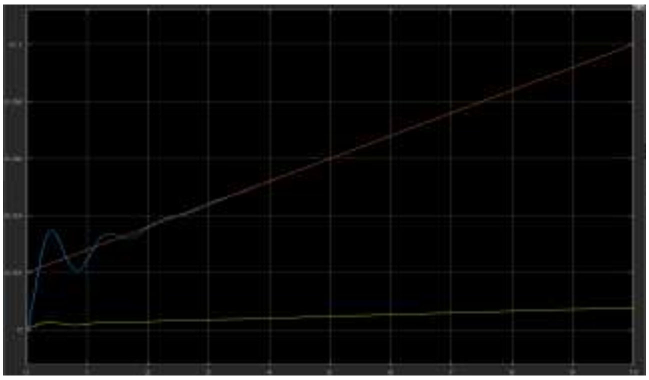

Fig. (14) Output at passenger seat for ramp signal

Result Table:

Input Signal	Time (sec)	Disturbance in Passive Suspension (m)	Disturbance in Active suspension(m)	Reduction in disturbance (in %)
Impulse	1.5	0.165	0.02	87.88
Step	1.5	0.158	0.015	90.50
Sine	2.5	0.055	0.01	81.82
Ramp	2.5	0.04	0.044	90

VII. CONCLUSIONS

From the result table, it is shown that the disturbance in suspension is reduced up to average 87% in proposed active suspension system than passive suspension system. The mathematical model developed in Simulink shows that, noise cancellation model works well theoretically for the given active suspension system. Although we cannot reduce the total disturbance to the zero, getting the graph closer to the zero is made possible by this model.

Therefore, it is concluded that the active suspension system has better performance capabilities over the passive suspension system.

Due to the change in vehicle concepts to the more electric car, the suspension system becomes ever more important due to changes in the sprung and unsprung masses. Active suspension systems can maintain the required stability and comfort due to the ability of adaptation in correspondence with the state of the vehicle.

It is suggested that specifications must also be drawn from on-road measurements on a passive suspension system to be able to better design the Active Suspension Model and also that it directly validates and helps us to optimize the Control Algorithms used for controlling the Controller.

ACKNOWLEDGMENT

This research is guided by Mr. Chinmay Samant (PhD student at Strasbourg university, France). This person has helped the authors in designing the project model.

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