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Application of Semi Active Suspension Systems in Rail Vehicle Dynamics

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***Abstract*:--** **The Paper explores the possibilities of implementing various semi active suspension systems in Rail Vehicle Dynamics. The dynamic behavior of the rail vehicle using various semi active suspension techniques is studied and the level of vibration isolation achieved for various suspension systems is compared. Different Semi-active models are explored and compared with the passive suspension model. The analysis is done with the help of MATLAB/SIMULINK model. Possible means of practically implementing the semi active suspension systems are also explored.**

***Keywords*:-- Rail dynamics, semi-active suspension,**

I. INTRODUCTION

With the advancements in transportation technology, the need for high speed and efficient transportation has been steadily increasing. Railway transportation has always been a very important transport medium since its inception. Current technological advancements in rail vehicles have been tremendous but developing nations like India still have a long way to go to develop more efficient rail vehicles at par with the world standard.

The dynamic analysis of a rail vehicle system is a complex procedure involving a number of variables in play. Due to this complexity, achievement of efficient suspension dynamics poses a problem. One of the most important semi active control systems, the skyhook control system was first proposed by Kamopp in 1974 [1] and several industries including automobile industries have put it to application. Yoshiyuki Maruyama et al [2] talk about the development of active rail suspension system using active actuators and control systems. Meral Bayraktar et al [3] discuss the procedure for modeling a rail vehicle vibration system using MATLAB and analyzing it. Karim H. Ali Abood et al [4] analyze the railway carriage model to study the dynamics of the car body running on curved tracks and provide the data for the various components of the rail vehicle quarter car model.

Rajesh Chandmal Sharma et al [5] explore the various methodologies of dynamic analysis of railway vehicles and specify the various performance indices. On the basis of these performance indices (vehicle lateral stability, curve negotiation capability and vehicle ride quality), the dynamic performance of a railway vehicle can be measured. Fernando D. Goncalves' [6] thesis explores the various semi active suspension systems that can be taken into consideration for the analysis.

In this paper, the authors have explored the various possible semi active suspension systems that can be practically applied to high speed rail vehicles. Three different semi active suspension concepts have been explored in the paper and conducted a humble analysis with the help of MATLAB/SIMULINK package. The vibration isolation is studied and compared for the different semi active suspension concepts applied to simple quarter car models. The developed quarter car models are subjected to step input excitation as road profile disturbance and the results are graphed in the form of transmissibility curve in the time domain.

II. PASSIVE VEHICLE MODEL

A generic rail vehicle model consists of a certain number of rigid or flexible bodies connected through springs, dampers and links. Broadly speaking, there are three major bodies; the wheel set, the truck body and the car body. It is the car body which contributes the major mass and is the object of dynamic study as it carries the transportation load.

Rigid body modeling is not always accurately possible in case of car bodies as they are bound to have structural flexibility of a certain degree giving structural vibration modes in different ranges. For the complete analysis, the structural flexibility of the wheel sets under torsion and bending may also be taken into consideration.
Owing to the various complexities of a modeling a complete realistic model of a rail vehicle, in this paper a

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simple two degree of freedom quarter car model (Figure 2) is used for initial analysis. As suggested by P. Sathishkumar et al [6], the mathematical modeling of a quarter car model is based on the fundamental Newton's second laws of motion.

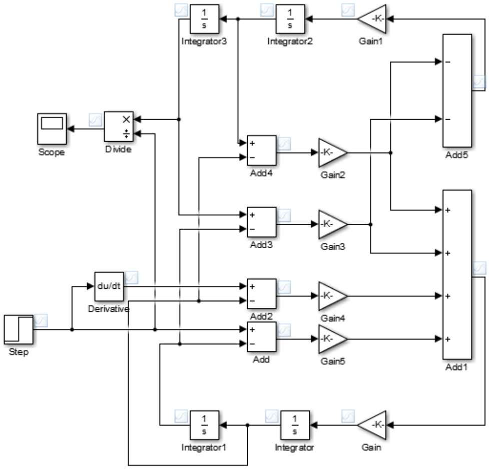

Figure 1SIMULINK Model Passive Suspension

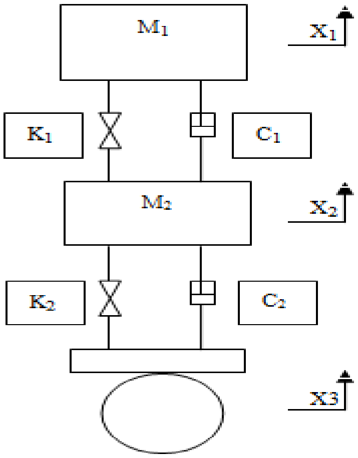

Figure 2 Quarter Car Model Passive Suspension

$$M_1\ddot{x}_1 + k_1(x_1 - x_2) + c_1(\dot{x}_1 - \dot{x}_2) = 0 \qquad (1)$$

$$M_2\ddot{x}_2 - k_1(x_1 - x_2) - c_1(\dot{x}_1 - \dot{x}_2) + k_2(x_2 - x_3) + c_2(\dot{x}_2 - \dot{x}_3) = 0 \qquad (2)$$

$$[M_1\ M_2\ 0]\begin{bmatrix}\ddot{x}_1\\ \ddot{x}_2\\ \ddot{x}_3\end{bmatrix} + \begin{bmatrix}K_1 & -K_1 & 0\\ -K_1 & K_1+K_2 & -K_2\end{bmatrix}\begin{bmatrix}x_1\\ x_2\\ x_3\end{bmatrix} + \begin{bmatrix}C_1 & -C_1 & 0\\ -C_1 & C_1+C_2 & -C_2\end{bmatrix}\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\\ \dot{x}_3\end{bmatrix} = 0 \qquad (3)$$

For the analysis of given passive model, a SIMULINK block model (Figure 1) is created and a step input is provided at the road input. The transmissibility curve is plotted in the time domain to derive the displacement of the car body with respect to the road input.

III. SEMI-ACTIVE VEHICLE MODEL

Several Semi Active Suspension concepts have been studied over the decades. Most notable of which has been the skyhook suspension system. Two other semi-active concepts are also extensively studied which are taken into consideration by the authors of this paper. The fundamental concept of a semi active suspension system is real time analysis of the relative velocity and acceleration between two masses connected together through a damping medium. With a control feedback system, the data provided by the accelerometers can then be used for set point tracking and provide the optimum damping characteristics to the system.

In the Quarter car models (Figures 4, 6 and 8) of the Semi Active policies C1 and C2 represent the actual dampers whose damping variables can be varied as allocated by the feedback control system. Ccs and Cts represent the imaginary dampers on the basis of which the analysis of the SIMULINK models (Figures 3, 5 and 7) is done.

3.1 Sky Hook Policy Attached To Car Body

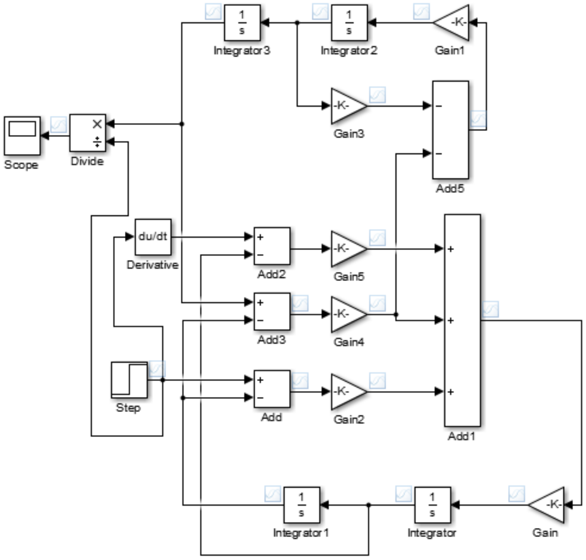

Figure 3SIMULINK model skyhook policy (1)

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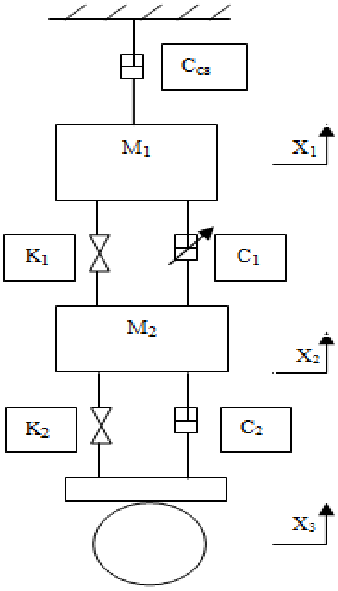


Figure 4 Quarter Car model Skyhook policy (1)

$$M_1\ddot{x}_1 + k_1(x_1 - x_2) + c_1\dot{x}_1 = 0 \qquad (3)$$

$$M_2\ddot{x}_2 - k_1(x_1 - x_2) + k_2(x_2 - x_3) + c_2(\dot{x}_2 - \dot{x}_3) = 0 \qquad (4)$$

$$f_c = \max \quad (\textit{when force exerted by skyhook(imaginary) damper is in the same direction as the actual damper})$$
$$f_c = \min \quad (\textit{when force exerted by skyhook(imaginary) damper is in the opposite direction as the actual damper})$$

3.2 Skyhook Policy Attached To Truck Body

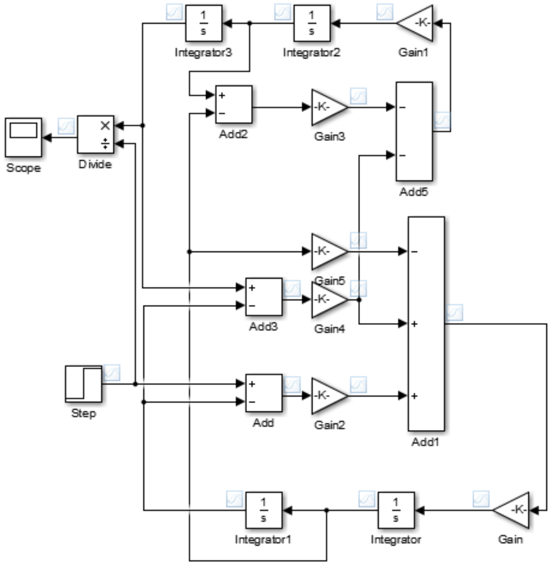
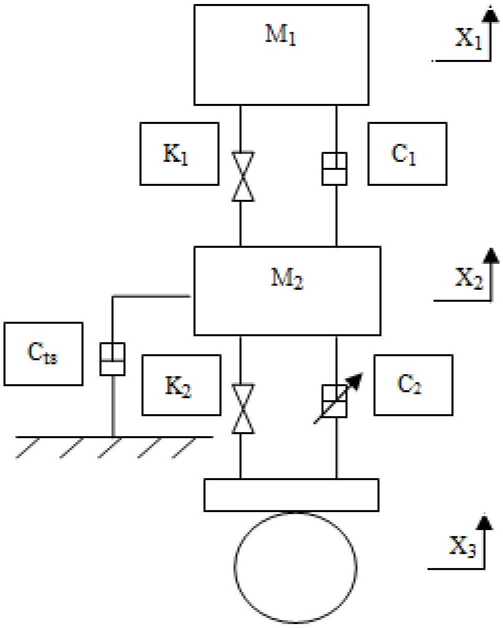


Figure 5 SIMULINK model skyhook policy (2)



$$M_1\ddot{x}_1 + k_1(x_1 - x_2) + c_1(\dot{x}_1 - \dot{x}_2) = 0 \qquad (3)$$

$$M_2\ddot{x}_2 - k_1(x_1 - x_2) - c_1(\dot{x}_1 - \dot{x}_2) + k_2(x_2 - x_3) + c_2\dot{x}_2 = 0 \qquad (4)$$

$$f_c = \max \quad (\textit{when force exerted by skyhook(imaginary) damper is in the same direction as the actual damper})$$
$$f_c = \min \quad (\textit{when force exerted by skyhook(imaginary) damper is in the opposite direction as the actual damper})$$

3.3Hybrid suspension policy

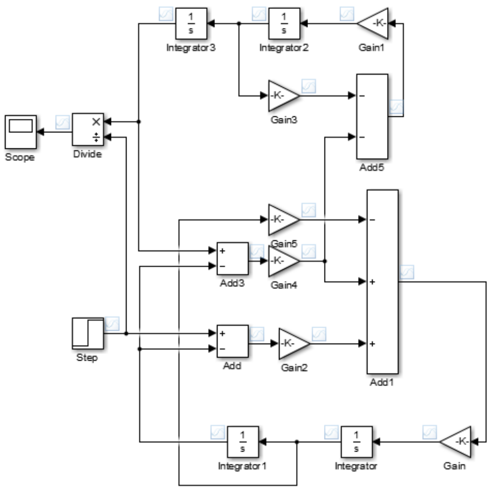


Figure 7SIMULINK model Hybrid policy

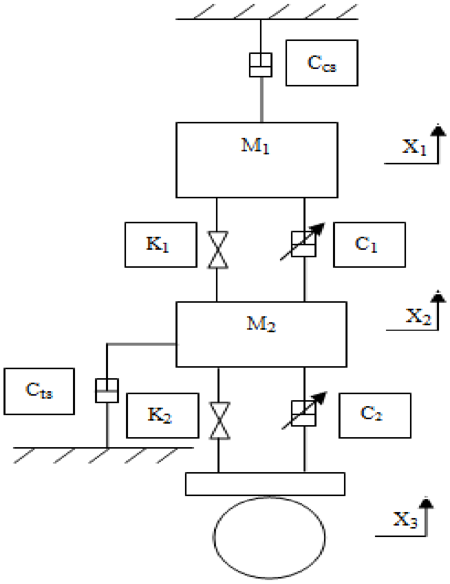


Figure 8 Quarter Car model

$$M_1\ddot{x}_1 + k_1(x_1 - x_2) + c_1\dot{x}_1 = 0 \qquad (5)$$

$$M_2\ddot{x}_2 - k_1(x_1 - x_2) + k_2(x_2 - x_3) + c_2\dot{x}_2 = 0 \qquad (6)$$

$$F_{sa} = G(\alpha\sigma_{sky} + (1-\alpha)\sigma_{ground}) \qquad (7)$$

$F_{sa} = total\ damping\ force$

$G = gain$

$\sigma_{sky} = component\ of\ skyhook\ damper$

$\sigma_{ground} = component\ of\ groundhook\ damper$

$\alpha = split\ ratio\ factor\ between\ skyhook\ and\ groundhook\ policy$

Fernando D. Goncalves [5] has done extensive research in the various semi active suspension concepts and provide the methods through which these concepts can be implemented in vehicles.

K.S. Sim et al [7] study the implementation of sky hook suspension for optimization and improvement of lateral disturbances and velocities of a car body.

IV. COMPARATIVE STUDY

The given MATLAB models are representations of the various semi-active suspension concepts and provide a comparative study for the selection of the best possible semi active suspension concept in a generic manner. The passive model shows the result of the displacement of mass M1 (car body mass) with respect to the unit step road input, i.e. X1/X3. The graph (Figure 7) shows the variation in the aforementioned ratio and time taken to reach dead state.

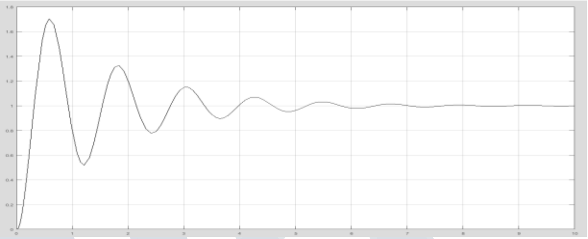


Figure 7 Passive model

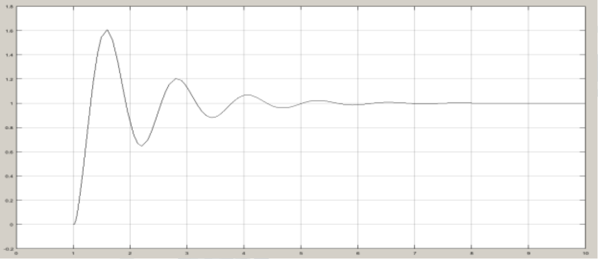


Figure 8 Skyhook policy attached to truck body

The skyhook policy attached to truck body (Figure 8) seems to work a little better than the passive model by decreasing the displacement peaks of the car body and decreasing the time taken to reach the stable dead state.

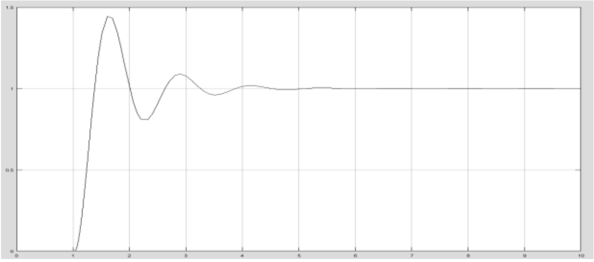


Figure 9 Skyhook policy attached to car body

The skyhook policy attached to the car body (Figure 9) works better than either skyhook attached to truck body or passive suspension as shown by the graph. The time to taken to reach steady state has considerably reduced with smaller displacement peaks.

We can see from the graphs that skyhook semi-active suspension policy may provide the best possible vibration isolation to the rail vehicle model under consideration. Although this is only a hypothesis since the dynamic requirements for a particular rail vehicle may vary depending upon its usage and application. In such a situation the Hybrid semi active suspension model is better suited as in this model we can easily manipulate the dampers to work in the skyhook or ground hook policy. The graph depicts the Hybrid policy suspension (Figure 10) with both groundhook and skyhook policies working simultaneously.

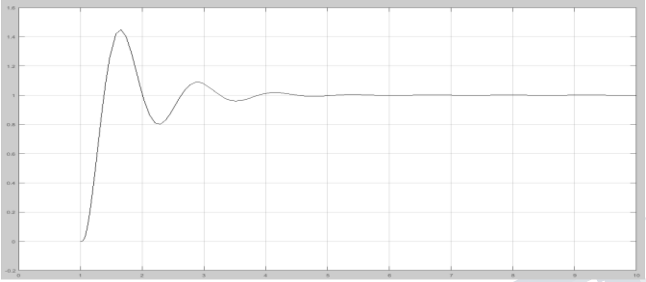


Figure 10 Hybrid semi active suspension policy

Table of Data

Table 1

Content	Detail	Unit	Value
M1	Car body mass	Kg	4.820×10^{4}
M2	Truck body mass	Kg	3.086×10^{3}
X1	Car body displacement	-	
X2	Truck body displacement	-	
X3	Road profile input	-	Unit displacement
K1	Secondary suspension vertical stiffness	N/m	3.086×10^{3}
K2	Primary suspension vertical stiffness coefficient	N/m	9.32×10^{5}
C1	Secondary suspension vertical stiffness coefficient	Ns/m	2.75×10^{4}
C2	Primary suspension vertical stiffness coefficient	Ns/m	3.00×10^{4}

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