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Application of Skyhook Semi-active Suspension in railway carriages for vibration isolation

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ABSTRACT

In this paper the authors have explored the possibility of implementing skyhook suspension system in Rail carriage suspension system. The dynamic effects of implementing skyhook suspension system in rail carriages have been studied and the vibration isolation levels for the different sprung masses of the rail carriage have been recorded. The degree of vibration isolation achieved through skyhook suspension system is also compared with that of passive suspension system. The Vibration isolation graphs are plotted and analyzed with the help of MATLAB/SIMULINK package. The means of practically implementing skyhook suspension system have also been explored.

Keywords: Rail carriage dynamics, semi-active suspension, skyhook suspension system, rail vehicle suspension

1. INTRODUCTION

Transportation has always been one of the major domains of technological development and improvement. An efficient transportation system directly relates to the social and economic improvement of the region it operates in. Technological developments in rail vehicles have always been a matter great importance as rail vehicles still constitute a major chunk of transportation sector. In developing countries like India, the improvement in rail vehicle technologies may have far reaching effects on its economy and technological structure.

Undertaking a dynamic analysis of a rail vehicle is an extremely complex procedure which involves a number of variables. Due to this complexity, an effective and efficient dynamic analysis of a rail vehicle poses certain limitations and issues.

The semi active suspension system in question, the skyhook semi active policy was first proposed by Karnopp in 1974 [1] and has been put to use by several industries.

Yoshiyuki Maruyama et al [2] discuss the development of active rail suspension systems with the help of active actuator control systems.

Meral Bayraktar et al [3] explore the procedures for modeling a rail vehicle vibration system using MATLAB and analyzing it.

Karim H. Ali Abood et al [4] analyze the rail vehicle model in order to determine the dynamic conditions of the rail carriage while maneuvering a curved track.

Rajesh Chandmal Sharma et al [5] explore various possible methodologies to dynamically analyze the rail vehicle models and specify the various performance indices. These performance indices (vehicle lateral stability, curve negotiation capability and vehicle ride quality), form the basis of the dynamic performance of a railway vehicle. Fernando D. Goncalves' [6] thesis lists out various semi active suspension policies that can be taken into consideration for application and implementation.

In this paper, the authors have explored the possibility of implementing skyhook semi active suspension concept to high speed rail vehicles. The passive as well as the Semi-active suspension policy have been analyzed with the help of MATLAB/SIMULINK. The vibration isolation is studied and compared for the semi active and passive suspension models. The developed quarter car models are subjected to step input excitation as road profile disturbances and the results are graphed in the form of transmissibility curve in the time domain.

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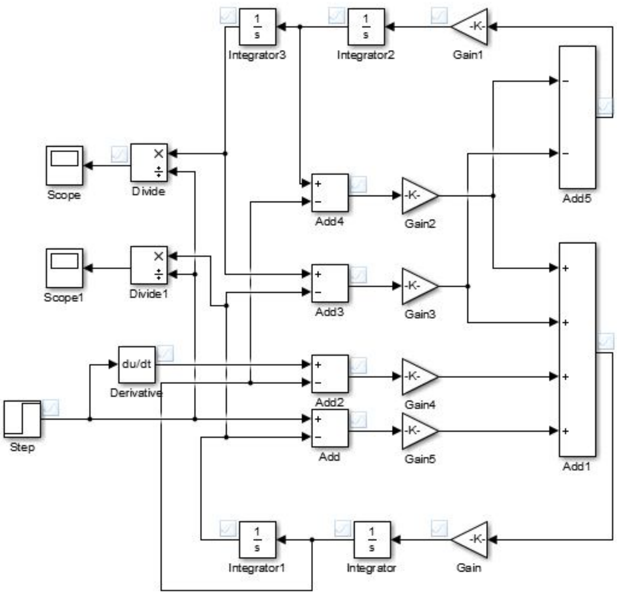
2. VEHICLE MODEL

A generic rail vehicle model primarily consist of three masses, the wheel set which remains in contact with the track, the truck body which is connected to the wheel set with the help of the primary suspension and the car body which is connected to the car body with the help of a secondary suspension. The car body contributes to the major mass of the entire rail vehicle and is also the subject of study as it carries the transportation load.

Creating a rigid body model for a railway carriage always poses a problem as the car body is bound to have some amount of structural flexibility which leads to the creation of structural vibration modes in different ranges. In order to undertake a complete analysis, the structural flexibility of the rail carriage under torsion and bending condition must also be taken into consideration.

Considering the various limitations and complexities involved in the complete and pragmatic modeling of a rail vehicle, in this paper a simple two degree of freedom quarter car model is used for the analysis.

Owing to the various complexities of a modeling a complete realistic model of a rail vehicle, in this paper a simple two degree of freedom quarter car model is used for initial analysis. In his works P. Sathishkumar et al [7] suggests that the mathematical modeling of quarter car model is derived and based on the fundamentals of Newton's second laws of motion.



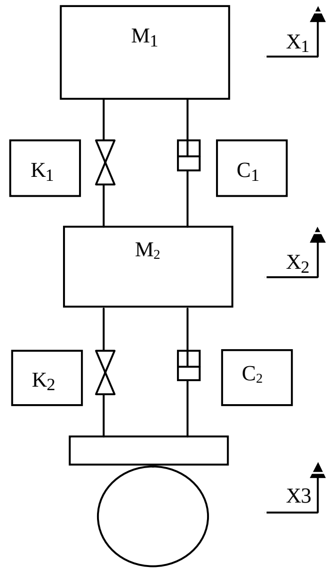


Figure 1 SIMULINK Model Passive Suspension **Figure 2** Quarter Car Model Passive Suspension

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

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

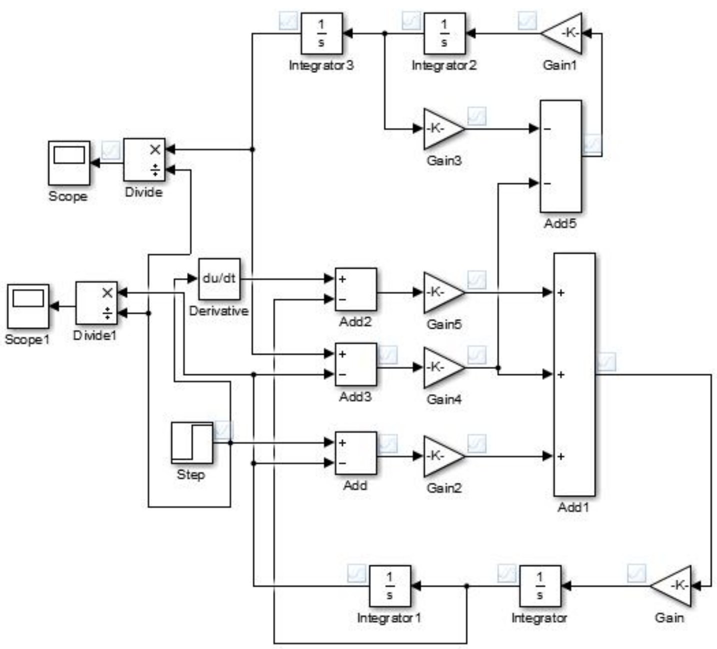
$$[M_1\, M_2\; 0]\begin{bmatrix}\ddot{x}_1\\ \ddot{x}_2\\ \ddot{x}_3\end{bmatrix} + \begin{bmatrix}K_1 & -K_1 & 0\\ -K_1 & K_1 + K_2 & -K_2\end{bmatrix}\begin{bmatrix}x_1\\ x_2\\ x_3\end{bmatrix} + \begin{bmatrix}C_1 & -C_1 & 0\\ -C_1 & C_1 + C_2 & -C_2\end{bmatrix}\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\\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

In order to analyze the given passive quarter car model (Figure 2), a SIMULINK model (Figure 1) is generated and the model is exposed to a road profile disturbance in the form of step input. Thus, a transmissibility curve is generated in the time domain to study the relative displacement of the car and truck body with respect to the road input.

3. SEMI-ACTIVE (SKYHOOK) VEHICLE MODEL

Of the various Semi Active suspension policies studied over the decades, Semi active suspension policy has always been the most notable one. Fundamentally, in a skyhook suspension concept, the damper is attached to an imaginary sky instead of any sprung mass of the vehicle body. This concept is achieved in practicality by having real time control over the damping characteristics of the damper with the relative velocities between the sprung and unsprung masses as the control parameters. A control feedback system with data inputs from accelerometers can provide efficient set point tracking can be performed to provide optimum damping characteristics to the system.

In the given Quarter car model (Figure 4) of the Semi Active policies C_1 and C_2 represent the real dampers whose damping characteristics can be controlled as allocated by the feedback control system. C_{cs} and C_{ts} represent the imaginary dampers attached to an imaginary on the basis of which the analysis of the models is done.



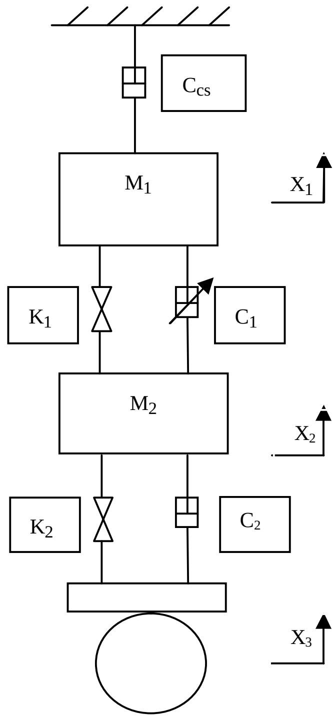


Figure 3 SIMULINK model skyhook policy

Figure 4 Quarter Car model skyhook policy

$$M_1\ddot{x}_1 + k_1(x_1 - x_2) + c_1\dot{x}_1 = 0 \qquad (4)$$

$$M_2\ddot{x}_2 - k_1(x_1 - x_2) + k_2(x_2 - x_3) + c_2(\dot{x}_2 - \dot{x}_3) = 0 \qquad (5)$$

$$f_c = \max \ \ (when\ force\ exerted\ by\ skyhook(imaginary)\ damper\ is\ in\ the\ same\ direction\ as\ the\ actual\ damper)$$

$$f_c = \min \ \ (when\ force\ exerted\ by\ skyhook(imaginary)\ damper\ is\ in\ the\ opposite\ direction\ as\ the\ actual\ damper)$$

4. Analysis and Results

For the given SIMULINK models, the transmissibility curves are plotted in time domain. Graphs are generated for the two sprung masses under consideration. The Car body and the truck body both are sprung masses receiving track disturbances through the primary and secondary suspensions. The graph displays the relative disturbances of the Car body and truck body with respect to the track disturbance. The track disturbance taken for the model is a step input signal. Since the Wheel set of a rail car generically and traditionally does not contain any rubber like elastic components, the track disturbance is considered integral with the wheel set displacement and hence the first suspension to receive disturbance is the primary suspension itself.

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4.1 Passive vehicle model

The following plots show the transmissibility of vibrations to the car body. The first graph (Figure 5) is plotted between x_1/x_3 and time. In the transient process the graph shows how soon and with how much variation the car body attains the stable state where the displacement of the car body equals the displacement of the wheel set which is equal to unit value.

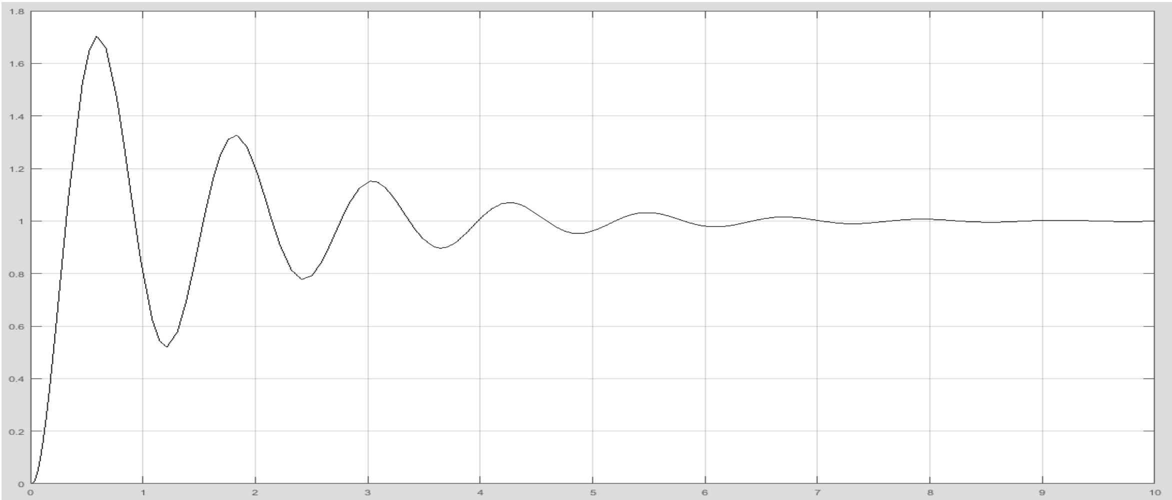

Figure 5 Vibration isolation of car body (passive suspension)

The second plot (Figure 6) shows the graph between x_2/x_3 and time. This plot depicts the transmission of vibrations from the car body to the truck body of the rail vehicle. The plot shows that the truck body has relatively less displacement as compared to the car body. This is obvious as the truck body is constrained on both the sides in the vertical plane by spring and damping elements.

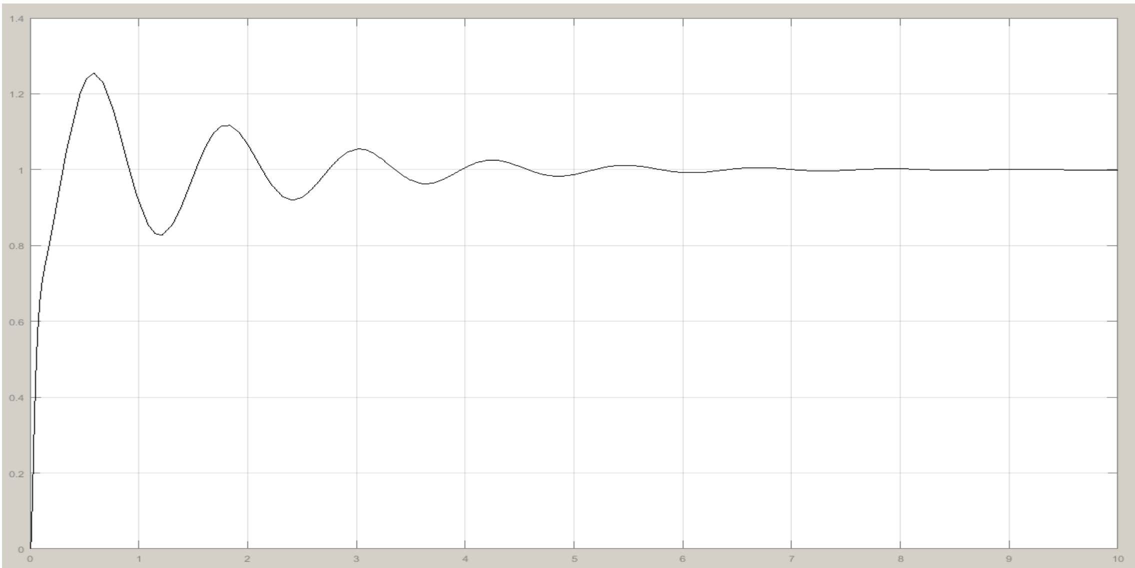

Figure 6 Vibration isolation of truck body (passive suspension)

4.2 Skyhook Semi-active model

In the skyhook semi active policy, the damper attached to the car body does not have its other end attached to the truck body. Instead, it is attached to an imaginary sky which provides better vibration isolation. The first plot (Figure 7) depicts the vibration isolation provided to the car body relative to the track excitation. The graph is plotted between x_1 $/x_3$ and time. It can be seen from the plot that the relative displacement of the car body is relatively lesser as compared to that of the Passive vehicle model. The time and peaks taken for the car body to reach steady state are also comparatively lesser in case of Skyhook policy.

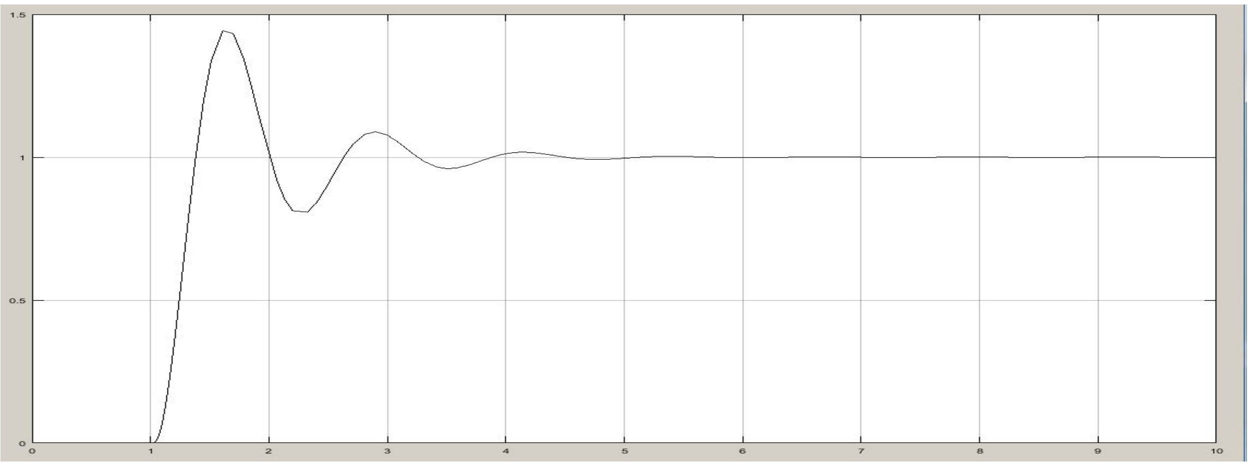

Figure 7 Vibration isolation of car body (Skyhook policy)

The second plot (Figure 8) shows the relative displacement of the truck body as compared to the road excitation. The graph is plotted between x_2/x_3 and time. The plot depicts that there is improvement in vibration isolation but slightly less as compared to the isolation improvement seen in the car body. The time taken to reach the stable state has decreased significantly though.

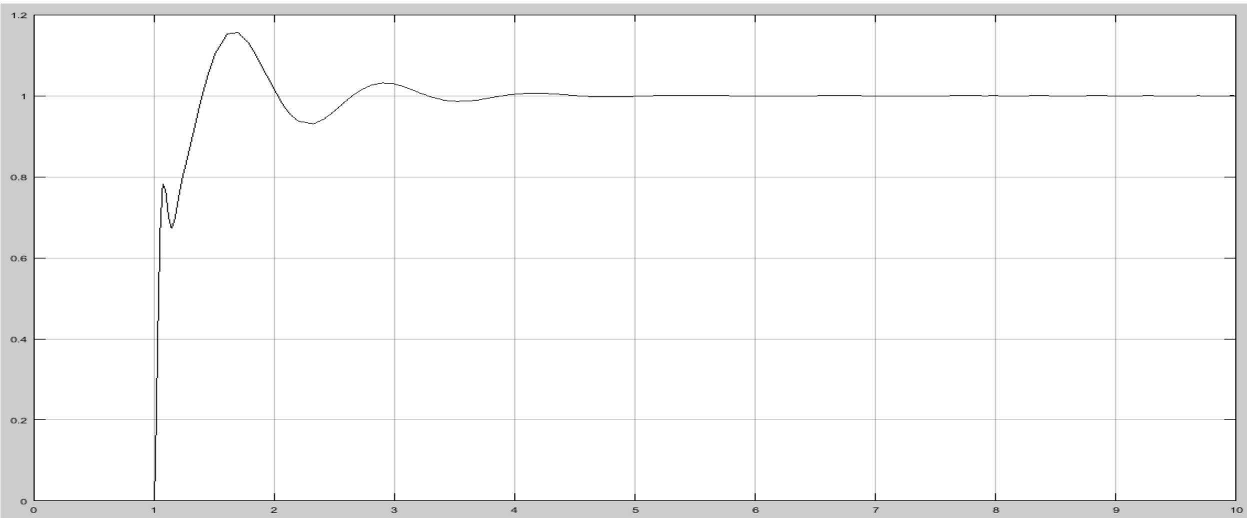

Figure 8 Vibration isolation of truck body (skyhook suspension)

5. Practical application and implementation

The concept of skyhook semi active suspension system fundamentally depends upon the real time control of damping variables of the damper being used in the vehicle. This can be achieved through a number of means. The most notable of these means which have been in use in the industry till now are as follows.

1. Solenoid valves

   A solenoid valve is a device which has a constriction that allows the passage of fluid through it. The area of passage for the fluid can be controlled electrically by varying the voltage across the solenoid valve. The larger the constriction area, the freely the fluid can flow through it. Thus the damping characteristics can be controlled by controlling the variation in the constriction area.

2. Rheological fluid

Rheological fluids are such fluids whose viscosity, density and other such properties can be changed through external stimuli such as electric voltage. By varying the external stimuli the damping properties can also be controlled of such fluids providing damping force control.

6. Conclusion and Table of Data

It can be clearly seen that implementation of skyhook semi-active suspension policy Improves the vibration isolation levels to a significant degree. Also the time taken to reach the steady state also decreases leading to a smoother ride for rail vehicle.

Vibration isolation is the key factor which may lead to the development of high speed rail technology. Improved vibration isolation also means that curve negotiation capabilities and cant deficiencies are also improved. The overall ride quality improvement can be ensured through the application of semi active suspension system (skyhook policy).

Table 1

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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