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Analytical Modeling of Railway Suspension System using MATLAB Simulink

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Abstract*: *In this paper the performance of quarter railway suspension system is investigated using MATLAB Simulink under step input condition of the track. Integral Coach Factory (ICF) Bogie is considered for the Analytical Modeling. A linear dynamic system model of quarter ICF Bogie is made and according to the model the mathematical equations are written. The equivalent Simulink model corresponding to the equations are made in MATLAB Simulink. The system is simulated under step input condition of the track to get the performance characteristics such as displacement, velocity and acceleration. The result shows that for the given step input, the major vibrations occurring to the bogie frame and the coach. These vibrations of the ICF Bogie affect the ride comfort of the passenger. The addition of proper controlling element like hydraulic actuator controlled by PID controller to the suspension system of ICF Bogie is suggested in order minimize the vibrations and to achieve the ride comfort for the passenger.

Key words*: *Bogie, modeling, simulation, suspension.

I. INTRODUCTION

Railway vehicle as an example of a mechanical dynamic system to which control can be applied in a manner such yields significant benefit from an engineering and operational view point. Railway vehicles employ steel wheels running on tracks with steel rails, which provide the support and guidance functions. Suspension components play key role in the running behavior of railway system [1]. Fundamentally there are three things that a suspension needs to do:

- Support the changing weight of the vehicle.
- Provide stability to give a satisfactory ride quality.
- Provide guidance so that the vehicle follows the intended path.

The implementation of change in the railway industry has been very slow, both organizationally and technically. To keep up with technological change the railway wagons have to be re-designed to maintain railway advancement. This process involves extensive simulation, modelling and testing. In mechanical terms, a bogie is a chassis or framework that carries wheels and it is attached to a vehicle. The wheels are mounted underneath the bogie structure on the wheel axles through bearings.

The Indian Railway Bogie is manufactured by Integral Coach Factory (ICF) located at Chennai and most modern passenger-carrying railway vehicles have the configuration shown in Fig. 1 and Fig. 2, which gives simplified side-view and top-view diagrams. The Bogie is designed to run on Indian Broad Gauge Track (1676 mm). Since coil springs are provided both in primary & secondary suspension, the bogie is known as All Coil Bogie [2].

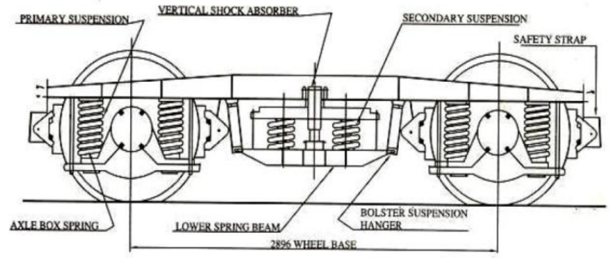

Fig. 1. Side-view of ICF Bogie.

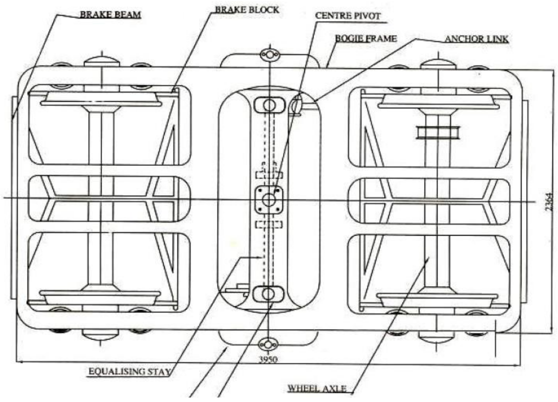

Fig. 2. Top-view of ICF Bogie.

The present work tries to analyse the performance of quarter railway suspension model of ICF Bogie. The Analytical model of the quarter ICF Bogie is made by analysing the physical structure of the Bogie. Dynamic response with track disturbances is simulated with fixed parameters of the system. Further design modifications by the implementation of control element like PID controller [3] to the suspension system of ICF Bogie are suggested.

II. ANALYTICAL MODELING

Analytical Modelling involves development of mathematical model of a system and studying the dynamic response of that system. The mathematical model of suspension components in a railway vehicle may have an important effect on the results of vehicle dynamics simulations and their accuracy in reproducing the actual vehicle behaviour. In the present investigation the vertical vibration in the system is considered by involving mass, spring and damper in the system model [4]. In order to model, the physical structure of ICF Bogie is analysed.

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The ICF Bogie consists of two types of suspension system. One is primary suspension and another one is secondary suspension system. The wheel is connected to two primary suspensions. There are two dampers positioned vertically inside the two primary suspensions respectively. The primary suspension system is attached to the Bogie frame. The coach or body is attached to the secondary suspension system by means of a centre pivot. The secondary suspension system has an arrangement of two suspension springs and a dashpot positioned vertically. The bogie frame hangs the secondary suspension system by means of a bolster suspension hanger with a lower spring beam [2].

According to the physical structure of the ICF Bogie, the linear dynamic system model with three degree of freedom system consisting of mass, spring and damper is made. The model is shown in Fig. 3. The quarter part of the ICF Bogie is considered for the analytical modelling [4].

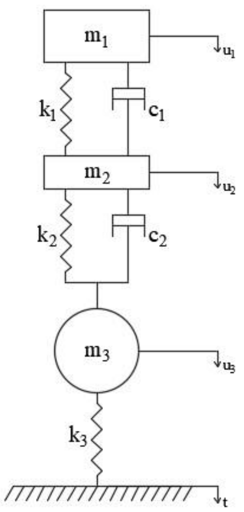

Fig. 3. Quarter linear dynamic suspension model of ICF Bogie.

The coach or body mass of the ICF Bogie represented by m_1. The secondary suspension spring stiffness is represented by k_1 and the corresponding secondary damping coefficient by represented c_1. The Bogie frame mass is represented by m_2. The effective primary suspension spring stiffness and the effective damping coefficient are represented by k_2 and c_2 respectively. In the Fig. 3, m_3 and k_3 represents mass and stiffness of the wheel- axle assembly respectively. The track input is represented by t and u_1, u_2 and u_3 are the displacements occurring at the masses m_1, m_2 and m_3 respectively for the corresponding track input profile. In the present investigation step track input condition is considered to get the performance characteristics like displacement, velocity and acceleration of the model.

A. Equations for the model

The mathematical equations are developed for the model shown in Fig. 3. The Newton's second law of motion is applied by considering the free body diagrams of all the masses [5]. The corresponding equations are:

$$m_1\ddot{u}_1 = -c_1(\dot{u}_1 - \dot{u}_2) - k_1(u_1 - u_2) \tag{1}$$

$$m_2\ddot{u}_2 = -c_1(\dot{u}_2 - \dot{u}_1) - c_2(\dot{u}_2 - \dot{u}_3) - k_1(u_2 - u_1) - k_2(u_2 - u_3) \tag{2}$$

$$m_3\ddot{u}_3 = -c_2(\dot{u}_3 - \dot{u}_2) - k_2(u_3 - u_2) - k_3(u_3 - t) \tag{3}$$

The state variable form of the above equations are given by,

$$\dot{y} = Ay + Bz \tag{4}$$

Where,

$$\dot{y} = \begin{bmatrix} \dot{y}_1 \\ \dot{y}_2 \\ \dot{y}_3 \\ \dot{y}_4 \\ \dot{y}_5 \\ \dot{y}_6 \end{bmatrix} \quad y = \begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \\ y_5 \\ y_6 \end{bmatrix} \quad z = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ t \end{bmatrix}$$

$$B = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{k_3}{m_3} \end{bmatrix}$$

$$A = \begin{bmatrix} 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ \frac{-k_1}{m_1} & \frac{k_1}{m_1} & 0 & \frac{-c_1}{m_1} & \frac{c_1}{m_1} & 0 \\ \frac{k_1}{m_2} & \frac{-(k_1+k_2)}{m_2} & \frac{k_2}{m_2} & \frac{c_1}{m_2} & \frac{-(c_1+c_2)}{m_1} & \frac{c_2}{m_2} \\ 0 & \frac{k_2}{m_3} & \frac{-(k_2+k_3)}{m_3} & 0 & \frac{c_2}{m_3} & \frac{-c_2}{m_3} \end{bmatrix}$$

III. SIMULATION USING MATLAB SIMULINK

To get the dynamic response of the system it needs to be simulated. The simulation of the proposed quarter suspension model of the ICF Bogie is done by using MATLAB Simulink [6]. The equivalent Simulink model of the system is created according to the equations (1), (2) and (3) as shown in the Fig. 4.

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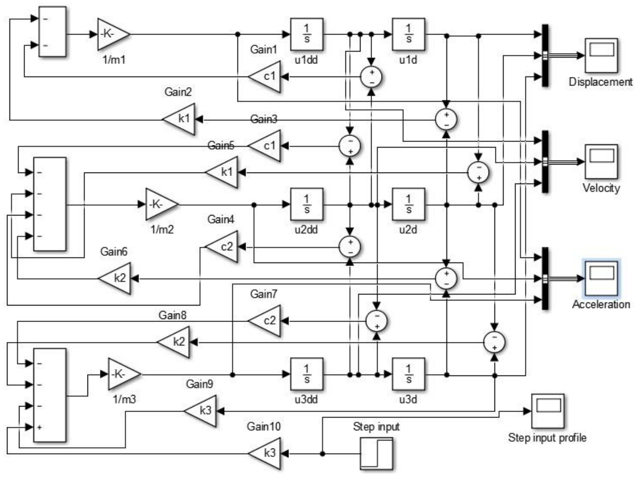

Fig. 4. Equivalent Simulink model.

The model is simulated for the fixed parameters of the system [2]. The track "t" is simulated for the step input condition [7]. The performance characteristics such as displacement, velocity and acceleration are recorded for the system model.

TABLE I. PARAMETERS OF THE SYSTEM USED FOR SIMULATION

Sl. No	Quarter Suspension Model Parameters of ICF Bogie		
	Parameters	***Symbol***	***Values***
1.	Mass of the Coach or Body	m_1	8000 (kg)
2.	Mass of the Bogie frame	m_2	653.75 (kg)
3.	Mass of the wheel	m_3	1500 (kg)
4.	Secondary spring stiffnes	k_1	5.8×10^6 (N/m)
5.	Secondary damping coefficient	c_1	120×10^3 (Ns/m)
6.	Primary effective spring stiffnes	k_2	7×10^6 (N/m)
7.	Primary effective damping coefficient	c_2	40×10^3 (Ns/m)
8.	Stiffness of the wheel	k_3	100×10^6 (N/m)

A. Step input condition

The track "t" is given a step input of amplitude 1 units. The graphical form of the step input is shown in the Fig. 5.

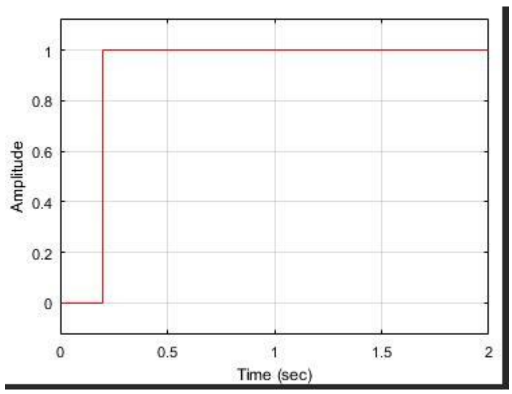

Fig. 5. Step input signal.

The corresponding body positions or displacements of the masses m_1, m_2 and m_3 are recorded and shown in the Fig. 6.

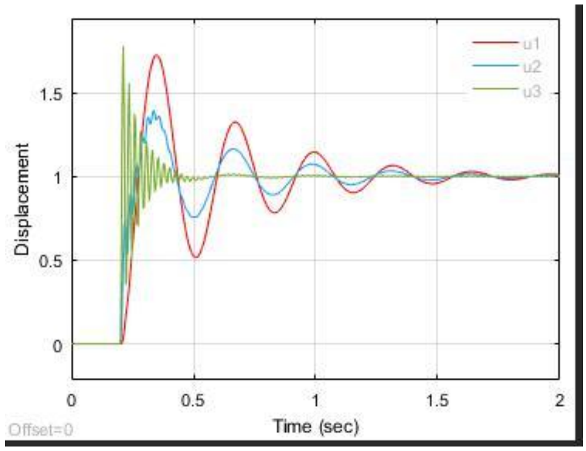

Fig. 6. Time response of the model displacements.

The corresponding velocities of the masses m_1, m_2 and m_3 are shown in the Fig. 7.

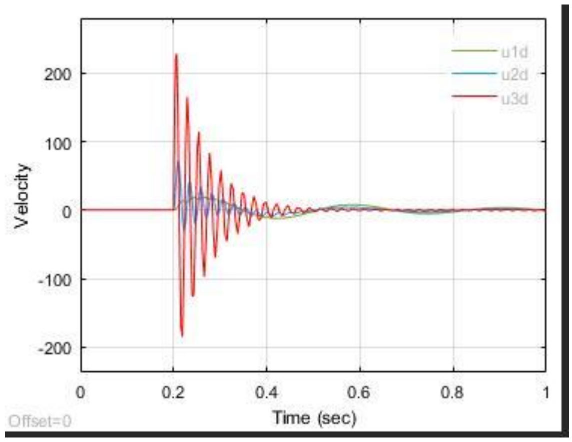

Fig. 7. Time response of the model velocities.

The accelerations of the masses m_1, m_2 and m_3 are shown in the Fig. 8.

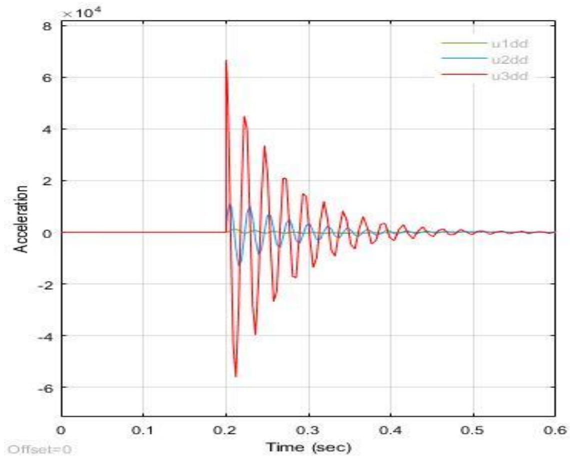

Fig. 8. Time response of the model accelerations.

IV. RESULTS AND DISCUSSIONS

From the Fig. 5, the result shows that the major displacement occurs to the coach and the Bogie frame with a larger settling time. The settling time of the wheel is very small when compared to the coach and the bogie frame.

From the Fig. 6, the result shows that there is a maximum velocity recorded for the system and the time taken to settle for the Bogie frame and the coach is large compared to the wheel.

From the Fig. 7, there is peak acceleration recorded for the wheel compared to the Bogie frame and the coach. But the settling time for all the accelerated mass components is same.

The overall results reveal that the major vibrations due to displacement, velocity and acceleration for the step input of the track are transmitted to the Bogie and the Coach with a longer settling time. This affects the ride comfort of the passenger. Modification to the system design of the ICF Bogie is suggested in order to minimise the vibration and to achieve the ride comfort for the passenger.

A. Modifications suggested

The addition of hydraulic actuator controlled by PID controller is suggested so that the vibrations occurring to the Coach and the Bogie can be minimised by which ride comfort of the passenger can be achieved.

There are three modifications to the previously modelled system is considered.

B. First modification

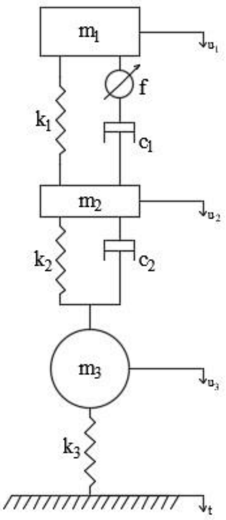

Fig 9. PID controlled hydraulic actuator fitted to secondary suspension.

C. Second modification

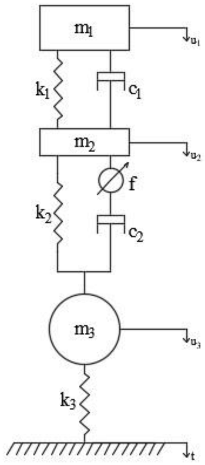

Fig 10. PID controlled hydraulic actuator fitted to primary suspension.

D. Third modification

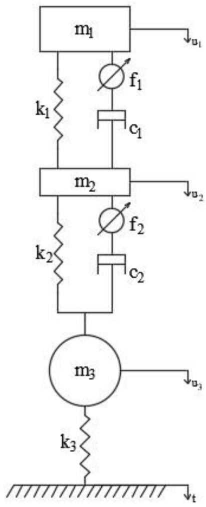

Fig 11. PID controlled hydraulic actuator fitted to both primary and secondary suspension.

V. CONCLUSION

Analytical modelling of quarter railway suspension system of ICF Bogie is done by considering a linear dynamic system model consisting of mass, spring and damper and having three degree of freedom system. The model is simulated to get the dynamic response using MATLAB Simulink under step input condition of the track. The result shows that the major vibrations occurring at the wheel are transmitted to the Bogie and Coach of the railway system with a large settling time. These vibrations of the ICF Bogie affect the ride comfort of the passenger. The modification to the ICF Bogie suspension system by adding hydraulic actuator controlled by PID controller is suggested in order to minimise the vibrations and to achieve the ride comfort for the passenger.

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