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Dynamic Analysis and Control of a Full Car Vehicle Model through Bondgraphs

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ABSTRACT

In present scenario, controller plays a very significant role in dynamical system, as it greatly affects the dynamics of the vehicle according to its influence on the achievable sources. It is mainly considered that the interaction between controller and body is one of the most important tasks of vehicle modelling. This work shows the development of a controller interaction model in multi-energy domains using bond graph approach. The main focus of the paper is modelling the spatial (3-dimensional) vehicle modelling of the complex dynamics. In this work, 3-dimensional vehicle model incorporated with 3-dimensional tire model of car has been developed through bond graph approach.

The simulation of the model is being carried out on Symbols sonata® software, which shows some interesting phenomenon.

Further the model incorporate with Proportional Integrated (PI) controller in the suspension system of vehicle model. Afterwards, the simulation study has been performed which is compared with the previous simulation. The proportional and integral gain has been optimized numerically to further apply real vehicle application.

Key words: PI controller; spatial vehicle model; bondgraphs.

I. INTRODUCTION

The increasing demands on vehicles together with relatively cheap and powerful electronics and actuator technology enable to extend purely mechanical systems with new control features. Such multidisciplinary systems together with requirement for shorter development time, lower development costs and new quality of products being developed have raised new CAE tools.Suspension systems are designed to maintain vehicle stability by reducing the effects of dynamic loads while providing a comfortable ride via the reduction of impulse forces from terrain features [1]. The word suspension originated from the original attempts of suspending the carriage body by leather straps from a framework connected to the wheels. As defined by Wong [2] ride is concerned with the sensation or feel of the passenger in the environment of a moving vehicle. Problems arise mainly from vibrations of the vehicle body, induced by sources such as aerodynamic forces and vibrations from the power train, drive train and road. As stated by Hrovat [3], vertical ground input disturbances caused by road roughness are the most relevant for ride studies. There are various studies of modelling and simulation, where vehicle has been modelled through bond graphs for evaluating a dynamic behaviour [4]. However some studies have incorporated different types of controller in suspension system [5,6].

Semi-active suspensions are similar to passive suspensions except they possess variable damping rates [7].Since the vibration suppression capabilities of the traditional passive and semi-active suspension systems are restricted, an active suspension system with additional control force to suppress the oscillations is one of the major development fields in recent vehicle industry. Fully active suspension system use hydraulic actuator which creates the desired force in the suspension system [8,9,10].

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This paper presents with the multi-rigid body theory through bond graph technique for modelling of a complex spatial car model. Primarily, bond graphs (BG) represent elementary energy-related phenomenon using a small set of ideal elements that can be coupled together through external ports representing power flow. With the aids of bond graphs, hierarchal modelling becomes possible through coupling energy exchange phenomenon, it is also possible to code on the graph the mathematical structure of the physical system to show the causal relation- ship(in computational relationship) among its signals. The conjunction of all these feature make the bond graph technique a physical based, object oriented, graphical language, which is most suitable for dynamic modelling, analysis and simulation of complex engineering system involving mixed physical and technical domains in their constitution [11].

This paper also incorporates the PI control system (which is combined form of proportional and integrated controller) to the vehicle suspension system with an objective to reduce vehicle jerks and increase comfort level of driver. The physical model of the vehicle structure is shown in fig.1. This vehicle is composed of components such as car model, suspension and wheels. Each component of vehicle act as a rigid body.

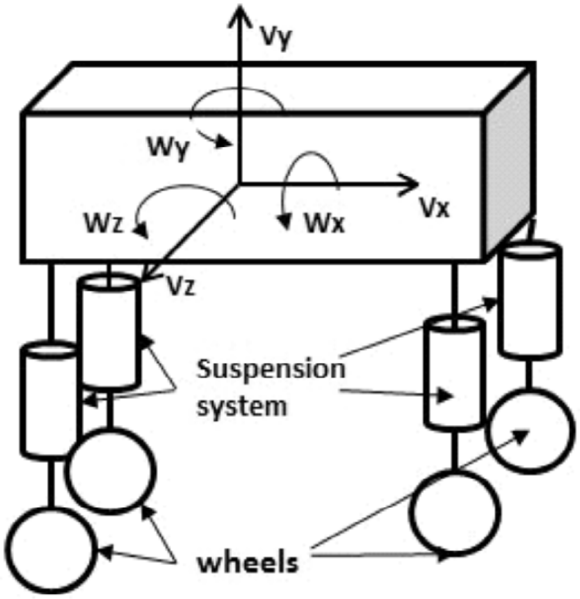

Figure 1: Three-dimensional car model of the vehicle

In the Fig.1 C.G of body is located at ‘h’ height above the axle of the vehicle; rear suspension is distance at ‘l’ simultaneously from C.G. the width of the vehicle is taken as ‘2w’. It has accommodated three modes pitching, rolling and steering and linear vertical motion.

II. COMPUTATIONAL MODELLING

This section represents the generalized form of mathematical model and addresses the essential issues concerning the bondgraph modelling of multi-body system as used in this system.There are various assumption made for construction this model: 1) The components of vehicle body act as a rigid body. 2) The spring and dampers of the suspension system elements have linear characteristics.3) the spring damper system is assumed to be mass less.4) the tires of the vehicle remain in contact with the road at all times. 5) Straight road is assumed.6) Bump type surface irregularity is assumed for both the wheel (rear and front).

(A) Chassis

The chassis of car modelled as a rigid body, represents a sprung mass by means of wheel shock absorbers. The model has 6-degree of freedom 3-translational and –rotational movements with respect to XYZ axis. The spatial model motions in local frame are determined through well-known Newton Euler equation, which appears in (1) and (2) both. $\{F_x, F_y, F_z\}$ and $\{T_{x,} T_y, T_z\}$ are the forces and torque vectors applied over the rigid body. Respectively,

$$F_x = mV_x + m.\omega_{y.}V_z - m.\omega_{z.}V_y \quad (1)$$
$$F_y = m_y + m.\omega_{z.}V_x - m.\omega_{x.}V_z$$
$$Fz = m_z + m.\omega_{z.}V_x - m.\omega_{x.}V_z$$
$$T_x = I_{xxx} + \omega_{y.}I_{zz}\omega_z - \omega_{z.}I_{yy}\omega_y \quad (2)$$
$$T_y = I_{yyy} + \omega_{z.}I_{xx}\omega_x - \omega_{x.}I_{zz}\omega_z$$
$$T_z = I_{zzy} + \omega_{z.}I_{xx}\omega_x - \omega_{x.}I_{zz}\omega_x$$

It is shown Fig. 1. The C.G of gravity of thecar is located "l" from the front axle and "l" from the rear axle. The width and height of C.G from the ground are 2w and h respectively.

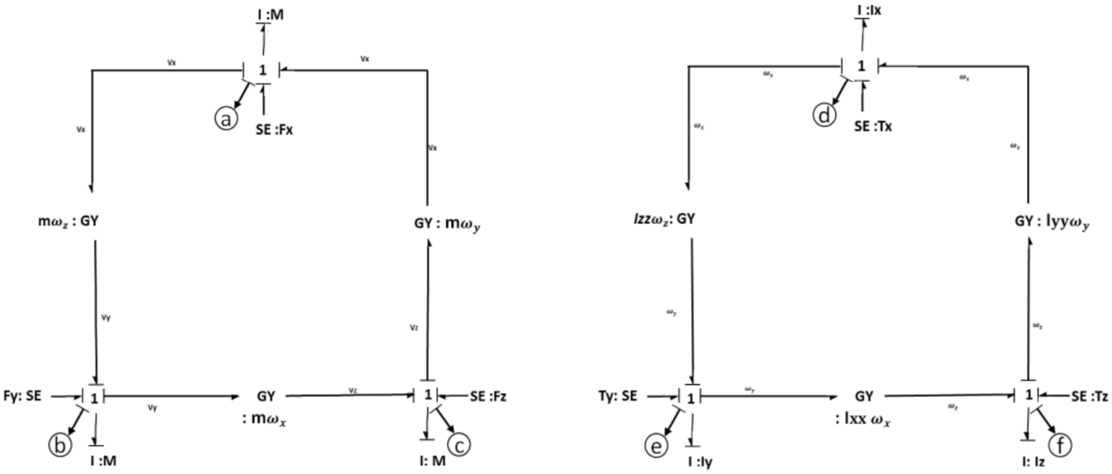

Figure 2: Generalized bond graph model for Newton and Euler equation

(B) Suspension

The vehicle suspension connects the chassis body with each wheel, allowing smooth movement between them. An individual shock absorber is built for each wheel and modelled by a spring damper element Fig. 2, the equation for suspension system are:

$$F_{damper} = C_d\,(V_1 - V_2) \quad (3)$$
$$F_{spring} = -\,K(Y_1 - Y_2) \quad (4)$$

Substitute the Eqs (3) and (4) to Eqs (1) and (2),

$$F_{suspension} = F_{damper} + F_{spring} \quad (5)$$

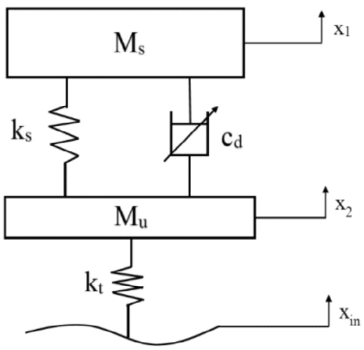

Figure 3: Schismatic diagram for spring-mass system

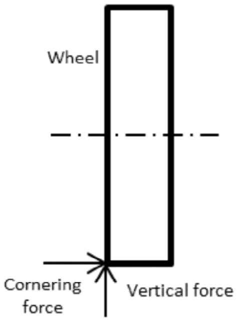

Figure 4(a): Force exerted on contact patch

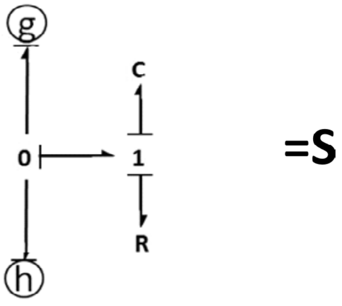

Figure 4(b): Bond graph model of suspension system

(C) Wheels

The wheels are modelled by their mass, rotary inertia, radius and tyre stiffness. The tyre is the most important among wheel components because tyre forces and moments play in important role in vehicle dynamics. Tyre forces are necessary to control the vehicle. As the tyres are the only means of contact between the road and the vehicle, they are the key factors determining the vehicle handling performance. Tyre models are broadly classified as physical models, analytical models, and empirical models. The physical models are constructed to predict tyre elastic deformation and tyre forces. Paceja's magic formula is a widely used empirical model with which one can compute the longitudinal and cornering forces and self-aligning moment [12].

The principle model of tire is presented in Fig. The wheel is also act as a rigid body, which have six degree of freedom. Similar to chassis body, the inertias are coupled by a pair of gyrator rings. The tyre-road normal contact force and the gravity force always act along inertial Z-axis. Thus the wheel vertical dynamics is coupled with longitudinal and lateral dynamics. The ground reaction force (Fz) and wheel radius (r_w) is used to modulate longitudinal and cornering dynamics, which are given in axle body-fixed frame.

(D) PI controller

A structure of PI controller is shown in fig 4. Where it can be seen that in a PI controller, the error signal e(t) is used to generate the proportional and integral actions, with the resulting signal weighting and summed to control signal u(t) applied to a plant model. A mathematical description of the PI controller is,

$$U(t) = K_p\, e(t) + 1/\, Ki \int_0^t e(\tau) \tag{6}$$

Where, u(t) is the input signal to the plant model, the error signal e(t) is defined,

$$e(t) = r(t) - y(t) \tag{7}$$

The proportional controller (K_p) will have the effect of reducing the rise time and will reduce, but never eliminate, the steady- stateerror. An integral control (Gi) will have the effect of eliminating the steady state error, but it may make the transient response worse.

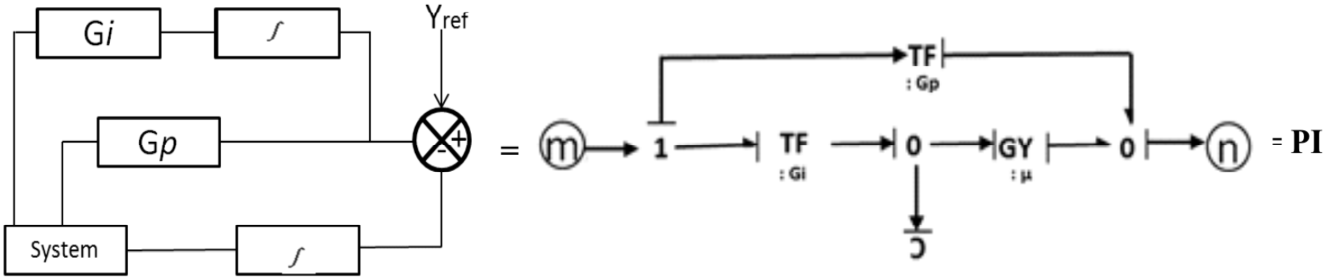

Figure 5: Block model and bond graph for PI controller

(E) Integrated Bond Graph model for car model with controller

The bond graph model of road truck is constructed by adding the models of different components of vehicle. However, the size of integrated model is very large, so the separate model of tire, cab frame with suspension and PIare constructed and shown through sub models 'T' , 'B+S' and 'PI' respectively (shown in Fig 5(a) and 5(b)). The bond graph model of road-truck is constructed by adding the sub models with suspension system, which is shown in Fig. 5 (C). This present model incorporate PI-control system with Left and Right rear wheel system.

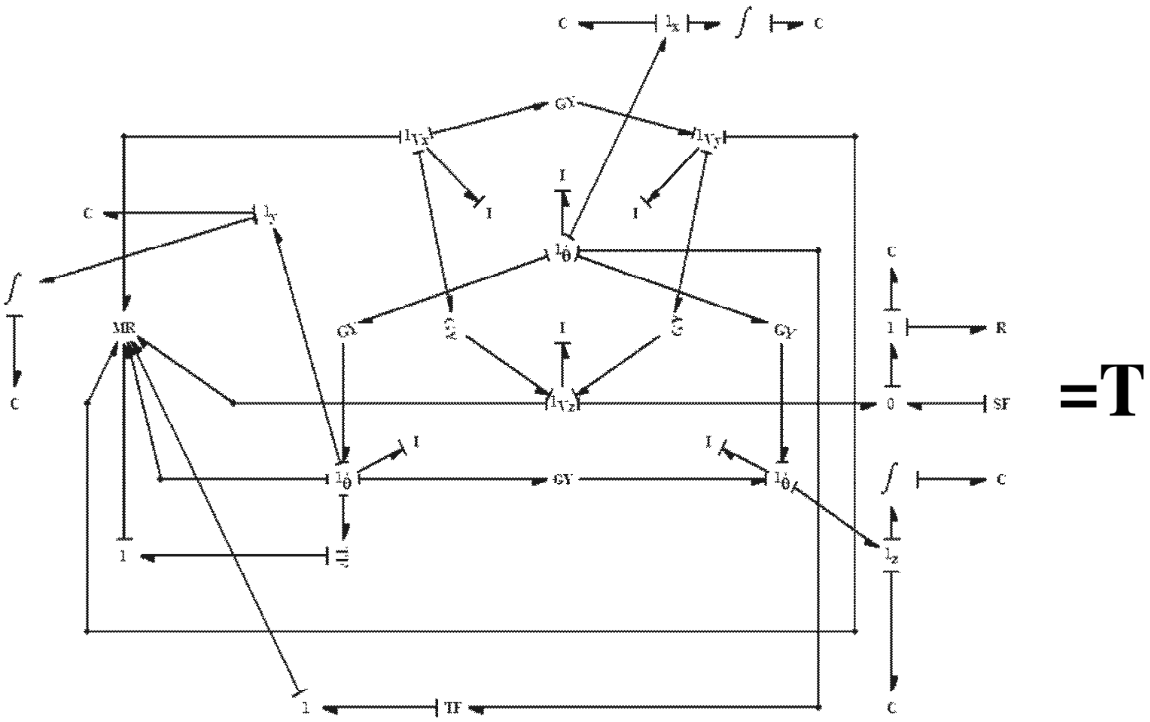

Figure 6 (a): Capsule model of Tire contact behaviour

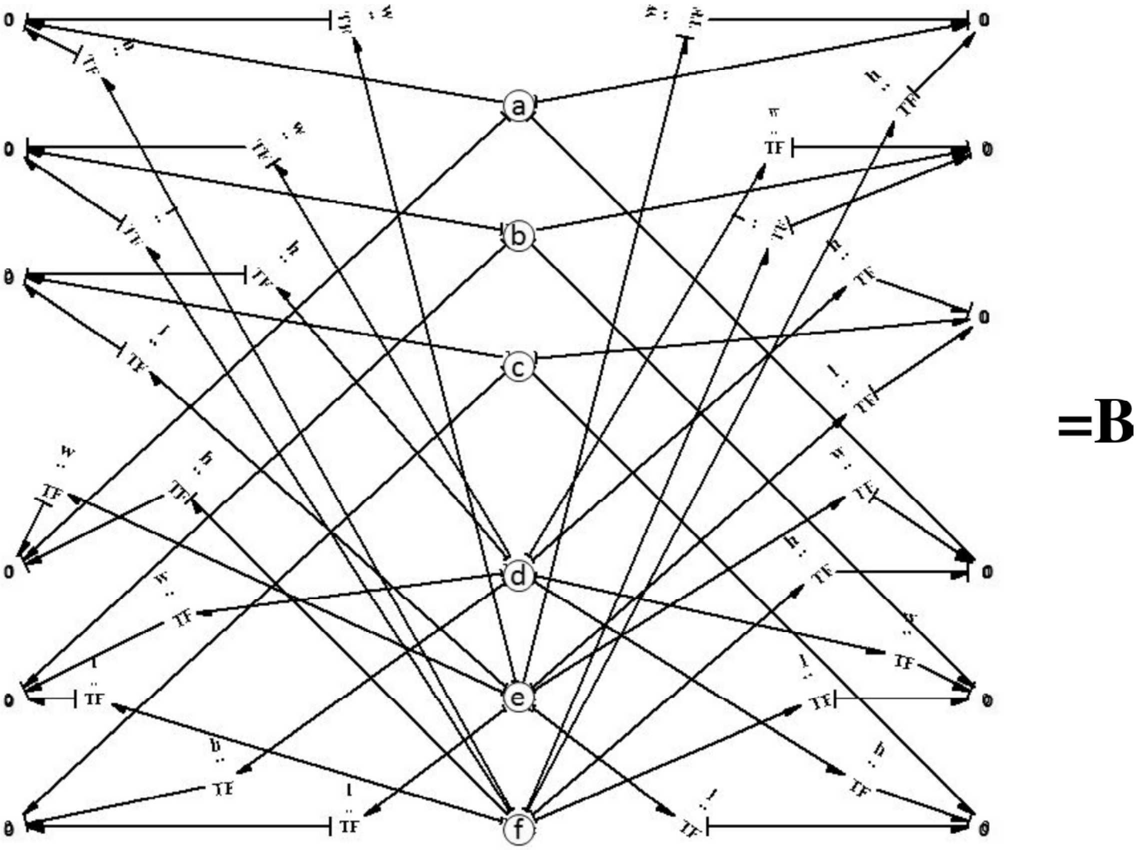

Figure 6 (b): Base model of vehicle in spatial coordinate system

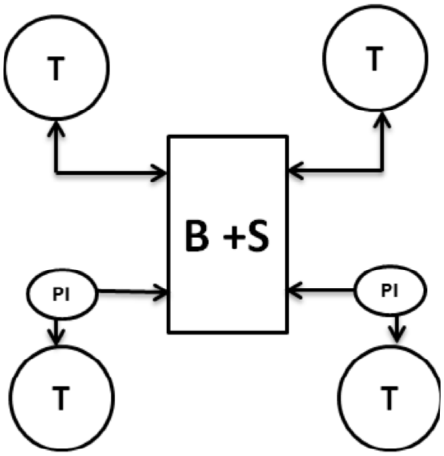

Figure 6 (c): Integrated bond graph model for car in spatial coordinate system

III. SIMULATION STUDIES

The bond graph model of the vehicle is simulated for 10sec to obtain different output responses. Total 1024 records are used in the simulation and simulation is kept error in the order of 5.0 x 10^{-4}. Runge-Kutta method of fifth order is used in present work to solve the differential equations. The parameters which is used for simulation is shown in Table 1. The simulation work is carried out on SYMBOLS-Sonata® software. The simulation of present model has conducted 1 sec before the bump, which clearly shown in the plots.The parameters are used for simulation is shown in Table 1.

Table 1
Model Parameter for full car vehicle model

Parameters	*Values*
Mass of vehicle (M)	1600 Kg
Distance of front and rear suspension from the base C.G (a)	0.9 m
Width of vehicle (b)	1.5 m
Inertia of vehicle in X-Y-Z directions	260-1110-1370 Kg/m^2
Mass of wheel (Mw)	15 Kg
Inertia of wheel in X-Y-Z directions	0.1-0.1-0.2 Kg/m^2
Suspension stiffness's in (X,Y and Z-directions)	1e7,1e7,80 N-s/m^2
Suspension Resistance	2000,2000,500N-s/m

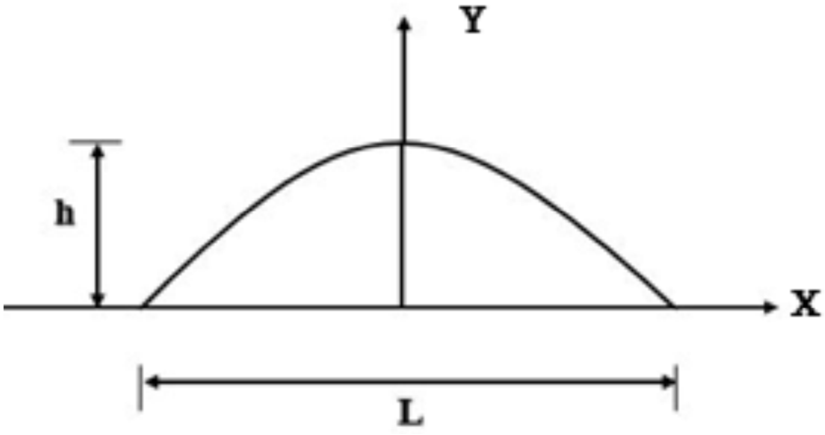

Figure 7: Bump type surface irregularity

3.1. Half sine bump

A sinusoidal profile of the road has been considered for simulation, which is shown in Fig. 6. The transient input chosen is a half sine bump and vehicle velocity is taken 60 m/s for analysis.

As a function of time, the road conditions are given by

$$y_f = \begin{cases} h * \sin\left(PI * \frac{V}{L} * t\right), & for\ 0 \le t \le \frac{L}{V} \\ 0, & otherwise \end{cases} \qquad \text{For front wheel} \tag{8}$$

$$y_r = \begin{cases} h * \sin\left(PI * \frac{V}{L} * \left(t - \frac{a+b}{V}\right)\right), & for\ \frac{a+b}{V} \le t \le \frac{a+b+L}{V} \\ 0, & otherwise \end{cases} \qquad \text{For rear wheel} \tag{9}$$

where, *h* is the height of the bump, which is 0.1m; is the length of the bump, which is 0.3m; *t* is the time and is the velocity of the vehicle.

Following output parameters are obtained in the simulation of the bond graph model of the complete truck model:

IV. RESULTS AND DISCUSSION

4.1. Deflection in Suspension system without controller

Body displacement vs time has been plotted for different speeds shown in Figs (6-9). It can be evident from Fig. 6 that suspension deflection at rear left wheel is marginally lower as other suspension deflection at 20 kmph. However magnitude of deflection has been reduced with increase in speed, while wheel passing over the road bump.It is also observed that the deflections of suspensionsare different for different wheels.

4.2. Deflection in Suspension system with controller

It is evident form the Fig.10- that the magnitude of displacement of suspension is comparatively lower when suspensions are connected through PI-controller. However, the settling time of jerks have been found to be almost same as passive system. Thus, PI controller with suspension give better response of a full car vehicle model in bump type road irregularity.

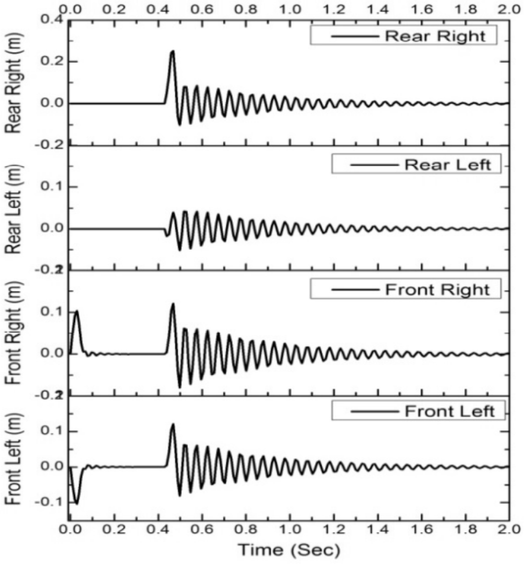

Figure 6: Defection of suspension system at 20 Km/hr

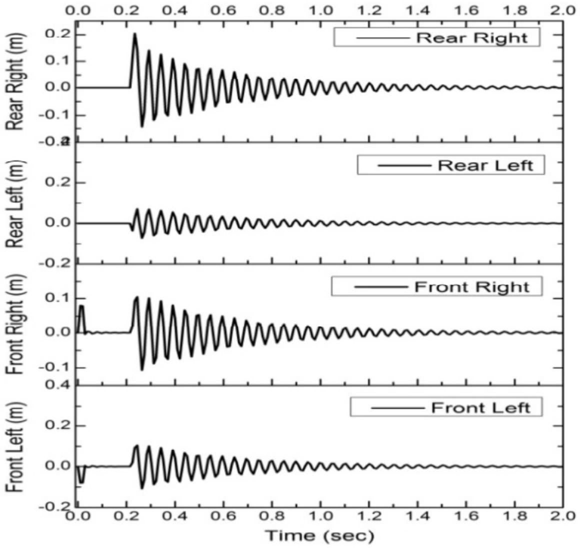

Figure 7: Defection of suspension system at 40 Km/hr

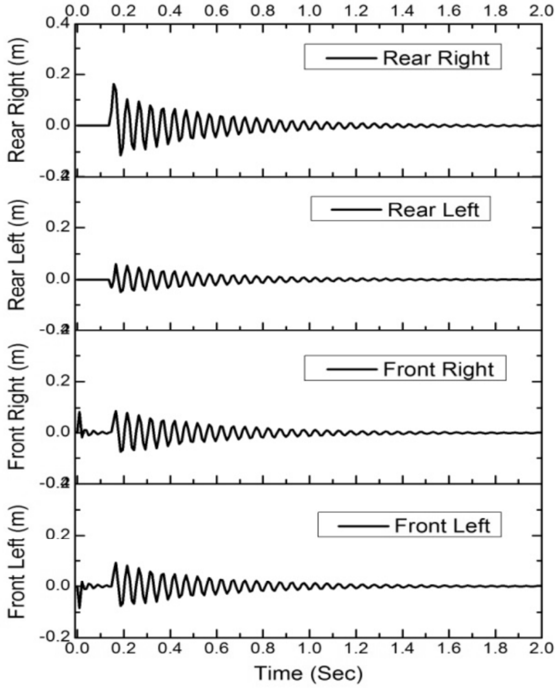

Figure 8: Defection of suspension system at 60 Km/hr

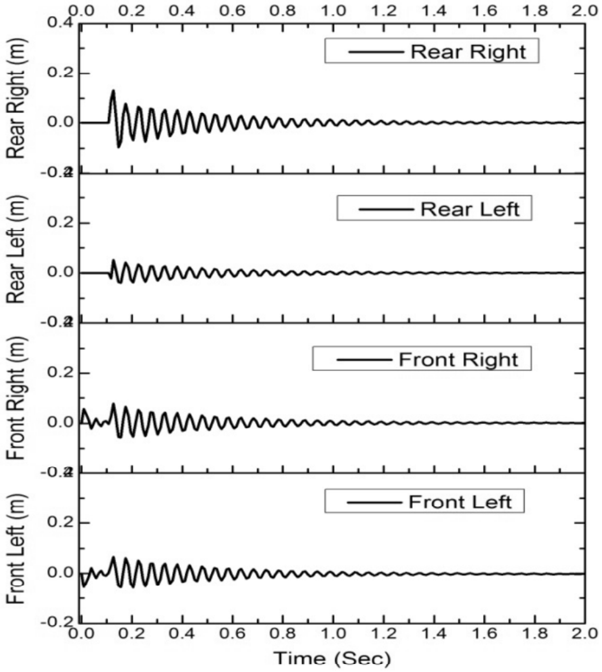

Figure 9: Defection of suspension system at 80 Km/hr

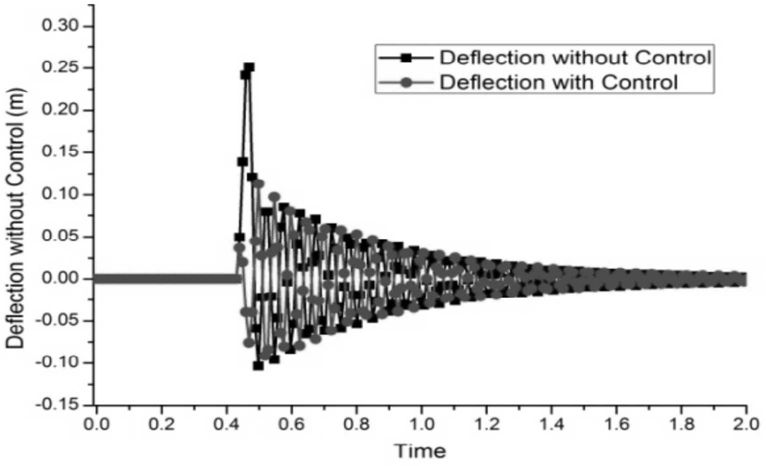

Figure 10: Defection of rear suspension at 20 km/hr

V. CONCLUSION

This paper has been attempted to obtain the dynamic behaviour of car through bond graph technique and to evaluate the different parameters through simulation at various speeds. The amplitude of comfort may be compared with the available study on this subject matter and show a considerable agreement. Moreover, these values will be changed in difficult environment conditions. However, the following conclusions are made in this study.

- The dynamic spatialmodel of car has been constructed through bond graph technique.
- The model of controller-suspension dynamics has been constructed by using bond graph technique.
- Minimum wheel deflection for better handling performance and minimum vertical car body velocity for ride comfort have been achieved in terms of low overshoot and settling time which is complimented by simulation results.

- The incorporation of controller has been improved the performance of passive suspension system.
- Further this computational may also be attempted to evaluate a steering and rolling effect on dynamics of the vehicle.

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