iJRASET
International Journal For Research in
Applied Science and Engineering Technology

# INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

**Volume:** 6 **Issue:** IV **Month of publication:** April 2018

**DOI:** http://doi.org/10.22214/ijraset.2018.4662

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
*ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887*
*Volume 6 Issue IV, April 2018- Available at www.ijraset.com*

# Modelling and Simulation of a Passenger Car for Comfort Evaluation

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***Abstract: Vehicle manufacturers all around the world are under constant pressure to increase speed, safety and comfort. Nowadays passenger comfort becomes a factor of prime concern for the car manufacturer and lot of research is going on in this area by vehicle designer and researchers. Although instruction new technologies in manufacturing and design guarantee improved ride quality, but it is impossible to completely removed the ground irregularities. So, lot of scope is still there in this area to increase speed of the vehicle maintaining the safety and comfort of the passengers at the same time. Apart from ground irregularities, dynamics of a passenger car also depends on vehicle load and the mechanical components like suspension system, seat, sprung and unsprung masses etc.***

***In the present work an attempt has been made to obtain the vertical dynamics of a passenger car through bond graph formulism. Total 8 degrees of freedom model is considered consisting of vertical motion of the passenger, sprung, unsprung mass and pitching, rolling motion of sprung mass. Weighted rms acceleration at the passenger seat is found and compared with ISO-2631 standard for assessment of ride comfort. SYMBOLS Sonata software [1] is used for modeling and simulation of the bond graph model.***

***Keywords: Bond Graph, Modeling, Passenger Car, Ride Comfort, Vertical Dynamics***

## I. INTRODUCTION

Vehicle design requires lot of time, money and effort to obtain the required characteristics of the vehicle and its sub-systems. The process is further followed by detailed design of components and subparts, and finally ended with fabrication and testing of prototypes. Today's vehicles are complex mechanical system and can be better designed and analyzed using modern modeling and simulation methods. The time and cost associated with the vehicle design and testing can be significantly reduced by using computer simulation in comparison to the actual field experiments. Simulation results, however only reduces few design steps and must followed with fabrication testing. But, they give insight, reduces cost and quickens the whole process.

The features of a ground vehicle may be defined by its performance, comfort, ride and handling. Performance is related with capability of vehicle to accelerate, to overcome hurdles, and deaccelerate. Handling refers to response of vehicle with respect to driver's inputs and its capability towards stabilization with disturbances [2]. Vehicle ride is influenced by number of factors like vibration, suspension quality, seat design and ambient factor. Out of these factors vibration is documented as a major factor influencing ride comfort. Apart from these, non-motion factors also influence passenger comfort. However, it is very difficult for one to consider all the factors simultaneously. No. of attempts to model the vehicle system have been reported and differs in terms of complexity of the model and the methodologies used.

Gao et. al. [3] have investigated the dynamic response of cars due to random road input using simplified half-car model. Rao et. al. [4] have implemented a new hybrid semi-active control strategy and compare the displacements and acceleration responses to those obtained with the passive system. A three-degrees of freedom quarter car model is used in the analysis. Duni et. al. [5] have described a numerical method built on the FEM and used the same for the simulation of the complete vehicle moving on different irregularities. Yoon and Hac [6] have consider a two degrees of freedom model to obtain optimized control in case of semi active suspensions under different road conditions at different speeds. A pitch-plane model of truck is presented by Rideout and Khan [7] to study its longitudinal dynamic. Ren and Lee [8] have studied the effect of parts universality of different passenger cars on ride comfort by using simulation software ADAMS. The present study aims to investigate the effects of road imperfections and vehicle speed on ride comfort through bond graph formulism. The author uses bond graph methodology for modeling due to ease ness of approach in modeling multibody systems. The bond graph, being multi-energy domain unified modelling tool is well suited for modelling of multibody system like robots, rail and road vehicles [9-14].

 

## II. PASSENGER CAR MODELING

A complete eight DOF model is considered consisting of vertical motion of the passenger, sprung, unsprung mass and pitching, rolling motion of sprung mass. Figure 1 shows the schematic of a full car model including passenger seat, sprung mass and unsprung mass. The passenger seat and sprung as well as the unsprung mass are modelled as rigid bodies and are characterized by their mass–inertia properties and are given in Table III. The tire is modelled as massless spring and is characterized by its equivalent stiffness.

The sprung mass motion will be described by its rotations about x (roll) and Y (Pitch)-axis. The passenger seat and the unsprung masses are assumed to move in vertical direction only (bounce).

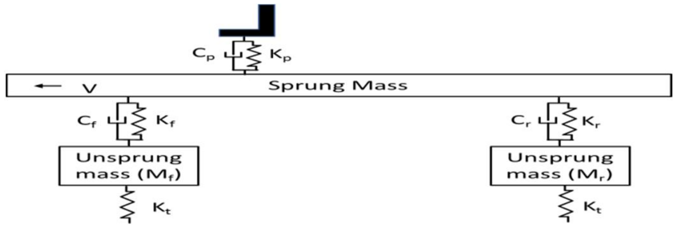


Fig.1 Schematic of full car model [15]

## III. ROAD IRREGULARITY MODEL

In actual running a vehicle may encounter different type of periodic, aperiodic or random irregularities, but in this study only bump kind irregularity is considered. For simplicity, right and left side wheels of the car are exposed to identical irregularities. The irregularity is defined by half of sine wave and express mathematically by Eqs. 1-4.

The vertical motion of the front wheels due to irregularity is given by

$$y = \mathrm{H} \times \sin\left(\pi \times \frac{V}{Lir} \times t\right) \quad for \quad 0 \le t \le \frac{Lir}{V} \tag{1}$$

$$= 0 \qquad for \quad t > \frac{L}{V} ir \tag{2}$$

The vertical motion of the rear wheels due to irregularity is given by

$$y = \mathrm{H} \times \sin\left(\pi \times \frac{V}{Lir} \times \left(t - \frac{A_1}{V}\right)\right) \quad for \quad \frac{A_1}{V} \le t \le \frac{A_1 + Lir}{V} \tag{3}$$

$$y = 0 \qquad for \quad t > \frac{A_1 + Lir}{V} \tag{4}$$

The above Eqs. 1-4 are differentiated with respect to time to obtain corresponding flow and these flows becomes input to the system model.

TABLE I: Geometric And Inertial Parameters Of A Passenger Car [15]

| S. No. | Parameter | Nomenclature | Values |
|---|---|---|---|
| 1. | Mass of passenger seat | $M_P$ | 100 kg |
| 2. | Sprung mass | M | 2160 kg |
| 3. | Front unsprung masses | $M_f$ | 85 kg |
| 4. | Rear unsprung masses | $M_r$ | 60 kg |
| 5. | Passenger seat stiffness | $K_P$ | 98935 N/m |
| 6. | Passenger seat damping coefficient | $C_P$ | 615 N-s/m |
| 7. | Front suspension springs stiffness | $K_f$ | 96861 N/m |
| 8. | Rear suspension springs stiffness | $K_r$ | 52310 N/m |
| 9. | Front suspension damping coefficient | $C_f$ | 2460 N-s/m |
| 10. | Rear suspension damping coefficient | $C_r$ | 2281 N-s/m |
| 11. | C.G position w.r.t front axle | a | 1.524 m |
| 12. | C.G position w.r.t rear axle | b | 1.156 m |
| 13. | Transverse distance b/w wheels | 2W | 1.450 m |
| 14. | Seat position | $X_P$, $Y_P$ | 0.234, 0.375 m |
| 15. | Tire stiffness | $K_t$ | $2 \times 10^4$ N/m |

## IV. RIDE COMFORT EVALUATION

Ride comfort can be defined as general sensation of subjective well-being. Ride comfort may be analysed with respect to three different aspects namely dynamic factors involving vibration components; ambient factors involving temperature and pressure and passenger's ergonomics. Out of these factors vibration is documented as a major factor influencing ride comfort. No. of standards are available for evaluating human exposure to whole-body vibration. For assessments of comfort in relation to health, the following standards are used:

*1)* International Standard (ISO 2631-1)
*2)* British Standard (BS 6841)

In this study ISO 2631 standard is used to evaluate ride comfort

### *A. International Standard (ISO 2631-1)*

ISO 2631-1 [16] gives standard procedures for the measurement of periodic, random and transient whole-body vibration. It offers guidelines for determining the likely effects of vibration on individual's health. In the case of vertical vibrations human beings are found to be most sensitive within frequency range of 4-12 Hz. The comfort evaluation according to ISO 2631 will be governed by Eq.

$$a_w = \left[\frac{1}{T}\int_0^T a_w^2(t)dt\right]^{1/2} \tag{5}$$

where,
$a_w(t)$ is the weighted acceleration ($m/s^2$)
T is time (s).

In practice, it is more convenient to calculate the weighted r.m.s acceleration in the frequency domain using:

$$a_w = \left[\sum_i (a_i w_i)^2\right]^{1/2}$$

where,
$w_i$ is the weighting factor for $i^{th}$ $1/3^{rd}$ octave band.
$a_i$ is the r.m.s. acceleration of $i^{th}$ $1/3^{rd}$ octave band.

The perception of ride comfort according to ISO 2631standard is given in Table II.

TABLE II: RIDE COMFORT CHARACTERIZATION [16]

| Vibration level r.m.s. | Ride comfort |
|---|---|
| Less than 0.315 $m/s^2$ | Not uncomfortable |
| 0.315 $m/s^2$ to 0.63 $m/s^2$ | A little uncomfortable |
| 0.5 $m/s^2$ to 1 $m/s^2$ | Fairly uncomfortable |
| 0.8 $m/s^2$ to 1.6 $m/s^2$ | Uncomfortable |
| 1.25 $m/s^2$ to 2.5 $m/s^2$ | Very uncomfortable |
| Greater than 2 $m/s^2$ | Extremely uncomfortable |

## V. BOND GRAPH MODELING

The bond graph model is developed by imposing the kinematic relationships among the flow variables appropriately. Flows are added as per the kinematic relationship using 0-junctions. The transformers modulus are obtained from the relationship between angular velocity and linear velocity components. The bond graph model of the passenger car is presented in Fig. 2.

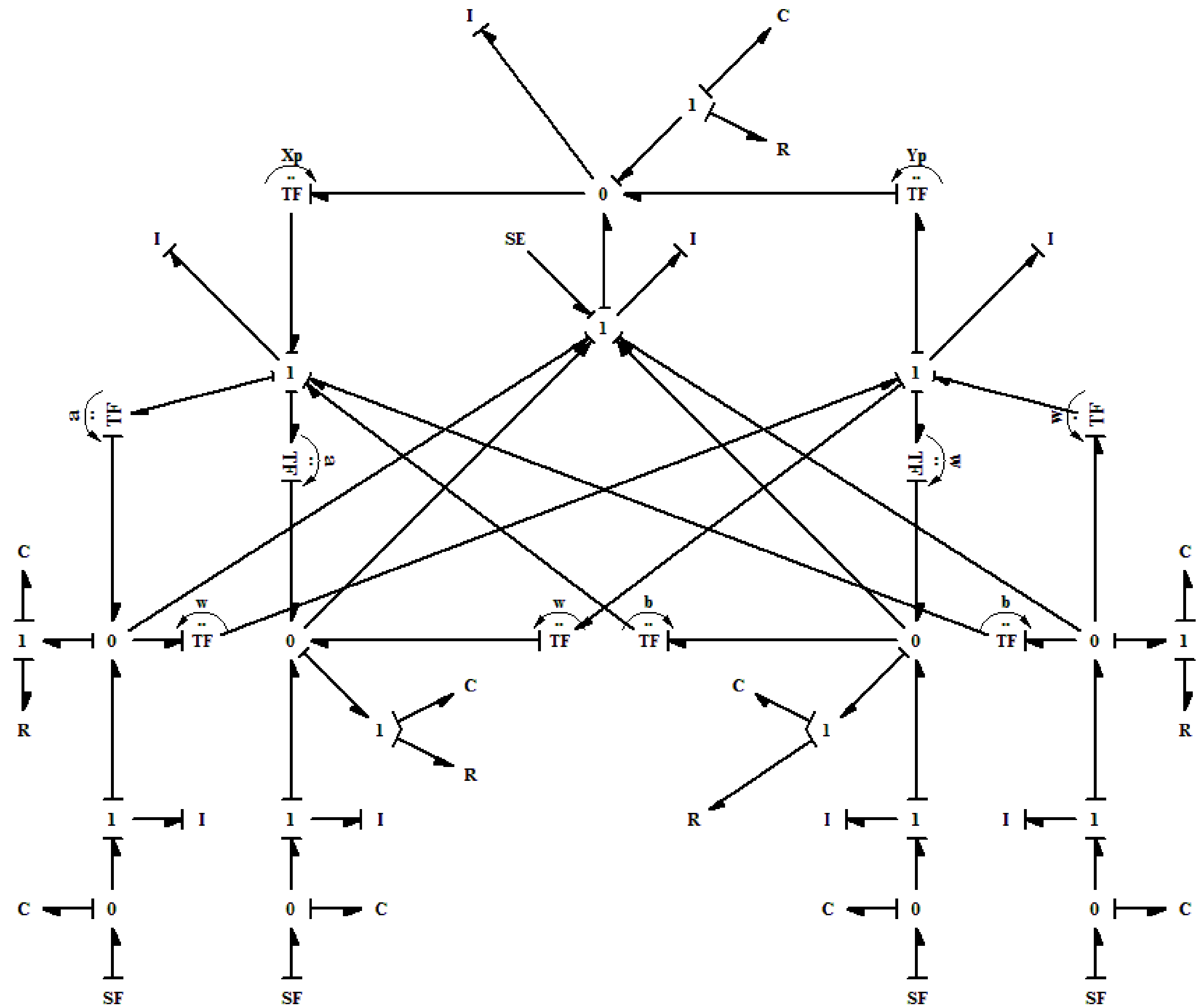


Fig. 2: Bond graph model of car

## A. Comfort Evaluation

Ride comfort has been evaluated for speed varying from 5 - 80 km/hr. Fast Fourier transformation of the seat acceleration has been obtained to get peak acceleration at different speeds and are shown in Fig. 3-7. The weighted r.m.s. acceleration has been found in accordance with relation given in ISO 2631-1:1997 [16]. Depending upon geometry and size of road irregularity the weighted r.m.s. acceleration at different speeds has been given in Table III.

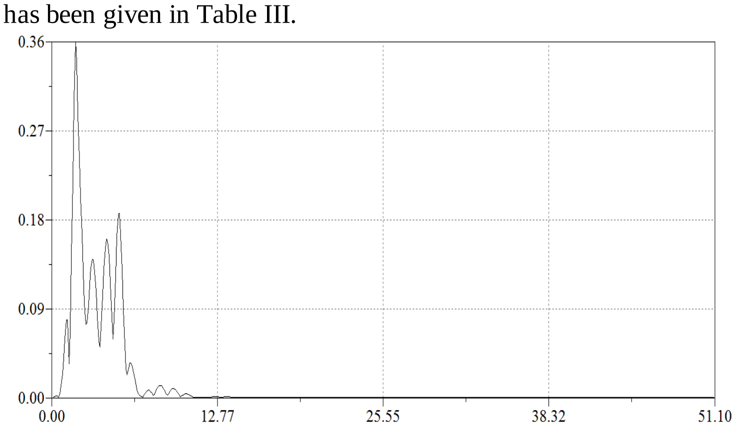


Fig. 3 FFT of vertical Acceleration of passenger seat for vehicle speed of 10 km/hr

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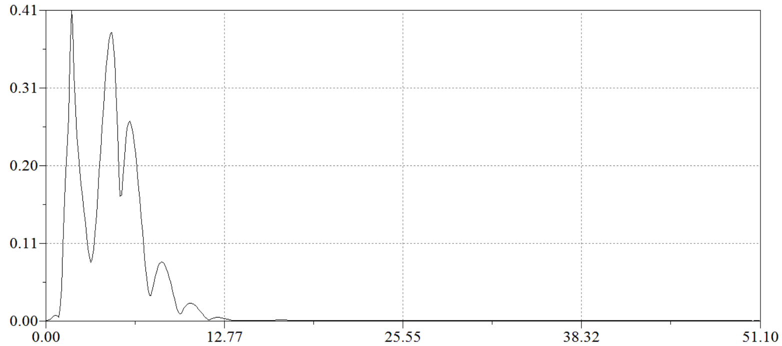

Fig. 4 FFT of vertical acceleration of passenger seat for vehicle speed of 20 km/hr

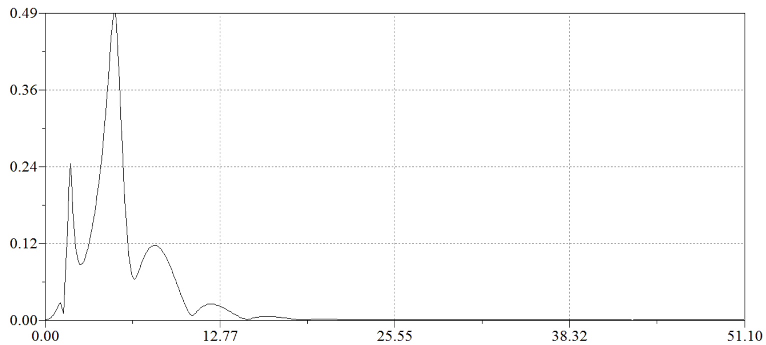

Fig. 5 FFT of vertical acceleration of passenger seat for vehicle speed of 40 km/hr

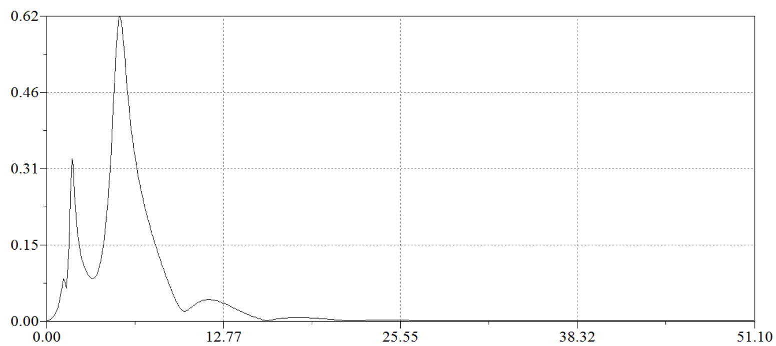

Fig. 6 FFT of vertical acceleration of passenger seat for vehicle speed of 60 km/hr

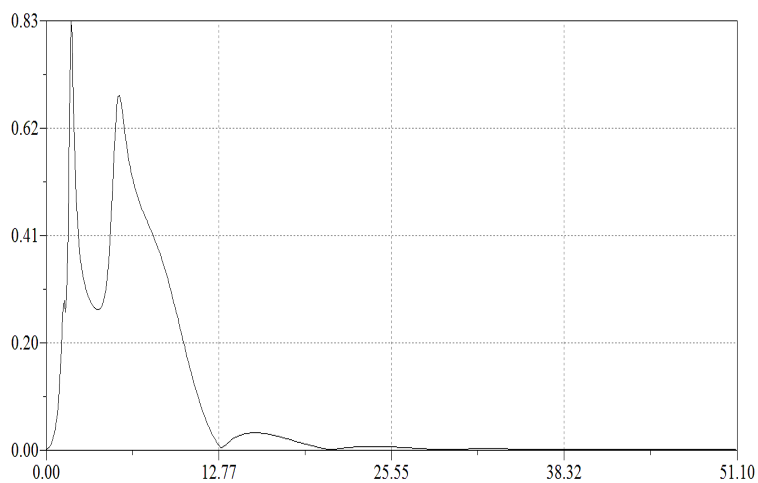

Fig. 7 FFT of vertical acceleration of passenger seat for vehicle speed of 80 km/hr

Table III: Weighted Root Mean Square Acceleration For Different Vehicle Speeds

| S.No. | Vehicle Speed(Km/h) | Weighted RMS Acc. ($a_w$)(m/$s^2$) |
|---|---|---|
| 1 | 10 | 0.34 |
| 2 | 20 | 0.50 |
| 3 | 40 | 0.55 |
| 4 | 60 | 0.67 |
| 5 | 80 | 0.76 |

## VI. CONCLUSION

A bond graph model of a passenger car moving on straight road has been developed for performing vertical dynamic analysis. An 8 degrees of freedom model has been used in the present work. The input to the model is given in terms of flow obtained by considering identical irregularity on both right and left side of the car. Vertical acceleration response at the seat has been obtained in the frequency domain. The results showed that the speed adversely affects the ride comfort of the occupants. The present model with certain modification can be used further for investigating the effect of different type of irregularities on the ride and comfort performance of the vehicle.

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