Impact of Smart Engineering to the Vehicle Design for Rural Roads in India

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ABSTRACT

As per the records, India has second largest road network over 5,897,671 kilometers (3,686,044 mi) than USA having 6,153,024 kilometers in the world, out of which over 175161 kilometres (2.97%) of state highways, about 114,415 kilometres (1.94%) of national highways and expressways, plus another 586,228 kilometres (9.94%) of district highways, 546,714 kilometers (9.27%) urban roads and 329,090 kilometers (5.58%) is of Projects. As such around 4,146,063 kilometers (70.3%) of total road network of 5,897,671 kilometers are of rural base and built by Panchayats and PMGSY with pavement or bituminous of required strength and remaining of kuchcha (mud) roads. Thus there is need to evaluate 4-wheeled vehicle design for better comfort ride. It needs to cut down vibration drastically on poor road conditions for cost effective and environmental friendly design of vehicle.

From this research work, it is found that the gap of work is to work on smart engineering design for an economical vehicle run at regulated speed for comfort ride on rural road geometrics. The detailed work has been done and a model is developed, considering rural requirement and its various parameters. Considering all aspects of suspension, tire stiffness coefficient and damping etc and dependent parameters, a two wheeled vehicle engine 4-wheeled smart JEEP is fabricated which runs at 55-65 km / hour speed with petrol fuel consumption of 36 km / liter. From the results of the study, it is found that the new rural vehicle can run under comfort zone even at 65 km/hr speed on very poor rural roads conditions without affecting life cycle. The cost of the vehicles can also drastically reduce and it can also reduce global warming due to its better performance.

Keyword: Rural roads, Vehicle Design, Smart Engineering, Economical vehicle, Global warming

1. INTRODUCTION

As per data of 31 March 2017, India was having a network of over 5,897,671 kilometers of roads, which was second largest network than USA having 6,153,024 kilometres, out of which India had completed over 175161 kilometres (2.97%) of state highways, about 114,415 kilometres (1.94%) of national highways and expressways, plus another 586,228 kilometres (9.94%) of district highways, 546,714 kilometers (9.27%) urban roads and 329,090 kilometers (5.58%) is of Projects. As such around 4,146,063 kilometers (70.3%) of total road network of 5,897,671 kilometers is of rural base and built by Panchayats and PMGSY with pavement or bituminous of required strength and remaining of kuchcha (mud) roads. This shows that rural road network's major portion with mud roads. We also know that still 70% population of India lives in rural base and its mode of transport is impacting economy as well global warming and climate change. Thus 70% population's vehicles that are running on these roads need to take care of discomfort like serious stress and fatigue especially passengers and drivers due to bumps and pot-holes on damaged roads. Such light vehicles running on rural roads need proper design of spring, damper, leaf suspension and proper tyres stiffness to sustain comfort above higher speed.

Chart-1: Progress of Indian Road Network 1950-2017

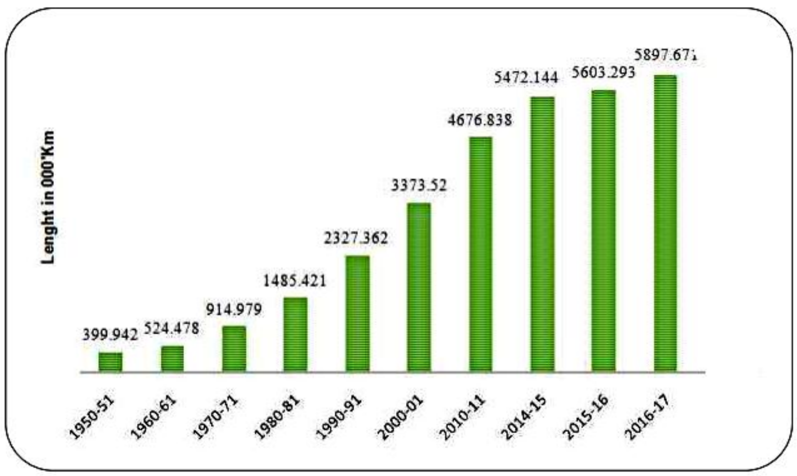

Table 1: Indian Roads Network as on 31st Mar 2017

S.No.	Type of Roads	Roads in Kms.	Remarks
1.	National Highways and Expressways	**114,415**	**1.94%** Connecting States
2.	State Highways	**175,161**	**2.97%** Roads within States
3.	Urban Roads	**546,714**	**9.27%** Roads within cities
4.	District Highways	**586,228**	**9.94%** Within Distt
4.	Roads under Projects	**329,090**	**5.58%** Roads within Projects
5.	Panchayat & PMGSY	**4,146,063**	**70.30%** Rural Roads
	Total:	**5,897,671**	

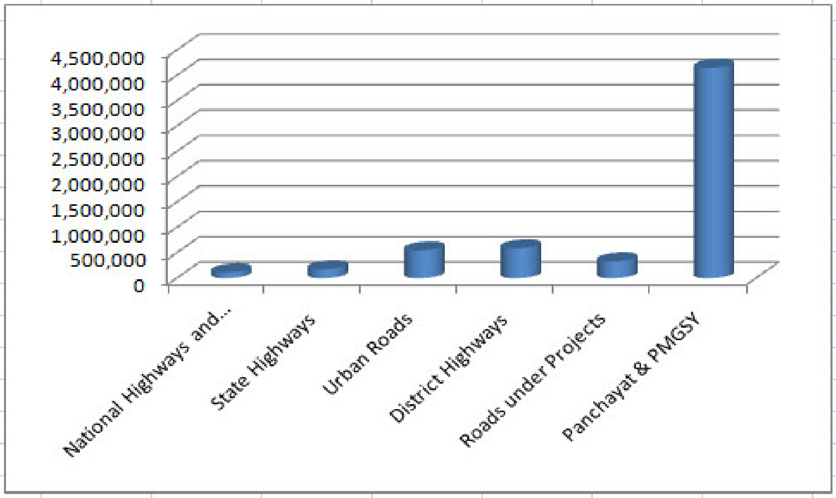

Figure 1: Status of Indian Road Net Work

In this area, studies were carried out on such work by various researchers and prepared proper mathematical model of light vehicle (car / jeep / dumper) with a non-linear equation, linear quadratic regulator method etc. They simulated their models either with algorithm, Matlab, 20Sim, Adams, Bond Graph, 20 Sim mechanisms or with Fuzzy Control etc.

2. LITERATURES REVIEW

A detailed literature studies are conducted and few studies are narrated as below:

An active suspension of full car model with seven degree of freedom was investigated by Adibi H., and Geoff R., (2006) for reduction in bounce, pitching and rolling effect on random road profile. Their hybrid bond graph simulation results of bounce acceleration, pitch acceleration, and roll acceleration. The bond graph concept was invented by H.M. Paynter (1961), of physical system modeling. This approach supports 0 and 1 junction element. It means that object as a system of interconnected element. A study on wheeled motors vehicle about comfort ride with eleven degree of freedom mathematical model was presented through MATLAB/Simulink vehicle was done by Jin, L., et al., (2016). The mathematical model of quarter car evaluated in spring mass, displacement and acceleration was simulated through MATLAB for comfort ride of quarter car speed not exceeds 6.75km/h by Hassaan, G.A., (2014), and simulation result was obtained using ADRC controller for comfort ride and Gao, J., et al.(2011) also developed a virtual model of comfort ride of vehicle.

Karnopp, D. and Rosenberg, R., (1975) created parameter mathematical system formulated by Kirchoff Bond graph approach to electrical network and Yazan, M. A. R., et al. (2009) studied a chassis of the car and its centre of gravity position was assumed to be fixed with swarm optimization technique. The simulation mechanism was used to build full car active suspension using the laws of motion.

Radionova L.V et al., (2015), Mehmood, A., et al., (2014), and Hassaan, G.A., et. Al., (2015), presented for building mathematical model using Matlab/ Simulink. R.S. and Pilbeam, C., (2016), Ashtekar, J. B., and Thakur, A.G.,(2014), Dahil, L., (2017), Wu, S.J., et al. (2004) and Shirahatt, A., et al., (2008) introduced potential road performance of active suspension limited control bandwidth is obtained with theoretically analysis while using .primary function of a vehicle suspension by tire to the transmitted passenger. The results bounce back passenger acceleration and displacement reduced by 74.2%, 82.7% and 28.5% respectively.

Junoh, A.K et al. (2011), performed vehicle comfort vibration of passenger car cabin have a comfortable driving environment. Discomfort depends on the magnitude, frequency direction and duration of vibration. German Filippini et al. (2005), evaluated four wheel non linear vehicle dynamic Bond graph model. Modeling and simulation 20sim software use Bond Graph model of chassis, transmission, pneumatic tire and vehicle obtain through 20sim simulation,

Sung K.G., et al. (2008) present robust vibration control using electro rheological (ER) suspension system passenger vehicle evaluated by fuzzy moving sliding more controller (FMSMC) was design and experimentally realized vibration level of sprung mass acceleration can be significantly reduce at body resonance using ER suspension. Wakeham K.J. Wakeham and Rideout, D.G., (2011), investigates vehicle active suspension controller using linear quadratic regulator (LQR) method. It was found that pitch acceleration 40% higher, decoupled model increased 90%. Chan, B.J. and Sandu, C., (2003) states the ride control system to evaluate their design simulation result obtain acceleration vs time and displacement vs time using Matlab. Compare result of modified MCVD system vs passive system of chassis acceleration, chassis displacement and axle displacement vs time.

Wu, G., et al. (2013), deal rigid and rigid flexible coupling vehicle multibody modes. Finite element method (FEM) builds flexible rear suspension. Banerjee, S., et al. (2016), deals with mathematical model of a full tracked with 17 degree of freedom trailing arm hydro-gas suspension. Mukherjee, A., and Samantray A.K., (2000), developed Symbols2000 software use modeling, simulation and design creation of model. It has incorporated a facility called encapsulation subsystem models are called capsules. Budzik, R. and Dolecek, R., (2012), states that driving safety and comfort on road for information in vibration signal allows. Motor engine as the vibration consider vibration generators rotating machinery

Dridi S., et al., (2017) state that tubular permanent magnet linear synchronous actuator (TPMLSA) dynamic actuator modeled by bond graph formalism. Minimization of wheel vibration problem for comfort ride vehicle. A.Sezgin, A., and Yagiz, N., (2012) study the effect of vibration using simulation program of a full vehicle model. The road roughness is used as an input to the system. If a driver has journey at a rate of 72 km/h (20m/s) from 5 hours to 6 hours on a smooth road he feel uncomfortable. Avesh, M., and Srivastava, R., (2012) propose active suspension system of automobile for improving ride comfort to passenger and stability of vehicle to reduce vibration effect on suspension system.

Hong, K.T., et al. (2003) deals with improving the ride comfort of passenger car using air cell. For different road disturbance using air cell make optimal pressure between human body and seat surface. Experimental method obtain spring constant and damping coefficient of an air cell with 3 degree of freedom of quarter car. Mahala, M.K., et al. (2007) stated lumped parameter mathematical model for study vehicle dynamics. In this paper different models are study at different road conditions. Louca, L.S., et al. (2001) presents integrated model of vehicle subsystem using bond graph. Energy based model methodology is applied for improvement performance of the vehicle system.

Patil, A.R. and Sanjay S.H., (2015), states that quarter car model s with non linear spring force property of Hyundai, Electra model suspension spring. Mitra, A., et al. (2013), states that full car model for various road profile analytically validated with Matlab/Simulink.

The gap of research work has been found that designing of light vehicle for Indian rural road conditions are not available considering its performance, economics and comfort. In this paper, authors investigate the reduction in vibration of full car having seven degree of freedom using Matlab/Simulink. The parameters for different road geometrics like: poor road, average road and good road condition for bumping and vibration were taken with an objective to design a control and active suspension system of full car with seven degree of freedom as compared to passive suspension system for comfort ride. The full car mathematical model is prepared and simulation results are tabulated, based on bouncing, pitching and rolling condition

3. DEVELOPMENT OF VEHICLE MODEL:

3.1 Dynamic Model

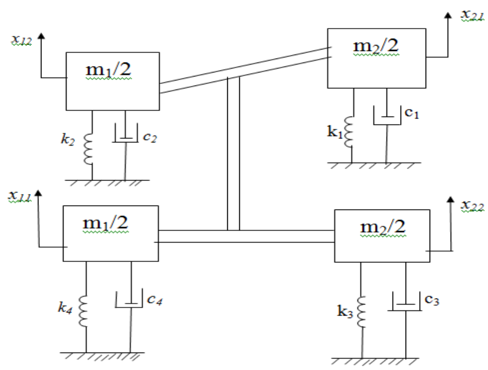

Figure 2: Dynamic model

The full car model develops linear equation of mass, spring and damper with seven degree of freedom suspension for comfort ride. To examine and optimize the vibration of a vehicle, full car vibrating model must be used. Full car model can be seen in **Fig. 2** Full car dynamic model. This model includes the body bounce the full car model may be different for the front and rear suspension and mass distribution, unsprung mass are $m_2/2$,$m_1/2$, $m_1/2$ and $m_2/2$ respectively,damping coefficient are c_1, c_2, c_3 and c_4 respectively,stiffness are k_1, k_2, k_3 and k_4 are respectively,displacement are x_{21},x_{12},x_{11} x_{22}

Using differential and law of motion authors develop the following linear equation are written as under:

a).Equations of motions of unsprung mass

$$\frac{m_2}{2}\ddot{x}_{22} + k_3 x_{22} + c_3 \dot{x}_{22} = 0$$

$$\frac{m_1}{2}\ddot{x}_{11} + k_4 x_{11} + c_4 \dot{x}_{11} = 0 \qquad \textbf{(1)}$$

Considering velocity, stiffness; damping coefficients and displacements are equal

$\dot{x}_{21} = \dot{x}_{22}$, $k_1=k_3$, $c_1=c_3$, $c_2=c_4$, $k_2=k_4$, $x_{21} = x_{22}$

We get final equation

$$\frac{m_1}{2}\left(\ddot{x}_{11} - \ddot{x}_{12}\right) + k_3\left(x_{22} - x_{12}\right) + c_3\left(\dot{x}_{21} - \dot{x}_{12}\right) + k_4\left(x_{11} - x_{12}\right) + c_4\left(\dot{x}_{11} - \dot{x}_{12}\right) = 0$$

$$\frac{m_1}{2}\left(\ddot{x}_{11} - \ddot{x}_{12}\right) + k_1\left(x_{22} - x_{12}\right) + c_1\left(\dot{x}_{21} - \dot{x}_{12}\right) + k_2\left(x_{11} - x_{12}\right) + c_2\left(\dot{x}_{11} - \dot{x}_{12}\right) = 0 \qquad \textbf{(2)}$$

3.2 Dynamic Model with Pitching

To excellent examine and optimize the full car model with pitching vibration of a vehicle, Full car vibrating model must be used. This model includes the body bounce and body roll. The full car model may be different for the front and rear full car due to different suspension and mass distribution. Sprung mass is m, sprung mass displacement are z_1,z_2,z_3 and z_4 respectively, rolling in x direction pitching in y direction and bouncing in z direction respectively, unsprung mass are $m_2/2$,$m_1/2$, $m_1/2$ and $m_2/2$ respectively,damping coefficient are c_1, c_2, c_3 and c_4 respectively, stiffness are k_1, k_2, k_3 and k_4 are respectively,displacement are x_{21},x_{12},x_{11} x_{22}
However, vibration model of vehicle must be expanded for including pitch and other modes of vibrations a and b are distance from mass centre to front and rear axle full car model includes body bounce and body pitch Full car model with pitching can be seen in **Fig. 3**

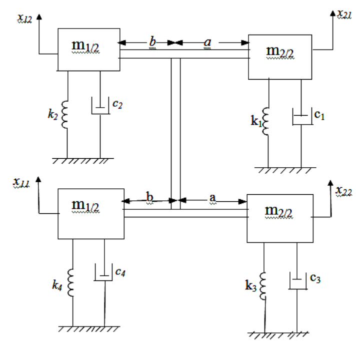

Figure 3: Dynamic model with pitching

Using newtons second law, the dynamic equation of bouncing are given as

$$m\ddot{z} - c_1(\dot{z}_1 - \dot{x}_{12}) - k_1(z_1 - x_{21}) - c_2(\dot{z}_2 - \dot{x}_{12}) - k_2(z_2 - \dot{x}_{12}) - c_3(\dot{z}_3 - \dot{x}_{22}) - k_3(z_3 - x_{22}) - c_4(\dot{z}_4 - \dot{x}_{11}) - k_4(z_4 - x_{11}) = 0 \quad (3)$$

Using newtons second law, the dynamic equation of pitching are as

$$I\ddot{\theta} - bk_2(x_{12} - b\theta) - bc_2(\dot{x}_{12} - b\dot{\theta}) - bk_4(x_{11} - b\theta) - bc_4(\dot{x}_{11} - b\dot{\theta}) + ak_1(x_{21} - a\theta) + ac_1(\dot{x}_{21} - a\dot{\theta}) + ak_3(x_{22} - a\theta) + ac_3(\dot{x}_{22} - a\dot{\theta}) = 0 \quad (4)$$

Using newtons second law, the dynamic equation of rolling are given as

$$I\ddot{\varphi} + bk_2(x_{12} - b\varphi) + bc_2(\dot{x}_{12} - b\dot{\varphi}) + bk_4(x_{11} - b\varphi) + bc_4(\dot{x}_{11} - b\dot{\varphi}) - ak_1(x_{21} - a\varphi) - ac_1(\dot{x}_{21} - a\dot{\varphi}) - ak_3(x_{22} - a\varphi) - ac_3(\dot{x}_{22} - a\dot{\varphi}) = 0 \quad (5)$$

3.3 Simulink Model

Simulink model for the same road excitation, system needs to simulate the entire suspension system derive from equations (1) to (5) respectively for sprung mass, unsprung mass, unsprung wheel, pitching, rolling and bouncing. The mathematical model of 4-wheeled vehicle with driver seated on cushion seat is simulated with Simulink Software. It is observed that at ***bump height 0.150m***, vibration amplitudes are 0.161m, 0.151m, 0.150m, 0.150m and 0.42m and its corresponding vibration die out time periods are found 2 sec, 1sec, 1.5sec, 4sec and 1.5sec at vehicle speeds of 25 km/hr, 50 km/hr, 75 km/hr, 100 km/hr and 125 km/hr respectively. This indicates that at low speed (i.e., 25 km /hr), vehicle vibration gets die out in 2 sec and time taken was found larger up to 4 seconds and at 125 km/hr vehicle vibration gets die out and time taken was found least up to 1.5 second for the vehicle under examination for its comfort ride. Under these situations vehicle passes through non-harmonic vibrations and creates discomfort ride between 25km/h to 125 km/h even higher speeds for less time.

4. ACTUAL FABRICATED MODEL OF 4-WHEELED RURAL ROAD JEEP

Figure 4: Mini Jeep Fabricated by Students from Motor Cycle Engine

The Jeep is made of 4-Stroke Motor Cycle Engine of 6.5 HP Royal Enfield, having 5-gears, wheel of Motor Cycle with steering and gear box and suspension. It is of 4-Seater including driver seat, It runs at the speed 50-65 kms / hour and consumes petrol fuel with mileage 35-40 kms / liter. It is weighing 200 Kg. The fabrication is done by a team of Diploma students.

5.0 CONCLUSION

The performance of 4-wheeled vehicle design model with seven degree of freedom was developed. The mathematical model of the vehicle for rural roads was prepared on the basis of road condition in India with bumps taken as: 0.025 m, 0.050m, 0.075 m, 0.1 m, 0.125 and 0.150 for the comfort ride on such vehicles moving at different speeds of: 25km/hr, 50km/hr, 75km/hr, 100km/hr and 100km/hr. The fixed and variable parameters such as: stiffness, damping coefficient, sprung mass and unstrung mass etc., is listed.

The simulation analysis of the model is carried out at various conditions taking vehicle speeds from 25 km/h to 125 km/h and sprung mass displacement 0.025mm to 0.150 mm, from the **Figs. 2 to 3**, it is found that:

1) When vehicle speeds are kept 25km/hr to 125 km/hr on rural roads with bumps 0.025m to 0.075m and tyre coefficient is considered constant; vibration of vehicle gets die out with first spike in 2 sec to 4 seconds at speed of 25km/hr to 125 km/hr up to 0.075m bump. This situation creates discomfort to the rider at low speed and at larger speeds too.
2) When vehicle speeds are kept 25km/hr to 125 km/hr on rural roads with bumps 0.100m and tyre coefficient is considered constant; vibration of vehicle gets die out in harmonic condition in 4 sec to 5 seconds at speed of 25km/hr to 125 km/hr up to 0.075m bump. This situation creates comfort to the rider at 50km/hr to 75 km/hr speed and at larger speeds gives little discomfort.

3) When vehicle speeds are kept 25km/hr to 125 km/hr on rural roads with bumps 0.150m and tyre coefficient is considered constant; vibration of vehicle gets die out in harmonic condition in 3 sec to 3.5 seconds at speeds of 25km/hr and 50 km/hr and 0.150m bumps. This situation creates comfort to the rider at 25km/hr to 50 km/hr speed and at larger speeds 75km/hr to 125km/hr no comfort situation is seen.

In Indian Rural Road conditions, it is therefore found from the simulations that 4-wheeled vehicles can be designed with a constant tyre coefficient at speeds of 25km/hr to 125km/hr with comfort ride and vehicles would also have considerably longer life. This will also impact on cost effectiveness of the vehicle as well as reduction in global warming impact.

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