ICSV13 - Vienna
The Thirteenth International Congress on Sound and Vibration
Vienna, Austria, July 2-6, 2006

DYNAMIC ANALYSIS OF A TRACKED VEHICLE FITTED WITH HYDROGAS SUSPENSION

M.K.Ravishankar[*1] and C.Sujatha[2]

Machine Design Section, Department of Mechanical Engineering,
Indian Institute of Technology Madras, Chennai – 600 036, INDIA
*Corresponding author: mkravishankar@rediffmail.com

Abstract

In the present work, ride dynamic behaviour of a typical tracked vehicle moving on rough off-road terrain is studied through computer simulations. A simplified in-plane mathematical ride model of a typical tracked vehicle is used, assuming constant vehicle speed and non-deformable terrain profile. The equivalent road wheel stiffness is computed taking into account the stiffness due to track pad and the spring rate due to track tension. The analysis has been done using a non-linear model of the hydrogas suspension and results have been compared with those for a linear suspension. The vehicle responses to different terrain (cross country, sinusoidal and half-sinusoidal tracks) are obtained by solving the equations numerically. The vehicle response obtained using a non-linear model of the hydrogas suspension shows slightly higher values of bounce acceleration of hull for the considered cross-country and sinusoidal terrain and for half-sinusoidal terrain. It is also seen that a hydrogas pressure of around 130 bar is optimal for all three terrain conditions.

INTRODUCTION

The dynamic response of off-road tracked vehicles to random road surface undulations has been of concern to automotive engineers for many years. This is due to the fact that excessive levels of vibration can lead to ride discomfort, ride safety problems and dynamic stressing of the vehicle structure arising from dynamic terrain-vehicle interactions. Ride vibrations transmitted to the driver's compartment are of high amplitude and low frequency, the conditions to which the human body is most fatigue sensitive. Prolonged exposure to such vibrations causes the operator bodily discomfort, physiological damage and reduces performance efficiency and thus the mobility performance of the vehicle is limited.

[*1] Research scholar- Email: mkravishankar@rediffmail.com and [2] Professor- Email: sujatha@iitm.ac.in

Computer simulation using an analytical vehicle model has become a very effective tool for evaluating the ride characteristics of ground vehicles, without resorting to the expensive and time-consuming process of repeated testing. Wheeler [1] worked on computer simulation of tracked vehicle ride dynamics and developed mathematical models incorporating the degrees-of-freedom associated with bounce and pitch motions of the sprung mass and vertical motion of each road wheel. Wong [2] has discussed simplified dynamic models of various types of ground vehicles. Rakheja *et al.* [3] have made studies on the ride dynamics of a tracked vehicle using a seven-degree-of-freedom in-plane model, incorporating kinematics of the road wheel suspension. Dhir and Sankar [4] have performed computer simulations of a military vehicle and validated their results with field-testing for specified vehicle configurations, terrain profiles and vehicle speeds. The same authors [5] have studied ride dynamics of off-road tracked vehicles, comparing various analytical models to study their effectiveness in modelling the wheel/track-terrain interactions. Sujatha *et al.* [6] conducted field tests on a military tracked vehicle and computed the natural frequencies of the vehicle using a rigid body model with degrees of freedom associated with bounce and pitch motions of the sprung mass and vertical motion of each road wheel.

DEVELOPMENT OF THE RIDE DYNAMIC MODEL

High-speed tracked vehicles although varying widely in shape, size and general physical appearance, share many common characteristics in the track and suspension assembly. From the point of view of analytical modeling, a typical tracked vehicle can be divided into track and suspension components and hull components. The former group includes the track, hull wheels (drive sprocket, idler and roller supports), road wheel assemblies and suspension components. Track and suspension components constitute the unsprung mass of the system. The hull represents collectively all remaining components of the vehicle and has been referred to as sprung mass.

For developing a ride dynamic model of the vehicle, the hydrogas suspensions connecting the wheels to the superstructure are to be characterized along with unsprung and sprung masses and inertia and elastic properties of wheels. Track effects such as track pull and track pad elasticity are also to be considered. The track is assumed to be a massless, continuous belt. Vehicle suspension units are modeled using independent suspension configurations and damping characteristics and are constrained to translate in the vertical direction.

The equivalent road wheel stiffness is computed taking into account the stiffness due to the track pad and wheel and the spring rate due to track tension [2]. For the present study, a simplified linear in-plane mathematical ride model (as shown in Figure 1) of a typical tracked vehicle formulated as a “2+N” degree of freedom system traversing an arbitrary, but specified non deformable terrain (a random course, a sinusoidal course, and a half-sinusoidal course), and running at constant speed is used. Here N is the number degrees of freedom corresponding to the N bounce modes (y_{wi}) of the N road wheels on each side. The remaining 2 degrees of freedom correspond to the bounce (y_h) and pitch (θ_h) modes of the centre of gravity (C.G) of the hull.

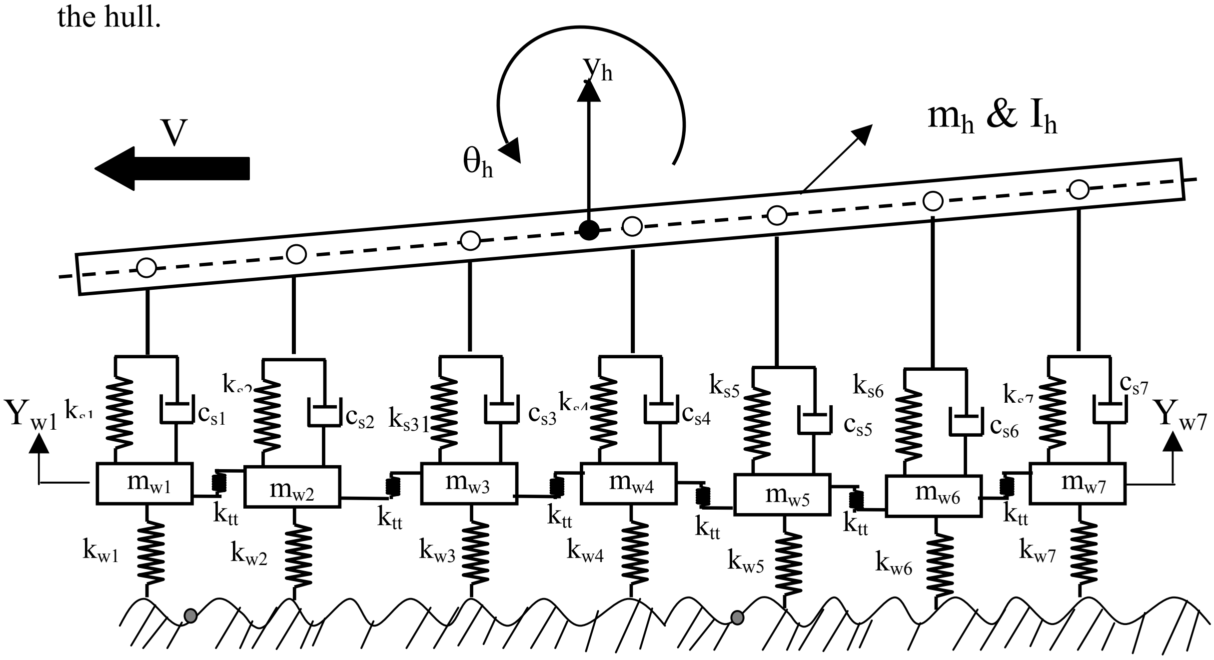

Figure 1 Equivalent dynamic model of tracked vehicle

Parameters used:

m_h	=	Half of hull sprung mass in kg	= 25000
I_h	=	Half of hull pitch moment of inertia in kg-m^2	= 190890
m_{wi}	=	Mass of ith road wheel assembly in kg	= 450
y_h	=	Hull bounce motion in m	
θ_h	=	Hull pitch motion in radians.	
y_{wi}	=	Bounce motion of ith road wheel in m	
a_i	=	Horizontal location of road wheel centers from C.G in m (a_1= -1.727, a_2= -0.859, a_3= 0.01, a_4= 0.835, a_5= 1.67, a_6= 2.48 & a_7= .29)	
k_{si}	=	Stiffness of ith suspension unit in N/m	= 88500
k_{wi}	=	ith wheel and track pad stiffness in N/m	= 981000
k_{tt}	=	Spring rate due to track tension in N/m	= 65672
c_{si}	=	Damping due to ith suspension unit in N-s/m	= 22520
T_r	=	Total vertical force acting at the road wheel center due to adjacent track segments in N	

Equations of motion of the in-plane tracked vehicle

Differential equations of motion for the in-plane tracked vehicle model are derived using Newton's second law of motion. Equations (1) and (2) represent the bounce and pitch motions of the sprung mass. Equation (3) represents the bounce motion of each road wheel.

$$m_h\ddot{y}_h + \sum_{i=1}^{7} C_{si}(\dot{y}_h - \dot{y}_{wi} + a_i\dot{\theta}_h) + \sum_{i=1}^{7} k_{si}(y_h - y_{wi} + a_i\theta_h) = 0 \quad (1)$$

$$I_h\ddot{\theta}_h + \sum_{i=1}^{7} a_i C_{si}(\dot{y}_h - \dot{y}_{wi} + a_i\dot{\theta}_h) + \sum_{i=1}^{7} a_i k_{si}(y_h - y_{wi} + a_i\theta_h) = 0 \quad (2)$$

$$m_{wi}\ddot{y}_{wi} - C_{si}(\dot{y}_h - \dot{y}_{wi} + a_i\dot{\theta}_h) - k_{si}(y_h - y_{wi} + a_i\theta_h) + k_{wi}y_{wi} - T_r = 0 \quad (3)$$

Total vertical force acting at the road wheel center due to adjacent track segments is given as [2]

$$T_r = k_{tt}(y_{wi+1} - y_{wi}) \text{ ....for i =1}$$

$$T_r = k_{tt}(y_{wi-1} - y_{wi}) + k_{tt}(y_{wi+1} - y_{wi}) \text{.........for i = 2,...6} \quad (4)$$

$$T_r = k_{tt}(y_{wi-1} - y_{wi}) \text{ ....for i = 7}$$

In the present study relative performance of the hydrogas suspension is assessed based on simulation of the test vehicle traversing over different terrain and at different speeds with hydrogas suspension units at all seven wheel stations. As the vehicle encounters any bump, deflection in the suspension unit causes the compression of the gas. This follows the adiabatic process that is non-linear in nature and hence the spring rate and the load characteristics are also non-linear. The stiffness versus stroke plots of hydrogas suspension at different gas pressures is as shown in Figure 2.

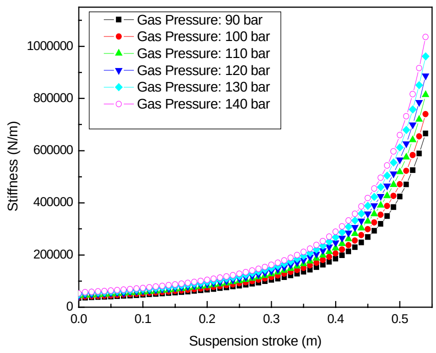

Figure 2 Stiffness versus stroke plots

DYNAMIC RESPONSE ANALYSIS

The natural frequencies of the tracked vehicle were determined by eigenvalue analysis using MATLAB and are listed in Table 1.

Table 1- Natural frequency in Hz of rigid body model

Mode	1	2	3	4	5	6	7	8	9
Frequency	0.43	0.81	7.76	7.81	7.94	8.12	8.32	8.50	8.62

The ride dynamic response of the tracked vehicle is evaluated for excitations arising from random undulations by carrying out Newmark's integration in time domain. Three types of terrain excitations have been considered; they are cross-country, sinusoidal and half-sinusoidal track. Time domain data corresponding to cross-country as shown in Figure 3 and a sinusoidal track with a peak-to-peak height of 0.42 m (h), wavelength (λ) of 4 m as shown in Figure 4 of length 28 m each is considered for the analysis. Also a half sinusoidal track of height 0.35 m (h) with wavelength of 3 m as shown in Figure 5 is considered.

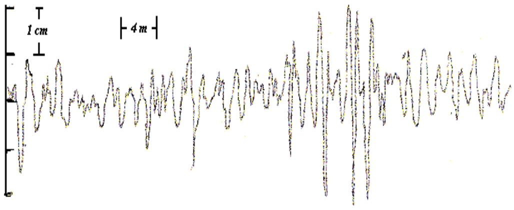

Figure 3 Cross-country undulation record

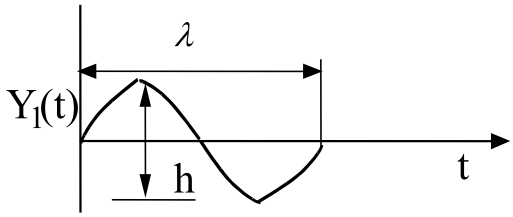

Figure 4 Sinusoidal undulation record

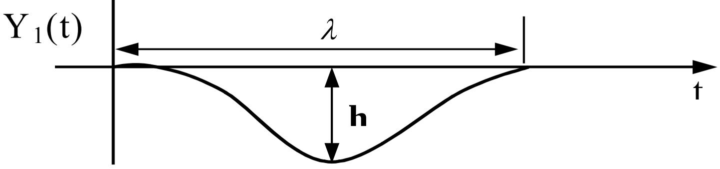

Figure 5 Half-sinusoidal undulation record

RESULTS AND DISCUSSION

Figures 6, 7 and 8 show a comparison of the hull bounce and wheel 1 bounce (WB1) accelerations for the different terrain at a constant vehicle speed of 18 kmph (5 m/s) for the linear and nonlinear models of hydrogas suspension of 90 bar initial gas pressure.

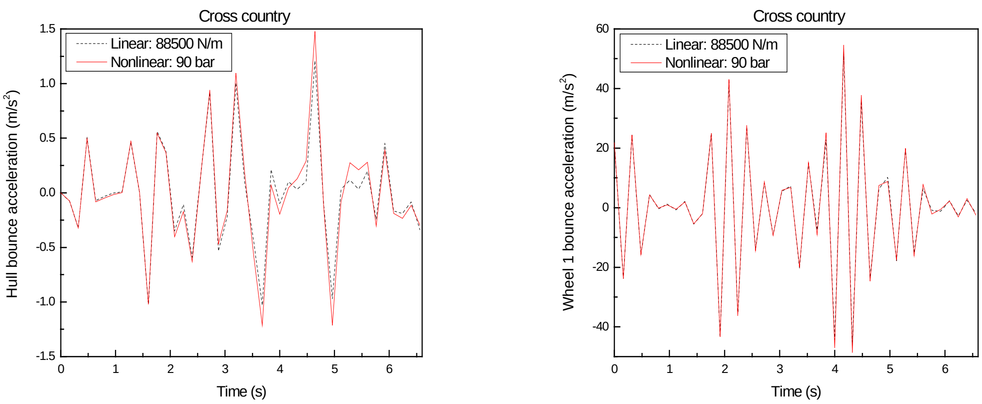

Figure 6 Bounce acceleration plots for cross-country input at 18 kmph (5 m/s)

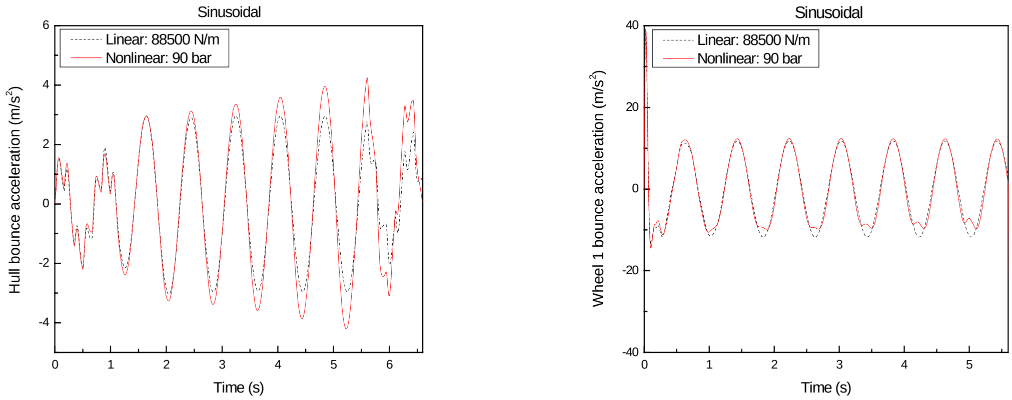

Figure 7 Bounce acceleration plots for sinusoidal input at 18 kmph (5 m/s)

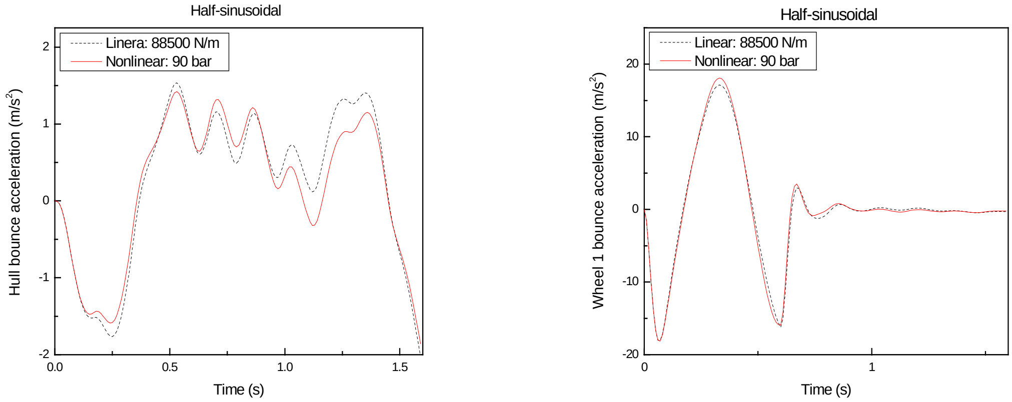

Figure 8 Bounce acceleration plots for half sinusoidal input at 18 kmph (5 m/s)

Figures 9, 10 and 11 show a comparison of the root mean square (RMS) values of hull bounce (HB) accelerations for the different vehicle speeds and terrain for linear and nonlinear suspension models, for varying gas pressures.

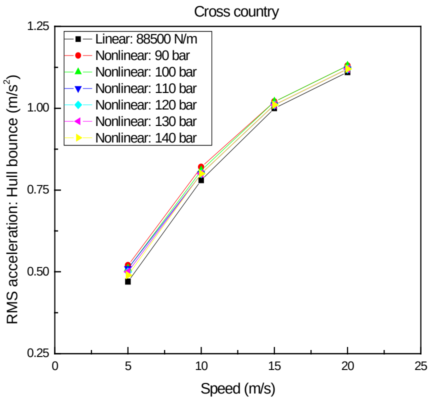

Figure 9 RMS acceleration: Hull bounce for cross country terrain

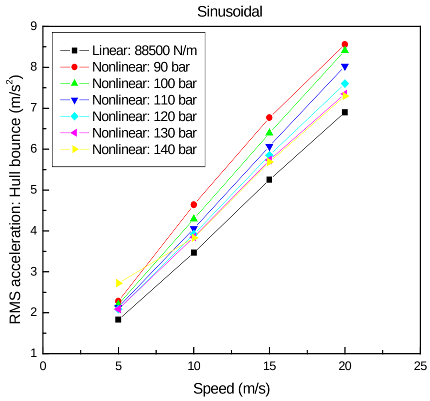

Figure 10 RMS acceleration: Hull bounce for sinusoidal terrain

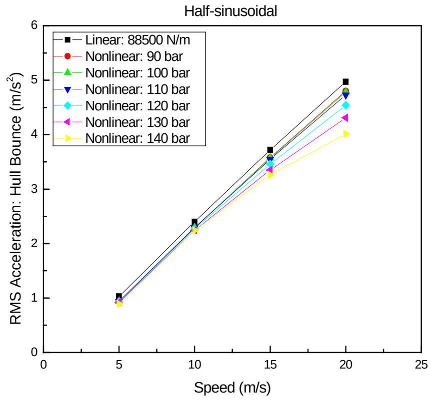

Figure 11 RMS acceleration: Hull bounce for half-sinusoidal terrain

Table 2 shows the root mean square (RMS) accelerations at different locations when the vehicle is operating at a speed of 18 kmph (5 m/s) for linear and non-linear models.

Table 2 RMS acceleration values at different locations on the model

Type of suspension	HB	HP	WB1	WB2	WB3	WB4	WB5	WB6	WB7
Cross country: 5 m/s speed									
Linear: 88500 N/m	0.47	0.17	21.91	21.71	21.51	21.60	21.61	21.53	21.65
Non-linear: 90 bar	0.52	0.19	22.55	22.33	22.08	22.19	22.26	22.22	22.18
Nonlinear: 100 bar	0.51	0.19	22.49	22.25	22.01	22.11	22.18	22.14	22.11
Non-linear: 110 bar	0.51	0.19	22.43	22.20	21.95	22.05	22.11	22.07	22.06
Non-linear: 120 bar	0.50	0.18	22.40	22.16	21.91	22.01	22.07	22.03	22.03
Non-linear: 130 bar	0.50	0.18	22.37	22.14	21.89	21.98	22.04	22.00	22.01
Non-linear: 140 bar	0.49	0.18	22.34	22.13	21.88	21.97	22.02	21.98	22.00
Sinusoidal: 5 m/s speed									
Linear: 88500 N/m	1.83	0.33	8.65	8.43	8.11	7.88	8.12	8.56	8.47
Non-linear: 90 bar	2.28	0.43	8.55	8.40	8.01	7.70	8.00	8.53	8.47
Nonlinear: 100 bar	2.20	0.41	8.56	8.40	8.03	7.72	8.00	8.53	8.47
Non-linear: 110 bar	2.13	0.40	8.57	8.41	8.04	7.74	8.01	8.54	8.47
Non-linear: 120 bar	2.09	0.39	8.58	8.40	8.05	7.75	8.02	8.54	8.47
Non-linear: 130 bar	2.09	0.39	8.61	8.39	8.04	7.75	8.02	8.55	8.48
Non-linear: 140 bar	2.72	0.61	11.49	8.26	7.99	7.58	8.09	8.69	8.56
Half-sinusoidal: 5 m/s speed									
Linear: 88500 N/m	1.03	0.53	7.31	6.89	6.72	6.80	6.70	6.85	7.39
Non-linear: 90 bar	0.94	0.55	7.57	6.98	6.81	6.91	6.85	6.95	7.43
Nonlinear: 100 bar	0.94	0.55	7.56	6.97	6.81	6.91	6.84	6.95	7.43
Non-linear: 110 bar	0.94	0.54	7.55	6.97	6.80	6.90	6.84	6.95	7.44
Non-linear: 120 bar	0.93	0.54	7.59	6.96	6.80	6.90	6.84	6.94	7.44
Non-linear: 130 bar	0.92	0.53	7.71	6.96	6.81	6.90	6.86	6.95	7.44
Non-linear: 140 bar	0.89	0.51	8.22	6.96	6.82	6.92	6.90	6.97	7.44

Note: HB: Hull bounce in m/s^2 ; HP: Hull pitch in rad/s^2 ; WB: Wheel bounce in m/s^2

From Table 2 and Figures 6, 7 and 8, it is clear that there is an increase in the hull bounce RMS accelerations of non-linear models of the hydogas suspension compared to the linear model for the considered cross country and sinusoidal terrain input. But this decreases as the gas pressure in the suspension increases. It is also seen that a hydrogas pressure of around 130 bar is optimal for all three terrain conditions. It is seen that wheel bounce acceleration is almost the same for all charge pressures and all three terrain inputs.

From Figures 9, 10 and 11 it is clear that there is an increasing trend in the RMS accelerations with the increase in the vehicle speed for both the linear and the non-linear models of the hydrogas suspension.

CONCLUSIONS

The present study shows a comparison of bounce acceleration of hull and wheel for a linear model (stiffness: 88500 N/m) and non-linear model of the hydrogas suspension (with variable stiffness) for different initial gas pressures (90 bar to 140 bar). The study was conducted for operation on different terrain (cross country, sinusoidal and half-sinusoidal) and different speeds 18 – 72 kmph (5 - 20 m/s). The hull bounce RMS accelerations of the model increase with increase in vehicle speed for all terrain inputs. The study shows that the linear model of suspension tends to underestimate the hull response and hence a non-linear model may be more realistic.

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