Available online at www.sciencedirect.com

ScienceDirect

Journal of Terramechanics 48 (2011) 125–137

Journal of Terramechanics

www.elsevier.com/locate/jterra

Hydro-gas suspension system for a tracked vehicle: Modeling and analysis

U. Solomon, Chandramouli Padmanabhan *

Machine Design Section, Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai 600 036, India

Received 13 April 2010; received in revised form 10 November 2010; accepted 5 December 2010
Available online 6 January 2011

Abstract

Tracked vehicles fitted with torsion bar suspensions are limited in their ability to achieve high mobility. This limitation is due to the linear characteristics and the consequent poorer ride performance. Hydro-gas suspensions due to their inherent non-linear behavior can provide higher mobility and better ride comfort performance. The hydro-gas suspension model has usually been developed from experimental force–displacement characteristics, which requires availability of suspension hardware.

In this paper, a hydro-gas suspension system is modeled using polytropic gas compression model to represent the spring characteristics, while the damper orifices are modeled using hydraulic conductance. The analytical model is then validated with experiments individually for spring and damper flow characteristics and then as a suspension-wheel assembly in a test rig. The validated suspension model is incorporated in an in-plane model. Using this model, simulation is carried out for sinusoidal inputs of different wavelengths, amplitudes and vehicle speeds. The simulation model is validated with data measured on a vehicle traversing an APG course. The proposed model agrees very well with the measured data. Based on the validated model, studies on the influence of suspension parameters on the ride comfort of a tracked vehicle are carried out.

Keywords: Suspension; Hydro-gas suspension; Damper; Tracked vehicle

1. Introduction

The ride dynamics of off-road tracked vehicles has been the focus of extensive research and development efforts leading to improved suspension systems that enhance crew comfort and improved mobility performance. However, most of these studies have been based on torsion bar suspension systems. Modeling of hydro-gas suspensions, where reported, is usually based on experimental data, which requires the availability of hardware.

Nieto et al. [1] have developed non-linear and linearized air-spring suspension models based on experimental measurements. The suspension consists of three principal parts: the air spring, an auxiliary tank and a pipe connecting the two. The solution of both the non-linear model and its first-order Taylor series linearized version are well in agreement with experimental measurements of the stiffness, damping factor and transmissibility for a reasonable operation range of the suspension.

Dahlberg [2] using a 5 degrees-of-freedom (DOF) in-plane linear vehicle model, travelling on a randomly profiled road, with the vehicle performance criteria based on mean square spectral densities, proved that one has to optimise with more damper and stiffness variables. A set of five variables led to 37% improvement whereas with two different single variables only 27% and 28% improvement was obtained.

An analytical solution for track-terrain interaction was suggested by Wong [3] based on five principal assumptions of constant track tension, inextensible track, small track deflection, full track-terrain contact and no shearing forces on track segments between the adjacent road wheels. While this model can be used to predict vehicle motion resistance

* Corresponding author.
E-mail address: mouli@iitm.ac.in (C. Padmanabhan).

0022-4898/$36.00 © 2010 ISTVS. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.jterra.2010.12.001

Nomenclature

Δp	differential pressure	$\dot{Z}_u$	unsprung mass velocity
F_d	damping force	Z_s	sprung mass
C_s	damping co-efficient	Z_u	unsprung mass
g_i	hydraulic conductance of an orifice	f_s	sprung mass force
g_p	effective conductance	λ	wavelength
g	acceleration due to gravity	v	velocity of the vehicle
k_s	non-linear spring	t	time
k_t	road wheel tyre spring (linear)	q	ground input for different wheels (i = 1–7)
C_t	tyre damping (linear)	C_d	co-efficient of discharge
Z_g	sinusoidal displacement	A_o	area of the fixed orifice
m_s	sprung mass	K_L	factor depending on type of restriction based on L/d ratio
m_u	unsprung mass	ρ	mass density of the fluid
$\ddot{Z}_s$	RMS acceleration	H_L	head loss
$\ddot{Z}_u$	unsprung mass acceleration	v	velocity of the vehicle
$\dot{Z}_s$	sprung mass velocity		

and drawbar pull, the above assumptions limit its ability to describe the general dynamic response.

Four track models of varying complexities, to be used in an in-plane ride dynamics model of a tracked vehicle, have been proposed by Dhir and Shankar [4]. In order to compare these track models, the ride response predictions of an armored personnel carrier were evaluated for each track model and directly compared with field measured data. The relative performances of these track models are assessed based on the accuracy of response predictions and associated computational time. Track model 4 while economical and convenient in view of modeling and computational requirement exhibited relatively less agreement. In track model 2, the track is well represented leading to a good correlation between simulated and measured ride response.

Dhir and Shankar [5] have made a compared the performance of torsion bar and hydro-gas suspensions on a tracked vehicle using their earlier in-plane model [4]. The hydro-gas suspension model is based on experimental data. The dynamic track load is modeled to account for track belt stretching and initial track tension, through an equivalent damper and continuous radial spring formulation. They compared the simulation results with measured field data, and demonstrated that the ride acceleration response improves significantly by replacing the torsion bar suspension with a hydro-gas suspension.

Dhir and Sankar [6] investigated the ride and safety performance of a tracked vehicle with a trailing arm suspension system, using a model based on the Lagrangian method, for a semi-circular bump input. A parametric sensitivity analysis, using the validated computer model, has been performed, to assess the influence of the conventional suspension parameters on the ride performance as well as the potential of a hydro-gas suspension. Rakheja et al. [7] carried out an in depth analysis of ride characteristics of a military tracked vehicle by including suspension, track tension and track-terrain interactions using a non-linear vehicle model. Also they assessed the ride quality of the vehicle fitted with a trailing arm torsion bar suspension in terms of average absorbed power. Rakheja et al. [8] investigated the driver seat suspension system under a sinusoidal excitation of frequency in the range of 0.5 to 0.8 Hz, which revealed that the seated human body contributes considerably to the overall ride performance.

Sujatha et al. [9] carried out a ride quality assessment on the basis of absorbed power. They conducted field tests on a tracked vehicle with acceleration levels being measured at a number of locations for four different types of terrain. The vehicle was also analysed using an in-plane, $n+2$ DOF model and the natural frequencies thus obtained were found to match prominent peaks in the transfer function and power spectral density plots of acceleration.

Wong [10] presented a brief review of the state of the art of tracked vehicle dynamics including mobility over soft terrain, ride dynamics over rough surfaces and maneuverability. Also, he discussed simplified dynamic models for various types of vehicles like automobiles and military tanks. Wong [11] also demonstrated the application of the computer simulation model, known as NTVPM-86 for the development of an infantry fighting vehicle, which has shown improved performance over the original on soft terrain. This model is shown to work well for high-speed tracked vehicles.

Most of the literature on ride-comfort of tracked vehicles is based on torsion bar suspensions. A few papers are available on hydro-gas suspensions and they clearly indicate better ride performance than a torsion bar suspension. However, the hydro-gas suspension models have been derived directly from experiments.

The main objective of this paper is to develop mathematical models which approximate the physics quite well and validate these with experiments. The gas spring is modeled using a polytropic compression/expansion model while the damper orifices are characterised by hydraulic conductance. Using an electrical analogy, the total hydrau-