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Ride dynamics mathematical model for a single station representation of tracked vehicle

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Abstract

Tracked vehicles are exposed to severe ride environment due to dynamic terrain-vehicle interactions. Hence it is essential to understand the vibration levels transmitted to the vehicle, as it negotiates different types of terrains at different speeds. The present study is focused on the development of single station representation of tracked vehicles with trailing arm hydro-gas suspension systems, simulating the ride dynamics. The kinematics of hydro-gas suspension system have been derived in order to determine the non-linear stiffness characteristics at various charging pressures. Then, incorporating the actual suspension kinematics, non-linear governing equations of motion have been derived for the sprung and unsprung masses and solved by coding in Matlab. Effect of suspension non-linear dynamics on the single station ride vibrations have been analyzed and validated with a multi-body dynamics model developed using MSC. ADAMS. The above mathematical models would help in estimating the ride vibration levels of the tracked vehicle, negotiating different types of terrains at various speeds and also enable the designers to fine-tune the suspension characteristics such that the ride vibrations are within acceptable limits. The mathematical ride model would also assist in development of non-linear ride vibration model of full tracked vehicle and estimate the sprung mass dynamics.

Keywords: Tracked vehicle; Hydro-gas suspension; Trailing-arm suspension; Multi-body dynamics; Ride dynamics

1. Introduction

Tracked vehicles are exposed to severe ride environment due to dynamic terrain-vehicle interactions. Hence it is essential to understand the vibration levels transmitted to the vehicle as it negotiates different types of terrains at different speeds. The fundamental theory of vehicle dynamics has been described in the book, written by Gillespie [1]. 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, by Solomon and Padmanabhan [2]. The experimentally validated suspension model is incorporated in an in-plane vehicle model and simulated over various terrains. A Lagrangian formulation of the tracked vehicle is derived using an arbitrary rigid terrain profile and constant vehicle speed, by Dhir and Sankar [3]. The track-roadwheel-terrain interaction has been taken into account through Lagrangian model formulation of an Armoured Personal Carrier vehicle, where the track dynamics have been considered. A non-linear in-plane computer simulation technique has been used for suspension dynamic analysis and ride quality assessment. The ride dynamic performance of a high-speed tracked vehicle with active suspensions have been studied and compared with that of a tracked vehicle having passive suspensions, by Rakheja et al. [4]. To achieve the above mentioned purpose, a

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non-linear, in-plane ride dynamic model which evaluates the driver's seat acceleration, ride height and hull angular acceleration of a typical high-speed tracked vehicle has been developed and its motion has been simulated. However in [2–4], the actual suspension kinematics have been transformed to the equivalent vertical component while formulating the governing equations of motion, which may yield some difference with the actual vehicle dynamics with trailing arm suspensions, unlike conventional quarter car, half car and full car models.

A field test conducted on a military tracked vehicle, in order to analyse the accelerations at selected locations on the vehicle for different types of terrains and different speed conditions, has been described by Sujatha et al. [5] in which a tracked vehicle with six bogie wheel stations, fitted with torsion bar suspension, has been considered for the analysis. Ride comfort aspects have been analyzed and compared with ISO 2631 standards. A finite element based simulation model to investigate the vibration and ride dynamic characteristics of a medium weight, high-speed military-tracked vehicle negotiating a non-deformable terrain has been described by Balamurugan [6]. A mathematical model of a 12-station vehicle with 78-DOFs have been studied by Hada [7] wherein, the torsion bars connecting the road arm to the hull chassis are considered as beams with 6-DOFs and the sprung mass with 6-DOFs. However, in [5–7], suspension non-linearity for hydro-gas suspension has not been considered for the vehicle dynamics.

Conventional implicit time-integration procedures, viz. Newmark, Wilson-θ and Houbolt methods and formulation, computational step-by-step procedures for linear and non-linear structural dynamics problems are given by Subburaj and Dokainish [8], wherein relative merits and stability aspects of these methods are described. The dynamics of the pendulum suspended on the forced Duffing oscillator, has been studied by Brzeski et al. [9] wherein a detailed formulation and bifurcation analysis of both oscillating and rotating periodic solutions of the pendulum, has been provided. From the above studies, it is observed that number of research activities have been undertaken in modeling the track vehicle dynamics to understand the vibration levels in tracked vehicles.

In most of the studies in literature the trailing arm suspension of the tracked vehicle are modeled as equivalent vertical spring, whereas in the present study the equations of motions for the single station representation of the tracked vehicle dynamics are formulated considering the actual kinematics of the tracked vehicle with trailing arm and HGS kinematics. At first, the kinematics of hydro-gas suspension system has been derived in order to determine the non-linear stiffness characteristics at various charging pressures. Thereafter, incorporating the actual suspension kinematics, the non-linear governing equations of motion have been derived for the sprung and unsprung mass and solved using Matlab, while such studies have not been reported in literature. Effect of suspension non-linear dynamics on the represented single station ride vibrations have been analyzed and validated with a multi-body dynamics model developed using ADAMS.

This study would help in development of the non-linear ride vibration model of full tracked vehicle and therefore estimating the vibration levels as the tank negotiates various terrain conditions and also would enable the designers for fine-tuning the suspension characteristics for obtaining the ride vibrations within desirable limits.

2. Approach to the ride dynamics study for single station model of tracked vehicles

The tracked vehicles generally use trailing arm hydro-gas suspension systems with non-linear characteristics. Before proceeding towards derivation of the governing equations of motion of tracked vehicles, the kinematics of hydro-gas suspension have been derived, taking into account the geometrical orientation of associated links. Thereafter, the non-linear suspension stiffness characteristics have been determined at different charging pressures. Equivalent viscous damping has been assumed at present, available from experimental data.

Consequent to derivation of the suspension kinematics and non-linear stiffness characteristics, mathematical formulation of non-linear static equilibrium conditions and ride dynamics of single station representation of tracked vehicles have been carried out. Base excitations have been applied to the single station mathematical model. The displacement and acceleration response at the sprung mass CG has been determined from the mathematical model and compared with the corresponding MBD model for validation purpose.

3. Scope of the present paper

The scope of the present paper is as follows:

- Derivation of kinematics and non-linear stiffness characteristics of the trailing arm hydro-gas suspension.
- Development of the 2 degrees-of-freedom non-linear mathematical ride vibration model for single station representation of tracked vehicle.
- Development of the 2 degrees-of-freedom MBD model for single station representation of tracked vehicle.
- Comparison of vertical displacement and acceleration response at the sprung mass CG, obtained from both the mathematical model and MBD model for single station representation of tracked vehicle.
- Performance comparison of trailing arm suspension non-linear math model with that of single station equivalent vertical spring mass system model.

4. Derivation of kinematics and non-linear stiffness characteristics of trailing arm hydro-gas suspension unit

The trailing arm hydro-gas suspension unit is a slider crank mechanism providing integral spring and damper,