Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Communications in Nonlinear Science and Numerical Simulation 12 (2007) 72–82
Communications in Nonlinear Science and Numerical Simulation
www.elsevier.com/locate/cnsns

Stability and vibrations of an all-terrain vehicle subjected to nonlinear structural deformation and resistance

L. Dai *, J. Wu

Industrial Systems Engineering, University of Regina, Regina, Saskatchewan, Canada S4S 0A2

Available online 15 February 2006

Abstract

This study intends to investigate the dynamic behaviour of an all-terrain vehicle travelling on rough terrains. A nonlinear analytical model is established for quantifying the response of the vehicle with spring and damping nonlinearities to various operation and terrain conditions. Focus of the study is on the motion characteristics of the vehicle operating on rough terrains. Stability analyses are performed for the all-terrain vehicles under the operation of surmounting large obstacles and the operation of the vehicle on rough terrain surfaces. Stability conditions are provided and stable and unstable region diagrams are plotted and analyzed with the analytical model developed. Analytical solutions are provided for weakly nonlinear dynamic systems. Numerical simulations for the motion of the all-terrain vehicle are also presented.

PACS: 45.05.+x; 45.40.−f; 47.20.Ky; 46.40.Ff; 02.60.Cb

Keywords: Vehicle dynamics; ATV; Numerical simulation; Vehicle dynamic stability; Nonlinear vibration; Vehicle modelling; Mathieu equation

1. Introduction

All-terrain vehicles (ATV) are widely used off-road vehicles. It is largely applied not only for entertainment but also for transportation procession, especially in the areas of military, agriculture and forestry. The ability that the vehicles can run on extremely complex and diverse road states is the most prominent character of the all-terrain vehicles [1]. The modern all-terrain vehicles are required to provide higher flexibility and suitability for driving in various operational and environmental conditions. These in turn demands a better understanding of the stability and dynamic response of the ATV subjected to the loading conditions of high nonlinearity and complexity. Since 1960s, systematic investigations on ATV motions are found in the literature with focus

* Corresponding author. Tel.: +1 306 585 4498; fax: +1 306 585 4855.
E-mail address: Liming.Dai@uregina.ca (L. Dai).

1007-5704/$ - see front matter
doi:10.1016/j.cnsns.2006.01.006

Nomenclature

a	constant system parameter
A	amplitude of the surface, matrix
c	damping coefficient
$f(k)$	effective nonlinear resistance
$f(c)$	effective nonlinear force
k	spring constant
M	effective mass of the vehicle
$p(t)$	exponential function of time
q_a	absolute vehicle motion
q_e	variation of the terrain surface amplitude
q_r	relative motion of $y - y_1$
$\bar{q}_r$	original periodic solution
$w(0)$, $\dot{w}(0)$	initial conditions
W	displacement matrix
x	perturbation value
y	displacement of the vehicle
α	coefficient relating to the nonlinearities of the effective spring force
β	coefficient relating to the nonlinearities of the damping resistance
ε	small quantity comparing to unit value
φ	phase angle
θ	phase angle
ω	frequency

on the aspects of general vehicle motion and the interactions between terrain and vehicles. Recent investigations are found on ATV's performance and handling characteristics, track force distribution, steering ability as well as ride properties [2–5]. Based on the research works available in the current literature, one may find that static analyses are commonly employed in this field, especially in ATV design practice. Linearization and simplification are also the common practices in the dynamic studies on the motion of ATV and dynamical response of ATV structures. Thorough and systematic analysis on the nonlinear motion of ATV and nonlinear dynamics response of the vehicle structures subjected to the loading and operating conditions of the real world is still in need.

It is the diversity of the road states that makes the nonlinearity become one of the most important factors that is needed to be highly taken into account during the analysis process. There are many factors that lead the ATV to display the highly nonlinear dynamic responses during operation, such as high irregularities of the ground, the nonlinear deformation of the terrain under the vehicle loading and the corresponding nonlinear response of the vehicle suspension system and undercarriage system.

The present research is to establish a methodology for investigating the stability and nonlinear response of all-terrain vehicles with spring and damping nonlinearities. A nonlinear model is to be established for nonlinear vibration and stability analyses on the basis of Lyapunov stability theory and Mathieu equation. Analytical and numerical approaches will be performed for investigating the stability and the nonlinear dynamic response of an all-terrain vehicle to the operation and terrain conditions.

2. Model development

The all-terrain vehicle studied in this research is assumed to be a symmetric body and its flexibility can be represented by a nonlinear spring and the energy absorption of the vehicle structure can be represented by a nonlinear damping system. The layout of the vehicle considered is illustrated in Fig. 1.