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Procedia IUTAM 22 (2017) 259 – 266

Procedia IUTAM

www.elsevier.com/locate/procedia

IUTAM Symposium on Nonlinear and Delayed Dynamics of Mechatronic Systems

Model Establishment and Parameter Analysis on Shimmy of Electric Vehicle with Independent Suspensions

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Abstract

In order to study the shimmy problem of the electric vehicle with independent suspensions, a 5 DoF model is established using the Lagrange Equation. Gyroscopic moment and tyre nonlinearity are both considered, and tyre-road constraint equations are derived on the non-slip assumption. Stability charts are conducted with the linearized model, while numerical simulation is also made so that these two methods can verify each other. The results show that bifurcation occurs at certain vehicle forward speed. Suspension structural parameters, such as caster angle, affect wheel shimmy. Furthermore, the presented model enables the analysis of any parameters in the system, and as an example, the influence of dampings on shimmy is investigated.

Peer-review under responsibility of organizing committee of the IUTAM Symposium on Nonlinear and Delayed Dynamics of Mechatronic Systems

Keywords: shimmy, electric vehicle, independent suspension, damping.

1. Introduction

”Shimmy”, the name of which originally comes from a dance move, is considered as a sustained vibration of wheels in the field of engineering, which occurs in many different mechanisms such as supermarket trolleys, baby strollers, skateboards, landing gears of the aircrafts, and cars. It can deteriorate the vehicle handling, stability, and even cause danger.

Early studies[1,2,3] about shimmy are generally based on the linear models, which can explain the phenomenon to various extent, but the problem is far from being fully solved. In recent studies, nonlinear characteristics such as tyre elasticity, dry friction, and clearance are considered. The research[4,5] carried out analytical and experimental work on quasi-periodic shimmy and corresponding Hopf bifurcations. By using the energy flow method in the study of tyre behaviour, Ran[6] found that tyre is responsible in transferring energy from forward to lateral and yaw motion. Lu[9] carried out research on a 5 DoF shimmy model with dependent suspension, and the numerical simulation shows that the clearance at the universal joint in handling mechanism makes a relevant contribution to the vehicle dynamic response. Li[10] analyzed the bifurcation characteristics of wheel shimmy based on a 3 DoF model, and presented some methods for attenuating shimmy. Venkata[11] established a multi-body dynamic model of a three-wheeled vehicle,

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Peer-review under responsibility of organizing committee of the IUTAM Symposium on Nonlinear and Delayed Dynamics of Mechatronic Systems
doi:10.1016/j.piutam.2017.08.034

the simulation results of which showed that the flexibility of steering column can cause system instability. The shimmy of aircraft nose landing gear (NLG) also gains a lot of attention [12,13], Terkovics [14] investigated the coupling between the NLG and the fuselage with a 2 DoF model, and Tourajizadeh [15] designed an optimal and robust nonlinear controller to suppress shimmy vibration of the NLG, which can also deal with the parametric uncertainties and external disturbances.

Since the energy crisis in the 1970s, electric vehicle (EV) has attracted increasing attention with its high efficiency and environmental friendliness. Much research has been made on the control strategies formulation and torque distribution for EVs, especially for those with in-wheel motors which not only is simpler in configuration but also facilitates the integration of different electronic control systems. However, accompanying with the convenience brought by the in-wheel motors, the increased unsprung mass and mass moment of inertia can lead to dynamic problems compared to the traditional vehicles, and the consequential electro-mechanical may also cause additional problem. Few studies have been carried out on the shimmy phenomenon of this new configurational vehicle. To investigate this problem, a proper and reliable multi-DOF shimmy model is needed, and this motivates our research.

Nomenclature

J_0	mass moment of inertia of wheel w.r.t. Y at CG
J_d	mass moment of inertia of wheel w.r.t. X or Z at CG
J_3	mass moment of inertia of pitman arm w.r.t. Z
k_1, k_2	equivalent torsional stiffness between wheel and pitman arm
k_3	equivalent torsional stiffness between pitman arm and steering gear
k_4, k_5	equivalent torsional stiffness of suspension w.r.t. X
k_z/k_y	vertical/lateral tyre stiffness
c_1, c_2	equivalent torsional damping between left/right front wheel and pitman arm
c_3	equivalent torsional damping between pitman arm and steering gear
c_4, c_5	equivalent torsional damping of left/right front suspension
c_e	torsional damping of wheel rotation about kingpin
M	vehicle mass without wheels
m	wheel mass
γ	caster angle
R	wheel rolling radius
e_2	pneumatic trail
r	scrub radius
a	half length of tyre contact patch
σ	relaxation length of tyre

2. System Modelling and Problem Formulation

Assume that the vehicle is running with constant speed V, the steering wheel is fixed, and there is no vertical displacement of the vehicle body.

A 5 DoF dynamic shimmy model is established in this section, including $\theta_{1,2}$ (shimmy angles of front wheels around kingpin, see Panel (a) in Fig.1), θ_3 (swing angle of the pitman arm, see Panel (a) in Fig.1), and $\varphi_{1,2}$ (swing angles of wheel-suspension subsystems, as shown in Fig.1 and Fig.2). The shimmy angles $\theta_{1,2}$ and swing angles $\varphi_{1,2}$ are in different directions of rotation. Compared to the conventional vehicle, the increase of unsprung mass due to the in-wheel motors is taken into account; in the meanwhile, this configuration with independent suspensions has no bridge between front wheels, thus the swing angles $\varphi_{1,2}$ of the front suspensions are considered separately. All this leads to the gyroscopic moments, as expressed in the following equations.

2.1. *Dynamic Model*

The kinetic energy of the system is expressed by

$$\begin{aligned} T =\ & \tfrac{1}{2}J_d\dot{\varphi}_1^2 + \tfrac{1}{2}J_0(\tfrac{V}{R} - \dot{\varphi}_1\theta_1)^2 + \tfrac{1}{2}J_d(\dot{\theta}_1 - \dot{\varphi}_1\gamma)^2 + \tfrac{1}{2}m(V - r\dot{\theta}_1)^2 + \tfrac{1}{2}m(l\dot{\varphi}_1 - r\dot{\theta}_1\gamma)^2 \\ & + \tfrac{1}{2}J_d\dot{\varphi}_2^2 + \tfrac{1}{2}J_0(\tfrac{V}{R} - \dot{\varphi}_2\theta_2)^2 + \tfrac{1}{2}J_d(\dot{\theta}_2 - \dot{\varphi}_2\gamma)^2 + \tfrac{1}{2}m(V - r\dot{\theta}_2)^2 + \tfrac{1}{2}m(l\dot{\varphi}_2 - r\dot{\theta}_2\gamma)^2 + \tfrac{1}{2}J_3\dot{\theta}_3^2 + \tfrac{1}{2}MV^2; \end{aligned} \tag{1}$$