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A new contact & slip model for tracked vehicle transient dynamics on hard ground

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Abstract

This study presents a new general transient contact and slip model for tracked vehicles on hard ground which is simple, accurate, and in agreement with the test results to a satisfactory level. Simulating zero track speed instances become possible with the new contact/shear model which is the major proposed improvement in addition to more accurate results for transient steering and tractive inputs. The model represents a general tracked vehicle having rear or front sprockets, with parameters for center of gravity, wheel positions, number of wheels, and track-pretention. To calculate longitudinal and lateral forces, a transient shear model is used. Shear stress under each track pad is assumed to be a function of shear displacement. The contact time formulation used in shear displacement calculation is improved to gain accuracy for transient and zero track speed conditions.

The model is implemented on the Matlab/Simulink platform and verified with a comprehensive program of road tests composed of transient steering and tractive/braking scenarios. The results of the simulations and the road tests are satisfactorily similar for both constant and transient input maneuvers. Moreover, sensitivity simulations for vehicle parameters are conducted to show that the model responses are inline with the expected vehicle dynamics behaviours.

Keywords: Tracked vehicle; Steering; Transient lateral and longitudinal dynamics; Shear model

1. Introduction

Studies on steering dynamics of tracked vehicles began in 1950's. Steeds (1950) is one of the first researchers who rigorously defined skid steering behavior of tracked vehicles. His basic assumption was that the interaction between terrain and the track obeyed the Coulomb law of friction. He considered uniformly distributed vehicle weight over the whole track area and suggested a trial and error type of solution. Weiss (1971) proposed calculation of normal loads under the track as concentrated point loads under each wheel on hard ground. His equations were solved graphically in the form of nomograms. Kitano and Jyozaki (1976) took into consideration the effect of lateral accelerations, longitudinal accelerations, and track tension on contact forces. They derived their formulas considering regularly spaced wheels of an n-wheeled vehicle and took the center of gravity in the middle of the vehicle. They excluded the effect of track pretension. Kitano and Kuma (1977) derived the differential equations to define the steering motion for transient cases. However, they again used the simple Coulomb's law of friction to calculate shear forces. Watanabe and Kitano (1986) extended the same model to analyze steerability of articulated vehicles. The

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Nomenclature

a_x	longitudinal acceleration (m/s^2)
a_y	lateral acceleration (m/s^2)
A_{tp}	single-track shoe bottom surface area (m^2)
B	vehicle tread (m)
CoG	center of gravity of the vehicle
d_{km}^{ij}	distance the track shoe cell sheered after it started to its movement (m)
f_r	coefficient of external motion resistance
g	gravity (m/s^2)
G	total vehicle weight (N)
G_1	total weight on first track (N)
G_2	total weight on second track (N)
H	Z coordinate of center of gravity (m)
i	number of the road wheel
j	number of the track
j_{xkm}^{ij}	slip displacement of a track shoe cell in x direction in vehicle coordinate system (m)
j_{ykm}^{ij}	slip displacement of a track shoe cell in y direction in vehicle coordinate system (m)
j_{km}^{ij}	total slip displacement of a track shoe cell in vehicle coordinate system (m)
K	shear deformation modulus (m)
L_1	Y distance of CoG to the first track in vehicle coordinate system (m)
L_2	Y distance of CoG to the second track in vehicle coordinate system (m)
L_{iJ}	X distance of road wheel to O_1-O_2 axis in vehicle coordinate system (m)
L_G	X distance of center of gravity to O_1-O_2 axis in vehicle coordinate system (m)
M	total vehicle mass (kg)
M_{xij}	moment created by longitudinal force at track shoe (Nm)
M_{yij}	moment created by lateral force at track shoe (Nm)
n	total number of wheels
O_1	arbitrarily selected point in the direction of first track
O_2	arbitrarily selected point in the direction of second track
p^{ij}	normal pressure over the bottom surface of a track shoe (N/m^2)
p_l	mean length of a track shoe (m)
p_w	mean width of a track shoe (m)
P_{ij}	total contact force of a track shoe (N)
P_{sij}	static load under each track shoe (N)
Q_{xij}	longitudinal force on each track pad (N)
Q_{yij}	lateral force on each track pad (N)
R_j	longitudinal force created by external rolling resistance (N)
s'_j	gradient of static load transfer (N/m)
s_{ij}	static load transfer (N)
t_{1j}	track force on 1st wheel (N)
t_{nj}	track force on nth wheel (N)
T_p	track pretension (N)
T_S	tension applied by sprocket to the track segments (N)
T_{1j}	track tension in front (N)
T_{nj}	track tension in rear (N)
V	combined velocity of the vehicle (m/s)
V_{sxkm}^{ij}	velocity of the track shoe cell in x direction in track shoe coordinate system (m/s)
V_{sykm}^{ij}	velocity of the track shoe cell in y direction in track shoe coordinate system (m/s)
V_{tj}	velocity of track (m/s)
V_x	velocity of the vehicle in x direction in vehicle coordinate system (m/s)
V_y	velocity of the vehicle in y direction in vehicle coordinate system (m/s)
xp_{km}^{ij}	X coordinate of a track shoe cell center in track shoe coordinate system (m)
xw_{ij}	X coordinate of a track shoe center in vehicle coordinate system (m)
X	X location of the vehicle in global coordinate system (m)
yp_{km}^{ij}	Y coordinate of a track shoe cell center in track shoe coordinate system (m)
yw_{ij}	Y coordinate of a track shoe center in vehicle coordinate system (m)
Y	Y location of the vehicle in global coordinate system (m)
β	side slip angle (rad)
ψ	yaw angle (rad)
ω	yaw rate (rad/s)
$\dot{\omega}$	yaw acceleration (rad/s^2)
θ_{fj}	approach angle of track (rad)
θ_{rj}	departure angle of track (rad)
ϵ_ψ	relative error of yaw angle (%)
ψ_{km}^{ij}	direction of slipping of track shoe cell (rad)
Δ_{ij}	load change on road wheel suspension due to track tension (N)
Δx	length of a track shoe cell in x direction in track shoe coordinate system (m)
Δy	length of a track shoe cell in y direction in track shoe coordinate system (m)
Δt_{km}^{ij}	slip displacement integration step size (s)
α_{ij}	dynamic load change due to lateral acceleration under each track shoe (N)
β'_j	gradient of the dynamic vertical load change relative to the distance from point O that is due to longitudinal acceleration under each track shoe (N/m)
β_{ij}	dynamic load change due to longitudinal acceleration under each track shoe (N)