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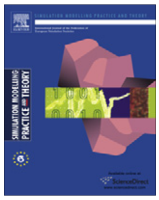

Evaluation of antilock braking system with an integrated model of full vehicle system dynamics

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ABSTRACT

Antilock braking system (ABS), traction control system, *etc.* are used in modern automobiles for enhanced safety and reliability. Autonomous ABS system can take over the traction control of the vehicle either completely or partially. An antilock braking system using an on–off control strategy to maintain the wheel slip within a predefined range is studied here. The controller design needs integration with the vehicle dynamics model. A single wheel or a bicycle vehicle model considers only constant normal loading on the wheels. On the other hand, a four wheel vehicle model that accounts for dynamic normal loading on the wheels and generates correct lateral forces is suitable for reliable brake system design. This paper describes an integrated vehicle braking system dynamics and control modeling procedure for a four wheel vehicle. The vehicle system comprises several energy domains. The interdisciplinary modeling technique called bond graph is used to integrate models in different energy domains and control systems. The bond graph model of the integrated vehicle dynamic system is developed in a modular and hierarchical modeling environment and is simulated to evaluate the performance of the ABS system under various operating conditions.

1. Introduction

The main motivating factor behind this work on vehicle dynamics and antilock braking systems are the conditions that prevail in Indian roads, especially in sub-urban, semi-urban and rural areas, where road infrastructure is poor and traffic is chaotic. The vehicle performance is severely challenged in these conditions and optimizing the performance of the mechatronic systems require controllers to be tuned by trial and error through exhaustive simulations and field testing. This is why Indian automobile industry has been very conservative in adopting modern technology. The ABS is to be designed for diverse driving conditions, especially where frequent braking and acceleration is required. Thus, increasing the life of the braking system in these conditions becomes important.

Modeling and simulation of physical phenomena and physical systems plays a very important role in understanding the underlying science. The necessary steps involved in modeling are writing the equations for each elementary physical system, sorting these equations and implementing them in a solver. This approach becomes time-consuming when the system becomes complex and multidisciplinary in nature. A common tool enabling a unified approach to the physical modeling of various disciplines is bond graph [1–4]. Bond graph technique is also well suited for modular modeling of large physical systems. A vehicle dynamic system is a multi-energy domain system which involves mechanical, hydraulic, pneumatic, electronic, electrical, chemical (batteries or fuel cells), thermal domains, to name a few. Bond graph modeling is an ideal tool to

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Nomenclature

a	distance of front axle from the vehicle cg
A	area
b	distance of rear axle from vehicle cg
B	stiffness factor
c	half of track width
C	shape factor
C_1	maximum value of friction curve
C_2	friction curve shape
C_3	friction coefficient difference between the maximum value and value at $\sigma_x = 1$
C_4	wetness characteristic value
D	peak value
E	curvature factor
F	force
h	height of vehicle cg from suspension reference point
J	polar moment of inertia
K	stiffness
k_g	discontinuous controller gain
l	length
m	mass
M	moment
r	effective radius
R	damping
V	volume
v, $\boldsymbol{V}$	velocity, velocity vector
x, y, z	displacements in three directions
$\dot{x}, \dot{y}, \dot{z}$	velocities in three directions
$\ddot{x}, \ddot{y}, \ddot{z}$	accelerations in three directions
x_0	output variable
y_i	input variable
α	lateral slip angle
γ	camber angle
δ	steering angle
$\dot{\theta}, \ddot{\theta}$	angular velocity, acceleration
τ	torque
σ	slip ratio
μ	coefficient of friction
μ_m	motor torque constant

Subscripts

a	arm
b	braking
bc	brake cylinder
bd	brake drum
c	vehicle body
cfr, crr	front and rear cornering force
ca	cable
cx, cy, cz	x, y, z direction of vehicle body
e	equivalent
E	engine
fr	front
l	left
lm	mechanical loss
m	motor
nfr, nrr	normal for front and rear wheel
r	right
re	return
rr	rear
stx, sty, stz	x, y, z direction of structure
st	steering (front axle)