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Improving the braking performance of a vehicle with ABS and a semi-active suspension system on a rough road

Herman A. Hamersma *, P. Schalk Els

Department of Mechanical and Aeronautical Engineering, University of Pretoria, South Africa

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Abstract

Rapid advances have been made in the field of vehicle dynamics in terms of improving the ride, handling and safety using actuators and control systems. Optimising a vehicle's ride comfort or handling has led to the development of semi-active suspension systems. Anti-lock braking systems (ABS) have resulted in significant improvements in vehicle braking whilst maintaining directional control over the vehicle. These advances have improved vehicle and occupant safety in general, but there are often some trade-offs. For example, the stopping distance of a vehicle fitted with ABS on an undulating road is significantly increased compared to braking without ABS. This has severe implications, especially in the off-road vehicle industry. The effects of spring and damper characteristics on the braking performance of a sports-utility-vehicle (SUV) on hard rough terrain are investigated. The approach is simulation based, using an experimentally validated full vehicle model of the SUV, built in Adams in co-simulation with MATLAB and Simulink. The simulations were performed on measured road profiles of a Belgian paving and parallel corrugations (or a washboard road). The results indicate that the suspension system has a significant impact on the braking performance, resulting in differences in stopping distances of up to 9 m.

Keywords: Off-road vehicles; ABS systems; Semi-active suspension; Tyre modelling; Multi-body dynamics modelling

1. Introduction

Stopping in the shortest possible distance without losing control over a vehicle is probably the most important active safety requirement of any vehicle that can prevent accidents or at least lessen the impact. Significant advances have been made since the dawn of brakes on vehicles, most notably the development of anti-lock brake systems (ABS). Prior to discussing how ABS works, it is important to understand the friction generation mechanism of tyres. A tyre's friction generation mechanism is due to adhesion and hysteresis between the tyre and the road in the contact patch. Adhesion arises due to the intermolecular bonds between the tyre and the road surface while hysteresis is due to the deformation of the tyre over a rough road surface [1]. The result of these phenomena is that the friction coefficient between the tyre and the road surface relies on slip between the tyre and the road. The longitudinal friction coefficient is typically characterised as a function of longitudinal wheel slip. Longitudinal wheel slip on a flat road is given by Eq. (1) [1]. Examples of typical longitudinal friction coefficients for different vertical loads are shown in Fig. 1. The data used in Fig. 1 is from the Pacejka-model used in this study (further discussion in Section 2.4).

$$\%slip = \frac{V - \omega R_{eff}}{V} \times 100\% \quad (1)$$

Curves similar to those shown in Fig. 1 may be obtained for the lateral friction coefficient, usually as a function of

* Corresponding author.
E-mail addresses: hhamersma@gmail.com (H.A. Hamersma), schalk.els@up.ac.za (P. Schalk Els).

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Nomenclature of symbols

f	Coefficient of friction [Dimensionless]	T	Brake torque [Nm]
p_a	Brake line hydraulic pressure [Pa]	V	Vehicle speed [m/s]
r_i	Inner brake pad radius [m]	$\Delta\theta$	Brake pad angle [rad]
r_o	Outer brake pad radius [m]	ω	Wheel angular speed [rad/s]
R_{eff}	Effective rolling radius [m]		

side-slip angle. From Fig. 1 one may conclude that braking with longitudinal slip at approximately 15% results in maximum brake force and thereby the highest deceleration and the shortest possible braking distance will be attained. However, when the tyre is generating maximum longitudinal force (for example during braking) the tyre cannot generate any lateral force [1]. Since lateral force is essential to controlling the lateral stability of the vehicle, braking at maximum longitudinal force may result in an uncontrollable or unstable vehicle. This led to the development of ABS.

When the vehicle brakes are initially applied, the tyre deflects, generating longitudinal slip that results in a corresponding longitudinal force as dictated by the relationship indicated in Fig. 2. If the longitudinal force exceeds the available friction force, the wheel locks up almost instantaneously.

ABS senses when wheel lock-up occurs or is about to occur and reduces the hydraulic brake pressure accordingly. This not only prevents the wheel from locking but also generates some capacity for the development of lateral force between the tyres and the road that helps to maintain directional control [2]. Once the control system detects that the wheel is not locked and spinning freely, the brake pressure is gradually reapplied. This process is then repeated until the brake is released by the driver or the vehicle speed reduces below a set value [2]. This is the cycling indicated in Fig. 2.

The ABS cycle has three distinct phases, namely hold, reduce or increase pressure. Initially, as the driver applies pressure to the brake pedal, the hydraulic pressure rises and the wheel is braked. The wheel speed thus decreases, but ABS has no control effect at this stage. If the wheel speed decreases too rapidly, the control system detects that lockup is imminent. At this stage the inlet valve from the master cylinder is closed and the hydraulic pressure cannot be increased further (the hold phase). If the wheel speed continues to decrease the outlet valve is opened and the hydraulic pressure is reduced as fluid drains back to the reservoir. With a reduction in brake pressure the wheel speed starts to increase again. If the wheel speed increases so that it is no longer braking acceptably, the controller again gradually increases the brake pressure, even if the driver presses harder on the brake pedal [2]. This process is repeated several times per second on each wheel. It may be noted that the only feedback necessary for the implementation of ABS is the wheel speed (further discussion in Section 2.2). The wheel speed is used to calculate the wheel deceleration and in more modern algorithms to estimate the longitudinal wheel slip. Therein lays the assump-

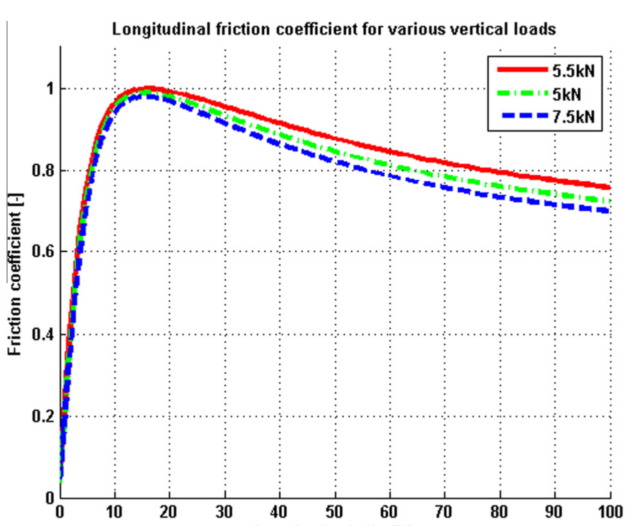

Fig. 1. Longitudinal friction coefficient as a function of longitudinal slip for various vertical loads.

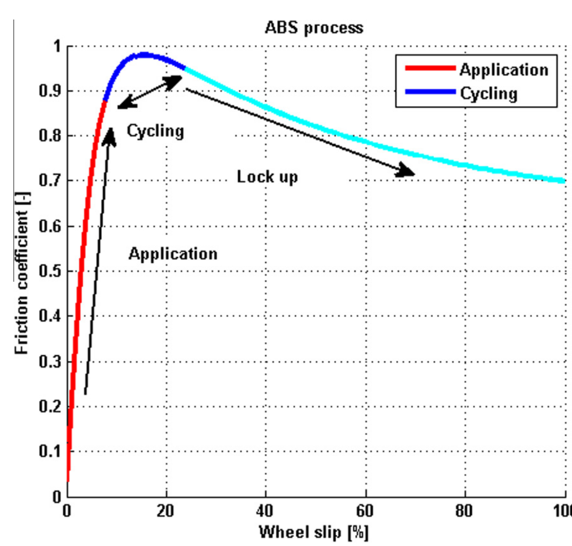

Fig. 2. ABS cycling process.