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Calculation of skid resistance from texture measurements

Andreas Ueckermann*, Dawei Wang, Markus Oeser, Bernhard Steinauer

Institute of Highway Engineering, RWTH Aachen University, Aachen 52056, Germany

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ABSTRACT

There is a wide range of routine skid resistance measurement devices on the market. All of them are measuring the friction force between a rubber wheel and the wetted road surface. Common to all of them is that they are relatively complex and costly because generally a truck carrying a large water tank is needed to wet the surface with a defined water layer. Because of the limited amount of water they can carry they are limited in range. Besides that the measurement is depending on factors like water film thickness, temperature, measurement speed, rubber aging, rubber wear and even road evenness and curviness. All of these factors will affect the skid resistance and are difficult to control. We present a concept of contactless skid resistance measurement which is based on optical texture measurement and consists of two components: measurement of the pavement texture by means of an optical measuring system and calculation of the skid resistance based on the measured texture by means of a rubber friction model. The basic assumptions underlying the theoretical approach and the model itself based on the theory of Persson are presented. The concept is applied to a laboratory device called Wehner/Schulze (W/S) machine to prove the theoretical approach. The results are very promising. A strong indication could be provided that skid resistance could be measured without contact in the future.

1. Introduction

Wet road skid resistance is an important functional property of road pavements. Pavements are designed to offer a safe ride to the road users under different climatic conditions and over a long service life. In order to maintain a sufficient level of skid resistance pavement monitoring is performed at regular intervals.

All of the measurement devices in use are based on the principle of rubber friction; generally, the friction force between a measuring wheel, operated at a defined speed, vertical load and transversal slip, and the pavement is measured. Those measurement devices are relatively complex and costly because in most cases a truck carrying a large water tank is needed to wet the surface with a defined layer of water. Because of the limited amount of water they can carry they are limited in range. Besides that the measurement is depending

* *Corresponding author*. Tel.: +49 241 80 26744; fax: +49 241 80 22141.
E-mail address: ueckermann@isac.rwth-aachen.de (A. Ueckermann).
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on factors like water film thickness, temperature, measurement speed, rubber aging and wear and even road evenness and curviness. All of these factors will affect the skid resistance and are difficult to control.

For this reason several efforts have been undertaken in the past to predict skid resistance solely from optical texture measurements. Optical sensors are comparably cheap and easy to combine with existing measurement equipment for monitoring purposes. They are independent of rubber properties and the influence of an interfacial water film.

However, most of the approaches failed. One of the mistakes was to exclude the rubber properties from the approach. Another reason was that the resolution of the texture measurements was not high enough to capture the geometrical features governing the rubber friction.

This paper is intended to make a contribution to contactless skid resistance measurement. It deals with the prediction of skid resistance from texture measurements using a rubber friction model. The approach, the investigations and results are presented below. To begin with a brief literature review on contactless skid resistance measurement and factors influencing skid resistance shall be given.

2. Existing approaches and factors influencing skid resistance

Recent advances on contactless skid resistance measurement are reported by Dunford (2008, 2010) where skid resistance is predicted from parameters directly extracted from images of the road surface. Many approaches use 2-dimensional or 3-dimensional topographical data of the surface collected by means of laser displacement sensors or laser profile scanners (Mu et al., 2003; Kebrle and Walker, 2007; Xie et al., 2008; Meegoda, 2009; Cigada et al., 2010; Goubert et al., 2010). Topographical data can also be generated by stereoscopic imaging. Although not new in the application to pavement texture analysis (Sabey and Lupton, 1967; Schonfeld, 1970) recent work on algorithms for the extraction of surface topography from image and the assessment of surface roughness by means of image-based descriptors is described (Ben Slimane et al., 2008; Xie et al., 2009; El Gendy et al., 2011). Light scattering methods based on depolarization (Spring III and King, 1981; Wambold et al., 1982) or back-scattering pattern analysis (Kazakov, 1986; Iaquinta and Fouilloux, 2003) have been proposed in the past but obviously not persued, presumably because optical pavement properties not necessarily reflect tire-pavement interaction.

Basically, three approaches to predict skid resistance from road surface data can be found in literature: prediction through texture or texture-related parameters, which correlate with rubber friction, prediction through modeling of rubber contact and rubber friction (partially including the lubricant), and a combined approach comprising both texture indicators and physical modeling as described in previous studies (Do et al., 2004a,2004b; Do and Zahouani, 2005; Kane and Do, 2006). The first approach can involve statistical regression models (Zahouani et al., 2000; Ergün et al., 2005; Shalaby and El Gendy, 2008; Schulze, 2011), fuzzy-logic (Ustuntas, 2007) and artificial neural networks (Kebrle and Walker, 2007; Xie et al., 2008; Wang et al., 2012). The second one largely focuses on hysteresis friction since hysteresis is the dominating mechanism during braking on wet road pavements. However, other phenomena like adhesion and the influence of water in the tyre/road interface are delt with as well in related papers.

It is widely acknowledged that the microtexture (wavelengths below 0.5 mm) governs the peak value of the wet friction coefficient-slip (or sliding speed) curve whereas the macrotexture (wavelengths between 0.5 and 50 mm) governs its decrease. The lower the macrotexture the steeper the decrease. A high macrotexture (i.e. a high water drainage capacity) can improve the skid resistance over a wide range of speeds. Pioneering studies on the role of micro/macrotexture under wet braking conditions can be found (Giles, 1957, 1965; Schulze, 1959, 1969, 1970; Moore, 1969, 1975; Geyer, 1972; Holla and Yandell, 1973; Moore and Humphreys, 1973; Balmer, 1975; Rhode, 1976; Holla, 1977; Taneerananon and Yandell, 1981; Holt and Musgrove, 1982; Horne and Bühlmann, 1983). Size, density and shape (slope) of the microasperities on top of the aggregates are essential to overcome the thin water film and to make direct contact with the rubber. A close relationship between friction coefficient and average slope of the microasperities in the contact zone can be observed and mathematically explained (Yandell, 1971; Forster, 1981; Pinnington, 2009). More recent approaches to define texture descriptors relevant to skid resistance can be found (Zahouani et al., 2000; Ergün et al., 2005; Shalaby and El Gendy, 2008; Schulze, 2011) as mentioned above. Other researchers emphasize the fractal nature of pavement texture and use a fractal or spectral description of the self-affine road surface (Majumdar and Bhushan, 1990; Majumdar and Tien, 1990; Radó, 1994; Kokkalis and Panagouli, 1998; Klüppel and Heinrich, 2000; Persson et al., 2001). Instead of a truncated Fourier series a combination of a Fourier series and a Weierstrass–Mandelbrot series is used (Radó, 1994; Pinnington, 2012), amongst others to allow for the asymmetry of worn pavement surfaces. Recent theories on rubber friction (Klüppel and Heinrich, 2000; Persson et al., 2001) assume a smooth rubber surface and a rigid substrate with a self-affine surface roughness that is described by the power spectral density or the height-difference correlation function. Two and three parameters respectively are needed to describe the texture. Close relationships between these parameters and wet tire traction have been observed (Heinrich, 1992a,1992b).

When skid resistance is measured, let's say with a measuring speed of 60 km/h and a fixed slip of 20%, only a part of the measured slip speed, which would be 12 km/h, is due to actual sliding, the other one is due to deformation of the tread elements. The amount of deformation slip depends on the tire stiffness: a blank, "stiff" tire would exhibit only little deformation implying that the measured slip speed almost equals the actual slip speed, whereas a treaded tire would undergo a higher deformation, depending on the elasticity of the tread rubber and the geometry of the tread pattern. In most cases the slip measured is just a mean value averaged over the contact length and thus a simplification of the real slip conditions within the contact area.

A three-zone model according to Moore (1966) can help to illustrate the contact conditions in the tire-road interface