

Using Generic Tyre Parameters for Low Friction Surfaces in Full Vehicle Simulations

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ABSTRACT

An intervention of vehicle stability control systems is more likely on slippery surfaces, e.g. when the road is covered with snow or ice. Contrary to testing on dry asphalt, testing on such surfaces is restricted by weather and proving grounds. Another drawback in testing is the reproducibility of measurements, since the surface condition changes during the tests, and the vehicle reaction is more sensitive on slippery surface. For that, simulation enables a good pre-assessment of the control systems independent from testing conditions. Essential for this is a good knowledge about the contact between vehicle and road, meaning a good tyre model and a reasonable set of tyre model parameters. However, the low friction surface has a high variation in the friction coefficient. For instance, the available lateral acceleration on scraped ice could vary between 0.2 and 0.4 g within a day. These facts lead to the idea of using generic tyre parameters that vary in a certain range. Benefit would be the robust testing of the stability control systems. Generic tyre parameters could also cover a high variety of available tyres on the market. Furthermore the model can be used to evaluate changing surface conditions. The extreme case of this situation are then the μ -slip manoeuvres, e.g. braking with asphalt on one lane and snow or ice on the other side.

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INTRODUCTION

A slippery surface means less friction between the tyre and road. This is the case when the road is wet or covered with leaves or sand. In winter, the roads may be full of snow or in icy conditions. All these situations make it more likely that the driver loses control over his vehicle than when he is driving on dry asphalt. Available stability control systems as e.g. the ESC (Electronic Stability Control) will intervene in dangerous situations and help the driver to gain control over his vehicle again.

The control intervention on snow and ice roads can be tested on winter proving grounds. However, this is restricted to certain locations and to a small period of time. Also the reproducibility of tests is poor compared to measurements on dry asphalt. Snow will get pressed and scraped ice will get very slippery when the measured vehicle or the measured tyre is driven always in the same lane. Scraped ice is generated by scratching hard frozen ice with a steel rake and let the loose ice freeze to the surface again. When driven on a parallel lane, the surface may also be different. Tests on wet roads are also difficult to reproduce.

Simulations can help to overcome these problems. They are independent of proving grounds, weather condition and temperature.

Furthermore they can deliver a good pre-assessment of the stability control systems before going to real winter tests. Target is to test the general behaviour and the robustness of stability control systems in vehicle dynamics manoeuvres on low friction surfaces in simulation.

Before starting simulations, it is important to define the models and parameters to be used. The car model for vehicle stability controls simulations is normally a real-time capable multi-body dynamics model. The algorithms for the vehicle stability control are delivered by the system suppliers or the internal software developers.

The tyre model plays an important role in the vehicle dynamics behaviour in simulation. Here many models are available. This ranges from mathematical models as the Magic Formula (MF), multi-body-system models as FTire to Finite Element Models as ABAQUS. The Pacejka based models are considered as sufficient for the vehicle stability controls simulation.

Next step is how to get the tyre parameters for the different kinds of slippery surfaces. Here two kinds of tests can be distinguished. Tyre measurements can be done on internal drum test benches as e.g. available at Karlsruhe university, Germany [1]. Second type of measurement is the road testing with a pulled tyre. Here the tyre is moved on the road in a trailer or a truck [2-3] or a complete vehicle is pulled [4]. Estimating the parameters of the tyres for MF-tyre is standard in industry [5-6]. Often this task is covered by commercial tools. In this paper, the approach of measuring with a trailer and of identifying the tyre parameters with in-house developed tools is used. These two topics, measuring the tyres and parameter estimation, are described in the first chapter of the paper “Getting the Tyre Parameters”.

Next chapter “Tyre Characteristics” in this paper will deal with the different tyre characteristics of the several tyres on different surfaces. Comparisons of a tyre on different surfaces can be found in literature e.g. in [3] and [7]. Software-in-the-Loop simulation (SIL) and validation of the tyres is described in the next chapters “Software-in-the-Loop Simulations” and “Validation of the Results”.

Last chapters “Generic Tyre Parameters” and “Application of the Method” will deal with the generic tyre model and its applications [8-9]. This approach will be explained in detail in this paper. The main idea is that the characteristic of a certain tyre type on a specific surface is defined. The available friction itself is not fixed, but may vary in a certain range. So the importance lies more on the qualitative form of the characteristic than on the quantitative aspects.

GETTING THE TYRE PARAMETERS

Tyre measurements on the road are connected with higher effort than measurements in the laboratory, e.g. on a Flat Trac®. This is especially the case for low friction surfaces as snow and ice. The weather often prevents stable testing conditions. Nevertheless, overall seven different tyres could be measured during two winter seasons. They are listed in a table below. Except of the commercial winter tyre, all other tyres are intended for passenger vehicles. Tyre size, inflation pressure and vertical stiffness are listed, too. They are typical characteristics for the kind of tyre and often influence the behaviour on low friction.

Table 1. Measured tyres on a winter proving ground in Sweden.

Tyre	Size	Inflation pressure [bar]	Vertical stiffness [N/mm]
Winter tyre	205/55 R16	2.3	215.10
Winter tyre (second)	215/55 R16	2.3	221.87
Commercial winter tyre	205/70 R15	3.3	285.43
Nordic winter tyre	265/65 R17	2.6	315.28
All-season tyre	215/55 R16	2.3	214.55
Cross-country tyre	265/65 R17	2.6	312.21
Summer tyre	215/50 R17	2.3	257.33

The measurements were done with the tyre test trailer from TASS, Eindhoven, Netherlands, on a winter proving ground in Sweden (Figure 1). Three different surfaces were used, whereby tests on snow were only driven in the first winter season (Figure 2). The truck is equipped with different measurement systems, mainly for force and moment, velocity, inclination and side slip. All measurements are recorded in TYDEX format (Tyre Data Exchange, which is a standardised format for tyre measurements, [10]).



Figure 1. Tyre test trailer of TASS, Netherlands.

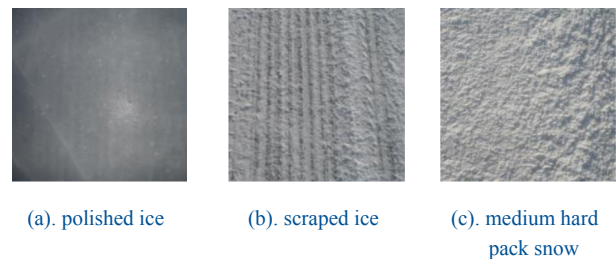


Figure 2. Different surfaces used for the winter test measurements.

Although external tools exist for getting Pacejka based parameters from measurements, an in-house solution was chosen. The first reason is that there is considerable experience existing in Ford with tyre parametrisation from Flat-Trac® measurements. Second reason is that the in-house solution should work both for the Ford internal tyre model and for MF-Tyre from TASS, Netherlands.

Some aspects of the in-house solution will be described here. Starting point for every parameterisation is the Magic Formula

$$y = D \cdot \sin \left(C \cdot \operatorname{atan} \left(Bx - E(Bx - \operatorname{atan}(Bx)) \right) \right) \quad (1)$$

The peak factor D is easy to determine as maximum. For the form factor C , a different way is proposed. Namely to use the asymptote y_a of the measured curve (Figure 3).

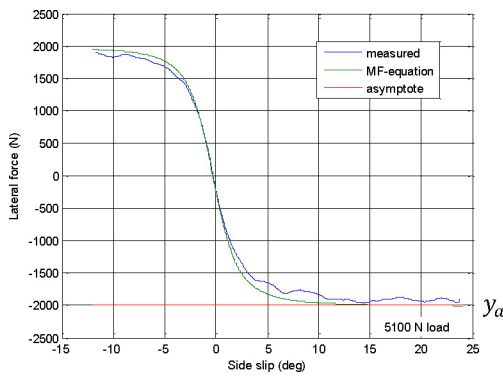


Figure 3. Getting the form factor with help of the asymptote.

When x is getting very big, the internal bracket will go to

$$\begin{aligned} \lim_{x \rightarrow \infty} \operatorname{atan}(Bx - E(Bx - \operatorname{atan}(Bx))) &= \\ &= \lim_{x \rightarrow \infty} \operatorname{atan}(Bx - E(Bx)) = -\frac{\pi}{2} \end{aligned} \quad (2)$$

under the assumptions that B is negative and $|E|$ is smaller than 1. This leads - under consideration that the sine function is not unique - to the equation for the form factor [6].

$$C = 2 - \frac{2}{\pi} \operatorname{asin} \frac{y_a}{D} \quad (3)$$

Other methods used for getting the parameters were constrained optimisations as certain values of the Magic Formula are only allowed in boundaries, e.g. $|E|$ must be smaller than 1. All further fitting is done in Matlab with bounded optimisation.

Following figure shows an example of a fitting of the second winter tyre on scraped ice for pure cornering.

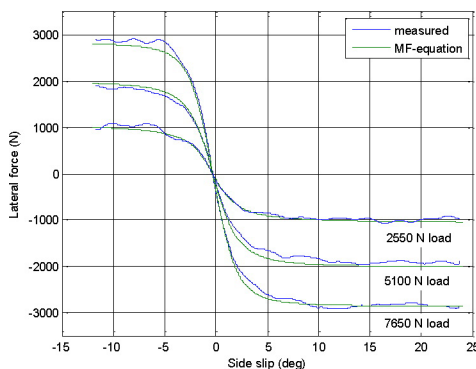


Figure 4. Fitting of a winter tyre on scraped ice - lateral force.

Same fitting is done for the aligning moment. For MF-Tyre, the pneumatic trail has to be calculated. Examples are shown in the next figures.

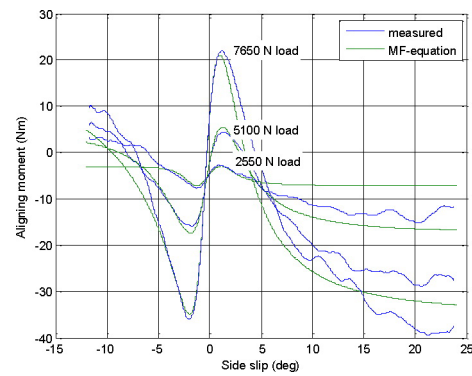


Figure 5. Fitting of a winter tyre on scraped ice - aligning moment.

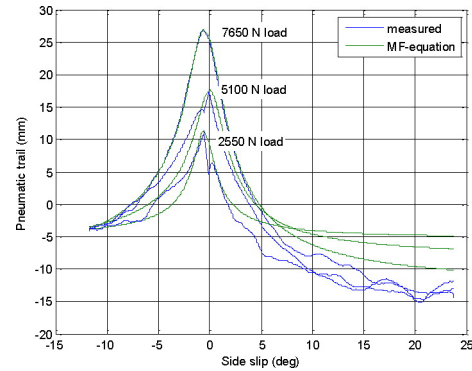


Figure 6. Fitting of a winter tyre on scraped ice - pneumatic trail.

Finally, a fitting for the longitudinal characteristic is done. This is more complex, as the measurements are done with braking manoeuvres only. For that, the trailer is driven with constant velocity. A brake pressure is increased linearly at the measured wheel until the tyre locks up. This means that also the braking resp. longitudinal force increases linearly. However this has the effect that most of the time of a measurement (about 3 seconds) the longitudinal slip stays under 5%. Only for the last time period the slip goes very quickly from 5% to 100% (about 0.2-0.3 sec). Also the maximum force has a much higher variation than for the pure cornering measurements.

Figure 7 shows as example the fitting of the second winter tyre at 5100 N load compared with measurements. The comparison of the fitted curves for different tyre types is discussed in the next chapter.

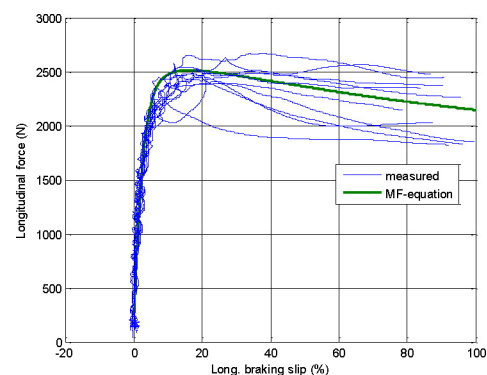


Figure 7. Fitting of a winter tyre on scraped ice - longitudinal force.