

The Delft Semi-Empirical Dynamic Tyre Model

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1 INTRODUCTION

Mathematical tyre models are used to calculate the tyre forces and moments as responses to the wheel motion with respect to the road. The model may be a part of a comprehensive vehicle model that serves to analyse the dynamic behaviour of the vehicle while running over a possibly uneven road surface. We may distinguish theoretical models based on physics of the tyre construction and empirical models which are solely based on tyre test results. Also, combinations of both approaches are used in the development of a tyre model.

The models that are in use nowadays range from very simple to highly complex descriptions of tyre behaviour. The model becomes more complex when we need to consider:

- larger magnitudes of wheel slip, requiring a non-linear description
- combined slip as opposed to pure lateral or pure longitudinal slip
- wheel camber and turn slip
- wet or icy roads making the friction coefficient dependency on speed no longer negligible
- time-varying wheel motion which requires a non-steady-state / transient tyre model
- high frequency inputs and/or high speed of travel necessitating the inclusion of tyre inertia
- short wavelength wheel oscillations and road irregularities requiring more detailed contact zone deflection considerations.

In the subsequent section a model is briefly described that has been developed at the Delft University of Technology during most of the last two decades. At TNO the model is further professionalised and managed. For further reading, one is referred to the author's book, cf. Ref.1.

2 SHORT WAVELENGTH INTERMEDIATE FREQUENCY TYRE MODEL

SWIFT is a model of relative simplicity in representing the actual physical structure of the tyre. The model, however, relies heavily on experimental evidence concerning the tyre-road slip properties, carcass compliance, natural frequencies and the rolling over road obstacles. The quasi-steady-state slip behaviour is modelled using the so-called *Magic Formula* thereby enabling the generation of slip force and moment characteristics with unmatched accuracy. For illustration the basic form of the equation is shown below for the representation of the side force F_y as a function of the side slip angle α .

$$F_y = D \sin[C \arctan\{B\alpha - E(B\alpha - \arctan(B\alpha))\}]$$

As Fig.1 indicates, D represents the peak factor and B the slip stiffness factor; C and E are shape factors. These factors are functions of amongst other things the vertical load as established through regression techniques.

To introduce transient force response properties of the tyre, one needs to include carcass compliance in the model. For higher frequency responses, inertia of the tyre is to be considered. As shown in Fig.2 the tyre belt is introduced and represented by a rigid ring that is elastically suspended to the wheel rim and connected through so-called residual springs with the contact patch. This simplification limits the model bandwidth to ca. 80Hz. Contact 'dynamic' behaviour of the contact patch, notably showing up at short wheel motion wavelengths, is represented by an approximate description of the exact frequency response characteristics of the non-linear brush model to lateral, longitudinal and turning motions of the contact patch baseline (Fig.2). Through this the wavelength of horizontal wheel motions is limited to not less than ca. 10cm. The outputs of the contact filters form the input of the quasi-steady-state slip models (*Magic Formulae*).

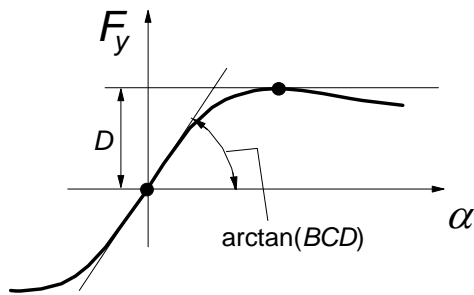


Fig.1. The tyre side force vs slip angle characteristic as generated by the *Magic Formula*.

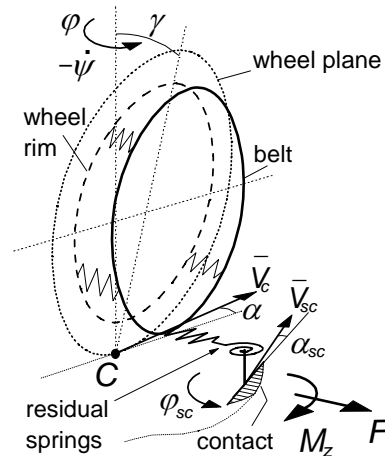


Fig.2. *SWIFT* model structure.

Rolling over road unevennesses is accomplished through the introduction of the so-called effective road plane that is defined by vertical positions of a 2-d tandem of oval cams, Fig.3, or a 3-d multiple set of cams that move over the actual, possibly sharp edged surface. Figure 4 shows example results of measured and simulated axle force and wheel speed responses to road cleats.

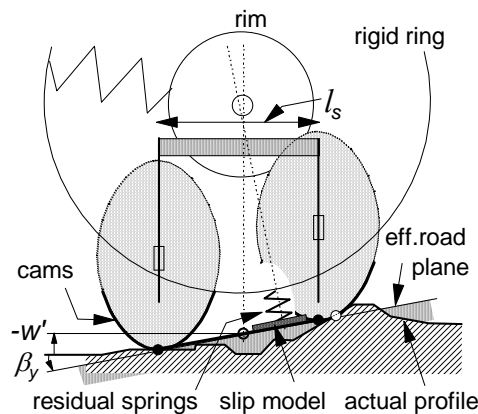


Fig.3. Road feeler with effective road plane.

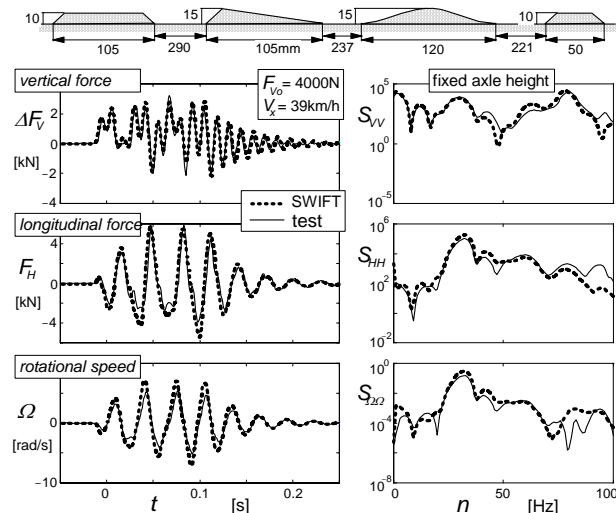


Fig.4. Model/test results for tyre running over series of cleats mounted on 2.5m drum.

REFERENCE

1. Pacejka, H.B. : *Tyre and Vehicle Dynamics*. Butterworth-Heinemann, SAE, 2002/2006.