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TRIP-ID: A tool for a smart and interactive identification of Magic Formula tyre model parameters from experimental data acquired on track or test rig

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ABSTRACT

Tyres play a key role in ground vehicles' dynamics because they are responsible for traction, braking and cornering. A proper tyre-road interaction model is essential for a useful and reliable vehicle dynamics model. In the last two decades Pacejka's Magic Formula (MF) has become a standard in simulation field.

This paper presents a Tool, called TRIP-ID (Tyre Road Interaction Parameters IDentification), developed to characterize and to identify with a high grade of accuracy and reliability MF micro-parameters from experimental data deriving from telemetry or from test rig. The tool guides interactively the user through the identification process on the basis of strong diagnostic considerations about the experimental data made evident by the tool itself. A motorsport application of the tool is shown as a case study.

1. Introduction

In the last few decades, electronics and informatics ground-breaking development has overwhelmed every scientific and industrial field.

The availability of increasingly powerful computers and sophisticated software has drastically reduced the processing time for complex mathematical models, offering a valid and unique support to engineers.

This revolution had a deep impact on ground vehicles R&D and riding experience: computer simulation of vehicle dynamics models allows predicting and analysing their performances and behaviour before building a physical prototype [1]. This led to a more efficient and less expensive designing process, reducing time-to-market and increasing products quality. On the other hand, there has been a massive diffusion of control systems for breaking (ABS and EBD), traction (TCS) and stability (ESP) [2,3] and of smart and intelligent subsystems for vehicles, in particular smart tyres [4–6], which brought to a great improvement in ground vehicles safety.

Simulation software packages and control systems require a mathematical model of the vehicle as much accurate as possible to act properly. *Multi-body* systems, constituted by several sub-systems representing vehicle's main dynamic compo-

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nents, are conceived and optimized for this task. Each sub-system is a structure of algebraic or differential equations with his own constants, variables and boundaries [7,8].

In this context tyre-road interaction mathematical models cover a fundamental role because it is through the *contact patch* that the forces ruling vehicles motion and trajectory are exchanged: longitudinal and lateral tangential forces are respectively responsible for driving (or braking) and turning the vehicle.

The characterization of this sub-system is quite difficult and delicate because tyre forces show a complex and strongly nonlinear dependence on slip ratio, slip angle, camber angle, vertical load, tyre structure, inflation pressure, inner and surface temperature, wear [9–12]. Road conditions and properties are very relevant too [13].

The most commonly used tyre-road interaction model in handling simulations is *Pacejka's Magic Formula (MF)* [9] because it offers a remarkable compromise between accuracy in reality's representation and relatively low computational burden.

The development of this semi-empirical model was accomplished by TU-Delft and Volvo, resulting in the following basic expression:

$$y(x) = D\sin[C\ arctan\{Bx - E(Bx - arctan\ Bx)\}]$$

with

$$Y(x) = y(x) + S_v$$

$$x = X + S_h$$

where:

$Y(x)$ output variable $(F_x, F_y\ or\ M_z)$;
X input variable (slip ratio or slip angle);
B stiffness factor;
C shape factor;
D pick value;
E curvature factor;
S_v vertical shift;
S_h horizontal shift.

These six coefficients are known as *Pacejka's macro-parameters* and define Pacejka's curve shape (Fig. 1).

Each *macro-parameter* is a polynomial (linear, quadratic, trigonometric, exponential) function of tyre's state (mainly vertical load and camber angle), combining several *micro-parameters* with a more or less clear physical meaning. During the last years, TNO automotive published several versions of *MF* connecting *macro-* and *micro-* coefficients [14]. The version 6.2, used in this paper, offers a good representation of tyre forces both for low and for high values of camber angles, so it is adequate both for cars and for motorcycles applications.

The main expression is the same both for longitudinal and for lateral force, but micro-parameters combinations are quite different and lateral interaction formulation is much more complex and articulated than longitudinal one. Furthermore, this expression refers only to pure interaction:

- *Pure longitudinal force* is applied to the tyre when there is slip ratio with no slip angle (velocity vector lies on the wheel's symmetry plane). This is the case of a vehicle moving straight forward.
- *Pure lateral force* is applied to the tyre when there is slip angle with no slip ratio. This happens when the vehicle is turning and the wheel is in a condition of pure rolling (total absence of driving/braking torques).

The main working condition of a tyre is known as *combined*: tyre-road tangential force has both longitudinal and lateral components respect ISOW reference frame and tyre's kinematic state consists of both slip ratio and slip angle. In combined conditions, longitudinal and lateral forces are lower than their pure corresponding, this is the reason why the MF pure model is reduced with a proper hill function known as "Pacejka's cosin version Formula" (see Fig. 2) [5].

The whole model (v.6.2) involves more than sixty parameters. A full *Pacejka's parameters set* should well represent the behaviour of a specific type of tyre (with its own geometry, shape, structure, compound) on a specific rough road. To get a *proper* set it is required an identification process on measured data. As a matter of fact, this is not a simple fitting problem because of the great amount of variables and of the strong complexity of the system.

In bibliography, it has been possible to find various examples of approaches adopted in order to solve the problem of Magic Formula model parameters identification from bench and outdoor data: in [15] the authors propose a method to identify the sole Pacejka's scaling factors, in [16] a novel approach, called TS (two-stage) is described and applied to particular manoeuvres, highlighting the sensitivity of stiffness parameters. In [17] a regression method from measured bench data to derive MF coefficients is proposed, with the limit that the technique requires a set of starting values to work on and a robust base of experimental data; in [18] a solution employing Genetic Algorithms is described with the aim to define a starting population of possible values of the parameters chosen in a proper range. The results show good fitting comparing curves with experimental bench data related to pure tyre interaction. In [19] the authors propose an updated version of the methodology, less dependent from the parameters starting set. In [20,21] an Extended Kalman Filter is used to identify lateral pure