From Real to Virtual Tyre
Tyre Model Parameterisation

The simulation of driving dynamics has to meet highest demands regarding model accuracy and reliability of the prediction results. Hence complex handling tyre models are used, which must be parameterised based on highly accurate tyre measurements. At IABG, a modern flat track tyre test stand is methodically integrated into the parameter generation process, from the creation of the test procedure up to model parameter update.

1 Introduction

An integral component of the modern tyre development is the highly precise measurement of tyre characteristics and the enhancement of test methods on tyre test stands. Compared to conventional tyre measurement, modern flat track tyre test stands offer significant advantages regarding the reproduction accuracy of the tyre-surface contact, the potential operational range and the flexibility during the test procedure preparation.

In the vehicle and tyre manufacturing industry the trend to shift complex tyre development loops from the real on-the-road testing to virtual prototypes and simulation can be observed at an increasing level. High model accuracy in particular of the tyre model, required for the analysis of the tyre effect on driving dynamics and comfort, is presupposed and can so far not be sufficiently guaranteed by the conventional tyre measuring methods. Thus roller drum test facilities possibly offer costs advantages; however, the changed shuffle geometry can only insufficiently represent the conditions between tyre and road. Measurement trailers, however, reveal deficits concerning the reproducibility due to constantly changing environmental conditions such as temperature and friction values. However, by integrating the flat track tyre test stand, driving dynamic parameters of the tyre can be obtained reproducibly and correlations between subjective and objective model criteria can be identified.

As substantial part of the tyre development process for various vehicle and tyre manufacturers a consistent process for tyre characterisation was established by IABG, with which tyre data for driving dynamics related applications are generated and consistently tailored to the requirements of the driving dynamics simulation. This article provides an overview of the test stand design, the measuring method, the data preparation and the parameter fitting of a Magic Formula [1] tyre data record using the parameter fitting programme MF-Tool [2].

2 Tyre Data Generation Process at the Flat Track Tyre Test Stand

The schematic view in **Figure 1** is supposed to illustrate the process described, based on flat track tyre test stand measurements. The measurement data are processed and used as an input to the parameter fitting procedure. The parameter fitting routine generates a tyre parameter dataset, which is used in offline and real time simulation models.

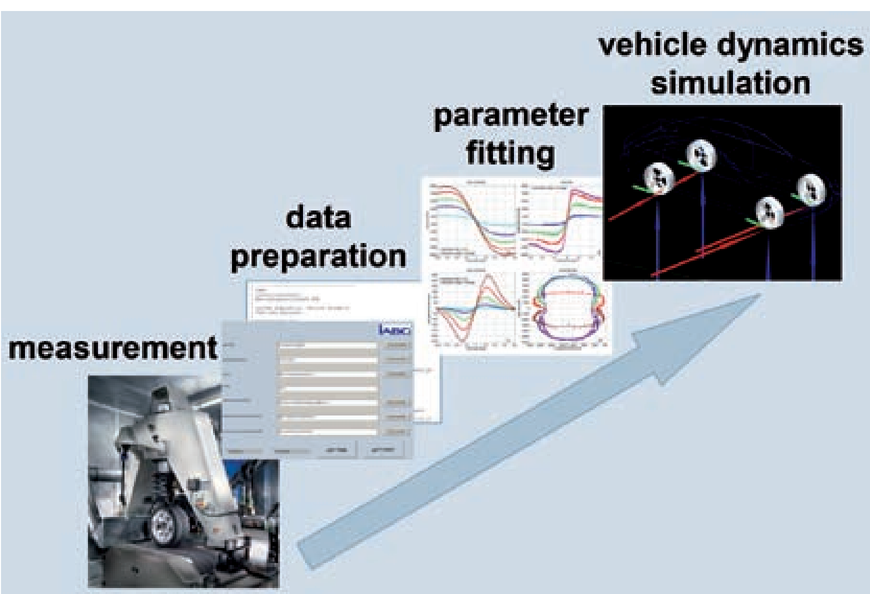

Figure 1: Schematic view of tyre data generation process for driving dynamics simulation purposes

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Table 1: Specifications flat track tyre test stand [3]

Maximum settings	Quantity	Accuracy	Unit
Tyre outside diameter	910	± 0,25	mm
Tyre width	450	± 0,25	mm
Speed capacity	250	± 1	km/h
Spindelspeed speed	3500	± 12,5	rpm
Wheel torque	2800	± 20	Nm
Slip angle	± 30	± 0.01	deg
Sweep rate	50	± 1	deg/s
Inclination angle	-12 to 45	± 0.01	deg
Sweep rate	5	± 0.1	deg/s
Vertical load	25000	± 1 %	N
Movement speed	300	± 3	mm/s
Tyre inflation pressure	700	± 3	kPa
Maximum measured values	**Quantity**	**Accuracy**	**Unit**
Longitudinal force Fx	10000	± 1 %	N
Lateral force Fy	15000	± 1 %	N
Overturning moment Mx	10000	± 1 %	Nm
Aligning torque Mz	3000	± 5	Nm
Wheel torque Tw	2800	± 20	Nm

3 Design of the Flat Track Tyre Test Stand

The modern flat track tyre test stand [3] operated by IABG allows the measurement of passenger car tyres, motorcycle and motoring tyres, respectively. The test stand enables operation up to a speed of 250 km/h and copies driving manoeuvres (wheel load, slip angle, camber angle, driving/braking) high-dynamically, **Table 1**. Apart from the kinematical tyre control the test stand offers the possibility of exerting forces and moments in a force-controlled manner as target data during test runs, which are obtained via six degrees-of-freedom force test hubs.

The tyre runs on an about 0.7 mm thick stainless steel strap, which can be coated with varyingly rough surfaces. Under the strap there is a hydrodynamic water reservoir, which absorbs the wheel loads and thus guarantees a plane contact area kept at a moderate temperature. The tyre pressure is controlled during the tests. By using adapter systems positioning off sets are compensated. Thus all standard vehicle rims can be used. The tyre forces and moments are obtained via a multi-component load cell. A separate engine powers and brakes the wheel.

The measurements are obtained under laboratory conditions. Interfering factors such as fluctuations in friction and temperature are hence minimised. The air temperature in the test chamber is held at 23 °C. The test chamber is also used for the preconditioning of the tyres. The metal band bonding has to meet highest qualitative demands (macro and micro roughness, tyre wear, speed resistance). The required roughness of a dry road is guaranteed with a special finishing procedure, which was validated in pre-tests with a friction value measuring method. Thereby the prerequisites for reproducible measurements are fulfilled, which are required for a continuous development process.

4 Measuring Method and Measurement Procedures

The following aspects are to be considered during the preparation of measurement procedures:
- development objectives (traction, braking distance, directional stability, etc.)
- tyre model
- measured variables

Table 2: Measurement plan for the determination of the Magic Formula parameters

Test Programme Passenger Car				
Spindeldrive attached			Free rolling	
Driving	Braking	Driving/Braking		
Tyre 1	Tyre 2	Tyre 3	Tyre 4	Tyre 5
Warm up/Tyre conditioning				
Setup Tuning Set				
Pure longitudinal	Pure longitudinal	Pure longitudinal braking FZ,max	Sideforce	Springrate
Longitudinal/lateral FZ,1	Longitudinal/lateral FZ,1	Longitudinal/lateral FZ,max	Sinsweep	
Longitudinal/lateral FZ,2	Longitudinal/lateral FZ,2	Pure longitudinal driving FZ,max	Vertical Stiffness	
Longitudinal/lateral FZ,3	Longitudinal/lateral FZ,3	Longitudinal/lateral FZ,max		

Table 3: Input data for the Magic Formula parameter fitting

Measured channels for Magic Formula		
Channel	**Description**	**Unit**
MEASNUMB	Measurement point number	–
SLIPANGL	SA Slip angle	rad
INCLANGL	IA Inclination angle	rad
LONGSLIP	SR Longitudinal slip	%
FX	FX Longitudinal force	N
FYW	FY Lateral force_ISOW	N
FZW	FZ Vertical force_ISOW	N
MZW	MZ Aligning torque_ISOW	Nm
MXW	MX Overturning torque_ISOW	Nm

– range of capacity of the test stand
– tyre temperature
– tyre wear
– test sequence.

From this a measurement plan can be generated as a sequence of specified operational conditions. The actual test sequence is foregone or followed by conditioning sequences (for example warm up or cool down). With the Magic Formula measurement procedure particular attention must be paid for example to keeping constant the factors of influence tyre wear and tyre temperature.

In **Table 2** a standardised Magic Formula measurement plan is displayed. For the total measurement campaign five tyres are required. The tyres one to three are applied for manoeuvres with driving and braking slip. Tyres four and five are provided for free rolling measurements.

In the single measurement routines the respectively operational conditions (wheel loads, speed, slip angle and camber angle, longitudinal slip, pressure) are initiated. The measurement routine "pure longitudinal" for example records the dependency of these quantities upon the longitudinal slip. For one pressure and one speed thereby 15 various operational conditions are necessary. The total measurement for a tyre parameter record requires altogether about 200 individual measuring processes.

Four various normal force levels are also evident in Table 2. The first three vertical force levels are typically determined (for example 800 N, 3200 N and 4800 N), in order to guarantee a direct comparability between various measurement procedures and measurement campaigns. The fourth vertical force level, marked "max", is variable and related to the type of tyre. It is obtained prior to the determination of the measurement procedure iteratively at the test stand. The objective is to collect working range data of the tyre as completely as possible.

Despite extensive elimination of factors of influence in view of a reproducible fitting process it became clear that repeated measurements are essential for parts of the measurement campaign. This particularly applies for complex operational ranges (for example transition adhesion, sliding).

The selection of the measuring channels which can be recorded and their sampling rate is adapted individually in view of the dynamic effects of interest and the handling of the resulting file sizes. Normally 32 measured variables are currently recorded at a sampling rate of up to 1 ms. **Table 3** displays the channels necessary for the parameter fitting.

5 Conversion and Evaluation Software

Only by applying suitable conversion and evaluation software the flat track tyre test stand turns into a high-power development platform. It represents the link between measurement raw data, simulation and tyre development. For this purpose IABG has developed a modular programme environment under "MATLAB", which is provided with a graphical user interface. The software accesses both the test control files (inputs) and the created measuring data files (output). Thus a comprehensive interpretation and documentation of test results is ensured.

Flexible adaption and standardisation of recurrent functions is provided. Further functionalities are also available, from automated measuring data storage up to the measurement report preparation. As a result for example "TYDEX" compatible data [4] are available.

The total data conversion process is recorded and documented by the evaluation software. From this results a transparent documentation of the time raw data post-processing. User entries are recorded amongst other data applied sequencing programmes as well as all control parameters and filter settings.

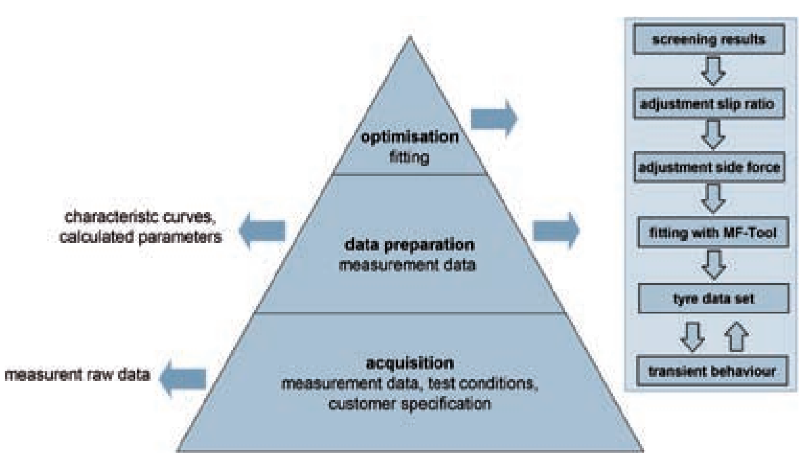

Figure 2: Sequence measurement data recording, processing and parameter optimisation

The functionalities of the IABG data converter regarding the parameter fitting process with MF-Tool are represented as follows:
- conversion and export of the individual measurement in "TYDEX" format (header, data and parameter range)
- digital filtering of the measured variables
- detecting and cutting of analysis-relevant measuring ranges
- separating and combining of individual measurements
- measurement analysis of special parameters (vertical tyre stiffness, kinematical rolling radius, "pre"-relaxation lengths)
- transformation of coordinates
- selection of measuring channel
- control and result plot preparation
- conversion report.

The conversion and evaluation process is represented in **Figure 2**.

6 Aspects to be Considered in the Fitting of a Magic Formula Dataset

Using individual data preparation steps it is shown, how the parameter fitting programme MF-Tool is embedded into the parameter fitting process, Figure 2.

At the beginning the prepared measuring data need to be validated; each measurement is checked regarding its usability as well as its range of validity. If necessary individual measurements are not being used and/or their range of validity is limited. The classification of measurement data is carried out on a half-automated basis, that is the analysis programme obtains a proposal for the measurement preparation. This must be acknowledged or corrected by the user in each case, **Figure 3** a and b.

The base factor for the filtering and representation of the measured variables (forces, moments) is the longitudinal slip of the tyre. The indirect determination procedure [5] of the longitudinal slip at the test stand bears a systematic inconsistency, that is slip-dependant measured variables do not indicate their origin at longitudinal slip zero. According to the model concept that longitudinal slip equivalent parameters, that is the longitudinal force also show zero values, vertical-force-dependant offset adjustments are being made, Figure 3 b and c. The required adjustments typically lie in a range of up to 3 %.

Additionally the measured lateral forces affecting the wheel must be adapted in the view of a consistent data evaluation: Adaption of the measured lateral forces in case of combined slip on the lateral forces with pure slip angle. This is due to the model concept that the combined load case can be transferred to the non-combined load case in each case. This procedure guarantees a consistent data collection of the drop in lateral force dependent on the longitudinal force and thereby provides more accurate longitudinal force sensitivity in the vehicle model simulation. The necessary lateral force adjustments lie in the range of up to 4 % of the respective normal force level, Figure 3 d and e.

Beyond the fitting of the quasi-stationary tyre parameters a precise alignment of the dynamic force response is important in longitudinal and lateral direction. Magic Formula contains a dynamic analogous model in form of a first-order (PT1) lag of deformations, which requires a special weighting of the measurements for the relevant operational range of the tyre. Decisive factors here are speed, vertical force, steering angle frequency and steering angle amplitude. The determination of these parameters is achieved via simulation of the tyre parameters set generated up to this point. The optimisation of the lateral force behaviour is for example affected using the sinus steering manoeuvre (Table 2: sine sweep) under specification of the steering angle, Figure 3 f.

7 Summary

The use of the ultra-modern flat track tyre test stand includes the vision to promptly provide the vehicle development process with a tyre which is already "fit for operation" with the required driving and handling characteristics. With the test stand qualitatively and quantitatively tyre measurements can be carried out under reproducible conditions, which form the starting point for the generation of tyre model datasets for the driving dynamics simulation.

Apart from the measurement equipment the measurement and evaluation methodology is of crucial importance for the generation of Magic Formula parameters. In the measurements for example abrasion and temperature influences are compensated and relevant operational driving dynamics conditions are covered.

Comprehensive evaluation software is used for the processing of the measuring data. It guarantees the preparation and optimisation of measuring data for the fitting.

Using the example of the commercial programme MF-Tool [2] the parameters for the Magic Formula tyre model [1] are determined from the pre-processed measurement data, **Figure 4**.

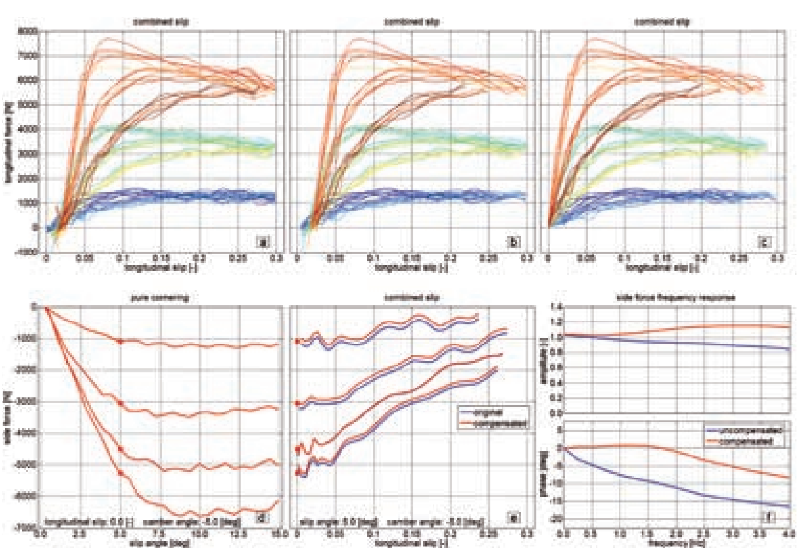

Figure 3: Schematic view of the measuring data preparation for the parameter fitting

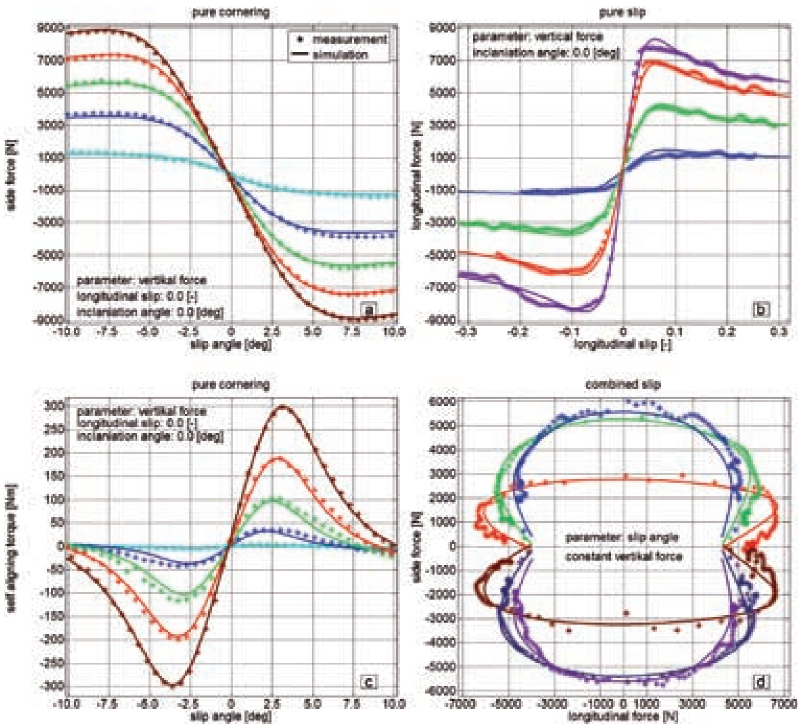

Figure 4: Exemplary result representation of a fitted dataset

8 Future Prospects

In the future tyre development it must be assumed that the tyre parameter identification procedure (for example also fitting and analysis) will increasingly be outsourced to tyre manufacturers or service partners after validation and standardisation of the test procedures. That means that in addition to the actual tyre, the tyre manufacturers have to provide the respective tyre model data or tyre parameters.

By using the flat track tyre test stand in the evaluation environment described, tyre and vehicle manufacturers and engineering partners can save costs and above all development time. Tyre measurements on a flat track tyre test stand will be standard in the future, to make results of measurement and tyre model parameters comparable. Apart from the determination of data for the simulation, tyres can be characterised and compared. Beyond that driving dynamics manoeuvres can be copied and the capacity of tyres in threshold ranges can be analysed.

In the context of a consistent development of the application range blow bar tests and footprint measurements are already accomplished at the flat track tyre test stand. These fulfil – amongst other things – the purpose to determine parameters for tyre models from the comfort division as for example "RMOD-K" [6] or "FTire" [7]. The conversion and evaluation software is enhanced with the target to supply consistent parameter datasets also for comfort tyre models at the push of a button.

References

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