Validation of Tyre Force Estimator
TNO in a Nutshell

- TNO is the Netherlands’ Organization for Applied Research
- 75 76 years of experience
- Independent R&D organization
- 5,000 employees world-wide
- HQ in Delft, the Netherlands
- Annual turnover approx. 550 M€
Contents

- Background
  - Why use vehicle motions for tyre assessment
- Tyre Force Estimator method and tool
- Validation results
- Summary
Challenges for assessment of tyre slip characteristics

- Tyre characteristics depend on operating conditions
  - Road texture, Road curvature, Tyre temperature, Speed, etc...

- Benchmarking/Ranking of tyres important for design choices in tyre development and in vehicle setup but ranking on tyre test equipment not always consistent!

- Relation between subjective vehicle assessment and tyre characteristics more important then tyre performance assessment

- Existing tyre testing methods laborious, costly, inflexible, etc...
Advantages of using vehicle motions

- Limited vehicle instrumentation
- Assessment for actual vehicle operating conditions (surface, speed, thermal load, ...)
- Easy change of tyres, can be combined with subjective evaluation
- Fast and cost effective!

Prerequisites for success:

- Not dedicated to one specific vehicle
- Sufficient accuracy for ranking and basic tyre model parameter assessment
- Easy data processing
Tyre Force Estimator method

1. Time histories of tyre forces and slip angle
   - Evaluation for specific conditions (e.g. exertion of friction potential in curves)
   - No specific test protocol required

2. Tyre characteristics
   - Tyre comparison in terms of basic characteristics
   - Dedicated test protocol
State Estimator concept

including:
Tyre forces
Slip angles
Example: Friction estimation

Estimated friction value

ice/snow transition
Tyre Force Estimator tool

- Step 1: Define vehicle & sensor parameters
Tyre Force Estimator tool

- Step 2: Load measurement data
Tyre Force Estimator tool

- **Step 3: Run State Estimator**
Tyre Force Estimator tool

- Step 4: Fitting of Magic Formula parameters
Validation

1. Dedicated measurement with vehicle equipped with wheel force transducers
2. Comparison of time histories of measured forces and estimated forces
3. MF-Fit of measured forces
4. MF-Fit of estimated forces
5. Comparison of force versus slip characteristics
Comparison of time histories
Mini-Hockenheim @ Papenburg

- Front slip angle
- Rear slip angle
- Front lateral force
- Rear lateral force
Comparison of Magic Formula fit of measurement and estimation: Circular test

Front axle  Rear axle
Comparison of Magic Formula fit Slalom test

Front axle  Rear axle
Comparison of Magic Formula fit
Spiral test (severe under steer)

Front axle

Rear axle
Some additional results...

- Low friction
Some additional results …

Effective cornering stiffness @ 5 inflation pressures

Suspension influence

Ranking is the same
Tyre estimator Way of Working

- Perform set of standard test track tests
  - Straightforward set of tests is supplied (steady-state circle, etc.)
  - Log ESC sensor data and ground speed

- Use State Estimation to calculate tyre forces

- Use MF-tool to fit tyre characteristics
  - Result is combination of tyre and suspension characteristics
Tyre estimator applications

- Tyre estimator identifies combination of tyre and suspension characteristics
  - Optimisation of tyre and suspension settings
    - tyre type, inflation pressure, tyre wear influences, speed effects, different road surface conditions
    - Suspension adjustment, camber, stabiliser, etc
  - Lap time evaluation
    - Time history of forces
    - Driver feedback
  - Subjective/objective studies
    - Relate driver assessment to estimated characteristics (of combination of suspension and tires!)
  - Input for simple vehicle model (e.g. bicycle model) or control system tuning
Conclusion

- Tyre forces can be estimated from vehicle motions using a State Estimator approach

- The method for tyre force estimation is proven for different vehicles on various road surfaces

- Ranking capability is proven

- The method can be applied using little vehicle instrumentation, simple driving tests and processing is supported with a GUI tool
Current developments

- Truck tyres
- Racing application
- Integration with sensor systems
- Application as a check on tyre condition during vehicle testing
- ....