Testing Facilities
Institute of Vehicle System Technology – FAST

Karlsruhe, September 2018
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Institute of Vehicle System Technology - FAST
Structure

Chair of Vehicle Technology

Passenger Cars & Trucks
LFF
Prof. Dr. rer.nat. Frank Gauterin

Mobile Machines
MOBIMA
Prof. Dr.-Ing. Marcus Geimer

Rail Vehicle Systems
BST
Prof. Dr.-Ing. Peter Gratzfeld

Safety

Energy Efficiency

Drivability

Cost

Light Weight Technology
LB
Prof. Dr.-Ing. Frank Henning
Flat Track / External Drum Test Bench
Technical Data

Measurement of Rolling Resistance

Outside diameter of the drums
- 2,00 m
- 1,71 m

Top speed
- on the drums 300 km/h
- on the flat surface 250 km/h

Camber angle -10° ... +10°

Slip angle -5° ... +5°

Measuring system for rolling resistance
6 component measuring system:
Max. vertical force 10.000 N
Max. lateral force, longitudinal force 1.000 N
Max. overturning torque 1.200 Nm
Max. aligning torque 300 Nm
Max. driving torque 30 Nm
Flat Track / External Drum Test Bench
Rolling Resistance Measurements

- Measurement of rolling resistance versus time, variation of velocity

<table>
<thead>
<tr>
<th>Time/ Minutes</th>
<th>50 km/h</th>
<th>90 km/h</th>
<th>120 km/h</th>
<th>150 km/h</th>
<th>180 km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal Force / N</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>30</td>
<td>25</td>
<td>20</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>10</td>
<td>20</td>
<td>15</td>
<td>10</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>15</td>
<td>10</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>30</td>
<td>10</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>40</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>50</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>60</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>70</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>80</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>90</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

- Reifen-Nr.: 1
- Reifengröße: 195/65 R 15
- Luftdruck: 2.9 bar
- Radlast: 80 % ETRTO
- Umgebungstemp.: 25 °C
Measurement of rolling resistance on different curved track surfaces on a combined flat track external drum test bench.

Influence of driving velocity on the rolling resistance for different track surface curvatures.
Internal Drum Test Bench
Technical Data

Inside diameter of the drum: 3.80 m

Track surfaces:
- Safety Walk
- Diverse concrete surfaces
- Diverse asphalt surfaces

Top speed:
- on Safety Walk: 200 km/h
- on asphalt / concrete: 150 km/h

Water film depth: 0 ... 4 mm

Ambient temperature: -20 ... +30 °C

Slip angle: -20° ... +20°

Camber angle: -10° ... +20° (+30° ... +45°)

Max. Tyre Radius: 480 mm
Max. Tyre Width (Contact-Width): 330 (270) mm

Measuring system for frictional force behaviour:

Rotating 6 component measuring system:
Max. vertical force, lateral force, longitudinal force: 15 kN
Max. driving torque, overturning torque: 5.500 Nm
Max. aligning torque: 1.500 Nm
Internal Drum Test Bench
Overview of Measurements

- **Test Methods**
  - Longitudinal force versus slip
  - Lateral force and aligning moment versus slip angle
  - TIME procedure
  - Tire comfort measurements (rolling over cleats)

- **Variation of ambient conditions**
  - Different track surfaces (safety walk, asphalt, concrete)
  - Dry, wet, snow and ice surfaces
  - Variation of ambient temperature
  - Different types of cleats
Internal Drum Test Bench
Installable Tracks

Analysis of the influence of
• different composites of the track
• different textures of track surface
for example:
• Safety-Walk
• asphalt
• concrete
on the frictional behavior of tires on wet and dry roadway.

Variation of skid resistance, tests on humid track surface
Internal Drum Test Bench
Longitudinal Force Measurements

Longitudinal slip / %

Longitudinal force / N

Lateral force / N

Manufacturer:  [Manufacturer Information]
Tyre size: 5.5 x 15
Rim size: 5.5 x 15
Velocity: 100 km/h
Inflation pressure: 2.1 bar
Slip angle: 0°
Waterfilm depth: 0 mm
Vertical force: var.

Manufacturer: [Manufacturer Information]
Tyre size: 7.5 x 16
Rim size: 7.5 x 16
Velocity: 40 km/h
Inflation pressure: 2.2 bar
Camber angle: 0°
Waterfilm depth: 0 mm
Vertical force: 4800 N
Internal Drum Test Bench
Measurements on Wet Track Surface

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Tyre size</th>
<th>Rim size</th>
<th>Velocity</th>
<th>Inflation pressure</th>
<th>Slip angle</th>
<th>Waterfilm depth</th>
<th>Vertical force</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>6.0 x 15</td>
<td>80 km/h</td>
<td>2.6 bar</td>
<td>0°</td>
<td>0 / 0.2 / 2 mm</td>
<td>var.</td>
</tr>
</tbody>
</table>
Internal Drum Test Bench
Measurements on Snow and Ice Surfaces
Lateral traction determined in 2 cycles by varying the slip angle.
Longitudinal traction performance is determined within one drum turn to avoid rolling over of iced surfaces.
On tracks with low hardness, high traction forces can be transmitted under high slip. Distinctive force maximum on hard packed snow and ice.
Internal Drum Test Bench
Measurements on Snow and Ice Surfaces

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Tyre size</th>
<th>Rim size</th>
<th>Inflation pressure</th>
<th>Velocity</th>
<th>Slip angle</th>
<th>Track surface</th>
<th>Ambient temperature</th>
<th>Vertical force</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>6.5 x 15</td>
<td>2.4 bar</td>
<td>80 km/h</td>
<td>0°</td>
<td>Ice</td>
<td>-10 °C</td>
<td>variable</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Tyre size</th>
<th>Rim size</th>
<th>Inflation pressure</th>
<th>Velocity</th>
<th>Slip angle</th>
<th>Track surface</th>
<th>Ambient temperature</th>
<th>Vertical force</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>6.5 x 15</td>
<td>2.4 bar</td>
<td>80 km/h</td>
<td>0°</td>
<td>Ice</td>
<td>-10 °C</td>
<td>6000 N</td>
</tr>
</tbody>
</table>
Internal Drum Test Bench
Measurements with the TIME Procedure

Adjustment of certain parameter combinations
(constant for 3 sec)

Measurement point / -

Slip angle / °

0 5 10

0 50 100

H-Axis-System

Measurement of tire forces
at adjusted parameter combinations

Measurement point / -

Lateral force / N

0 50 100

0 50 100

Vertical force

0 1000

Manufacturer Identity Tyre size Rim size Velocity Inflation pressure Inclination angle Waterfilm depth Vertical force

Manufacturer Identity Tyre size Rim size Velocity Inflation pressure Inclination angle Waterfilm depth Vertical force

: 7 x 16

: 40 km/h

: 2.4 bar

: var.

: 0 mm

: var.

: 7 x 16

: 40 km/h

: 2.4 bar

: var.

: 0 mm

: var.
Internal Drum Test Bench
Measurements for Tire Comfort Models

- Rolling over Cleats

Changeable Pavement and changeable cleats
Internal Drum Test Bench
Measurements for Tire Comfort Models

- Measurement of Forces and Moments

![Graphs showing measurements of forces and moments](image)

- Manufacturer: 
- Tyre size: 
- Form of cleat: 
- Vertical force: 4.000 N
- Velocity: 100 km/h
- Inflation pressure: 2.2 bar
- Slip angle: 0°
Inner Drum Test Rig
Determination of the Magic Formula Coefficients

Lateral force versus slip angle
Longitudinal force versus longitudinal slip
Inner Drum Test Rig
Equipment for Determination of Tire Envelopes

- Measurement under Real Driving Conditions at Internal Drum Test Bench
Inner Drum Test Rig
Equipment for Determination of Tire Envelopes

- wheel suspension
- gear wheel
- stepper motor
- cameras and laser for tread
- camera and laser for sidewall/mirror
- balance weight
- 15kN measuring hub
- tire
- balance weight
- gear wheel
- stepper motor
- cameras and laser for tread
- camera and laser for sidewall/mirror
- balance weight
- 15kN measuring hub
- tire
Inner Drum Test Rig
Equipment for Determination of Tire Envelopes

- Light Section Triangulation Method

![Diagram of Inner Drum Test Rig](image)
Inner Drum Test Rig
Equipment for Determination of Tire Envelopes

- **Measurement under Real Driving Conditions at Internal Drum Test Bench**
  - Non-contact measurement of tire contour
    - under real (even extreme) driving conditions
    - on real track surfaces
  - with measurement of tire forces and moments at the same time.

Measured tire contour for several load and slip angle conditions.
Inner Drum Test Rig
Setup for Acoustic Test

1. Drive shaft is decoupled mechanically by elastic flexible disc.
2. Acoustic dividing wall: Subdivision of the test rig into a measuring cabin and a cabin for the power unit.
3. Solid-borne sound reduction: wheelhouse with the hydraulic motor is placed onto dampening mounting feet
4. Applying the wheel force through an electrically driven ball screw
5. Absorption modules ensuring a semi-anechoic space

Result: Reduced sound generation caused by the power unit.
Inner Drum Test Rig
Analysis of Tires Contact Forces with Triaxial Force Sensor

Contact

Triaxial Force Sensor

Top View

Telemetry
Test Equipment of FAST
Visualization of the tire tread deformation

Mobile under-floor laboratory
installed into a common drain on the street

Easy integration

Illumination with > 14,000 Lumen
Recording of tire crossing > 2,300 fps

Simple handling
Test Equipment of FAST
Visualization of the tire tread deformation

mobile under-floor laboratory

start-up carpet avoids collecting stones and dust particles by the tire during drive up

light barrier (a) activates pre-defined torque at electric vehicle automatically ⇒ reproducible tangential forces can be applied

light barrier (b) activates camera recording

fully automated
Grip- and Abrasion Test stand (GAT)

loading unit

watering unit

drive unit

water supply

water drain
Grip- and Abrasion Test stand (GAT)

- pneumatic cylinder
- shock absorber
- load cell
- rubber sample fixation
- surface sample cast
- watering unit
Grip- and Abrasion Test stand (GAT)
Facilities of FAST at Campus Ost
Buildings 70.21 & 70.22

- Vibration Test Room
- Exterior Front View
- Mechanical Workshop
- Assembly area passenger cars
- Acoustic 4WD Chassis Dynamometer
- Vehicle-In-the-Loop Test Rig

Facilities of FAST at Campus Ost
Building 70.21

- Truck lift
- Assembly area passenger cars
- Exterior view Building 70.21
Facilities of FAST at Campus Ost
Vehicle-In-the-Loop Test Rig (VEL)

Vehicle-In-the-Loop Test Rig

Technical Data:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. vehicle mass:</td>
<td>12,000 kg</td>
</tr>
<tr>
<td>Max. wheel load:</td>
<td>3,000 kg</td>
</tr>
<tr>
<td>Wheel base:</td>
<td>1.8 – 4.9 m</td>
</tr>
<tr>
<td>Track width:</td>
<td>1.2 – 3.9 m</td>
</tr>
<tr>
<td>Max. Speed (1)</td>
<td>2,000 min-1 (200...260 km/h)</td>
</tr>
<tr>
<td>Max. Torque (1)</td>
<td>2,500 Nm</td>
</tr>
<tr>
<td>Power (1)</td>
<td>209 kW</td>
</tr>
<tr>
<td>Max. Slip angle front (2)</td>
<td>+/- 20°</td>
</tr>
<tr>
<td>Max. Aligning Torque (2)</td>
<td>1,000 Nm</td>
</tr>
<tr>
<td>Max. wind speed (4)</td>
<td>135 km/h</td>
</tr>
<tr>
<td>Room temperature</td>
<td>18 ... 65°C</td>
</tr>
</tbody>
</table>

Vehicles’ wheel hubs directly connected to the dynamic operating load engines. Torques are measured close to wheel (3).

Main applications:

- Direct, dynamic street load simulation with robots (pedals and steering wheel) for power & consumption measurement,
- Powertrain characteristic at certain speeds,
- Influence of tires force characteristic, …
Facilities of FAST at Campus Ost
Acoustic 4WD Chassis Dynamometer (AARP)

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. vehicle mass:</td>
<td>56,000 kg</td>
</tr>
<tr>
<td>Max. wheel load:</td>
<td>14,000 kg</td>
</tr>
<tr>
<td>Wheel base:</td>
<td>1.8 – 4.9 m</td>
</tr>
<tr>
<td>Track width (rollers inner &amp; outer edges):</td>
<td>0.85 – 3.55 m</td>
</tr>
<tr>
<td>Max. Vehicle Dimensions:</td>
<td>18 m x 4 m x 4.5 m (LxWxH)</td>
</tr>
<tr>
<td>Nom. I max. traction force:</td>
<td>240 kN I 440 kN</td>
</tr>
<tr>
<td>Max. air flow rate</td>
<td>180,000 m³/h @ 3 m x 3 m</td>
</tr>
<tr>
<td>Max. speed</td>
<td>160 km/h</td>
</tr>
<tr>
<td>Acoustic insulation</td>
<td>hemi-anechoic room (ISO 3745)</td>
</tr>
</tbody>
</table>

Simulator for sun and heat influence.

Cross Section of Test rig implemented in Building 70.22
(Source: Dömges Architekten, Dreher)
Facilities of FAST at Campus Ost
Test Setup for Analysis of Acclimatization at AARP

<table>
<thead>
<tr>
<th>Pos.</th>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Temperature Range</td>
<td>+20°C to +50°C</td>
</tr>
<tr>
<td>2</td>
<td>Speed of air:</td>
<td>1,5 m/s bis 49,5 m/s</td>
</tr>
<tr>
<td>3</td>
<td>Size of area for air intake of condenser / motor cooler:</td>
<td>1,2 m x 0,8 m</td>
</tr>
<tr>
<td>4</td>
<td>Size of area for air intake of vehicle acclimatization system:</td>
<td>0,5 m x 0,1 m</td>
</tr>
<tr>
<td>4</td>
<td>Humidity of air for acclimatization system:</td>
<td>max. 68 kg/h</td>
</tr>
<tr>
<td>5</td>
<td>Radiation power of solar simulators (6x, each 2000 W, HQI)</td>
<td>370 W/m² bis 1050 W/m²</td>
</tr>
<tr>
<td>5</td>
<td>Size of area, which can be radiated by solar simulators:</td>
<td>2,5 m x 1,0 m</td>
</tr>
<tr>
<td>6</td>
<td>Radiation power of infrared radiators (12x, each 2000 W):</td>
<td>148 W/m² bis 1100 W/m²</td>
</tr>
<tr>
<td>6</td>
<td>Size of area, which can be radiated by infrared radiators:</td>
<td>2,5 m x 2,3 m</td>
</tr>
</tbody>
</table>
Facilities of FAST at Campus Ost
Climate chamber for small vehicles

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>-25°C to +25°C</td>
</tr>
<tr>
<td>Inner dimensions (L<em>W</em>H)</td>
<td>5.48m<em>2.28m</em>2.25m</td>
</tr>
<tr>
<td>Max. Vehicle dimensions (L<em>W</em>H)</td>
<td>3.80m<em>2.00m</em>1.65m</td>
</tr>
</tbody>
</table>
Facilities of FAST
Noise, Vibration & Harshness Tests

Analysis of

1. Seismic mass (300t)
2. Shaker
3. Power cable
4. Sensor
5. Adapter
6. Acoustic torus measurement device

Car vibration

Tire vibration

Car noise

Tire noise
Test Equipment of FAST
Noise Generation: Pass-By Measurements

Experimental Setup

a: light barrier activates pre-defined torque automatically ⇒ reproducible tangential forces can be applied
b: experimental tire @ right front; slick tires @ left side
c: microphone & artificial head: 4m distance, 1.2m height
d: very dense surface, no ISO-surface
Test Equipment of FAST
Noise & Vibration analyzed with Elastic Wheel Hub

Noise and vibrations measured by multiple triaxial accelerator sensors, microphones and 3D-Scanningvibrometer (see complete list next slide).
### Test Equipment of FAST
**NVH – Equipment**

#### Sensors

<table>
<thead>
<tr>
<th>Amount</th>
<th>Type</th>
<th>Brand</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Freefield and Diffuse Microphone 1/2“</td>
<td>B&amp;K</td>
</tr>
<tr>
<td>12</td>
<td>Freefield Microphone 1/4“</td>
<td>G.R.A.S.</td>
</tr>
<tr>
<td>4</td>
<td>Microphone – pressure type bis 180dB</td>
<td>PCB</td>
</tr>
<tr>
<td>1</td>
<td>Acoustic Head Measurement System</td>
<td>Head Acoustics</td>
</tr>
<tr>
<td>16</td>
<td>Triaxial Accelerometer</td>
<td>B&amp;K</td>
</tr>
<tr>
<td>1</td>
<td>3D-Scanningvibrometer</td>
<td>Polytec</td>
</tr>
</tbody>
</table>

#### Data Acquisition

<table>
<thead>
<tr>
<th>No. of input channels</th>
<th>Performance</th>
<th>Brand</th>
</tr>
</thead>
<tbody>
<tr>
<td>96</td>
<td>$f_{\text{Mess}}$ 25,6 kHz; 16bit</td>
<td>B&amp;K Pulse</td>
</tr>
<tr>
<td>24</td>
<td>$f_{\text{Mess}}$ 51,2 kHz; 24bit; ICP</td>
<td>NI PXI</td>
</tr>
<tr>
<td>8 (drahtlos)</td>
<td>$f_{\text{Mess}}$ 25,6 kHz; 24bit; ICP</td>
<td>NI WLS</td>
</tr>
</tbody>
</table>
Test Equipment of FAST
Test Vehicles

- smart fortwo cdi
- Mercedes-Benz C 200 cdi
- Mercedes-Benz E 220d
- Mercedes-Benz S 500 as Acoustic Test Vehicle
- Mercedes-Benz A-Class converted to a "Battery Electric Vehicle"
- Mercedes-Benz Atego 815
- Mercedes-Benz Actros 1845 LS 4x2
## Test Equipment of FAST

**Test Vehicles: Battery Electric Vehicle**

<table>
<thead>
<tr>
<th>Technical and calculated* data</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal power (max.)</td>
<td>45 kW (65 kW)</td>
</tr>
<tr>
<td>Operating distance* (NEFZ)</td>
<td>150 km (90% SOC)</td>
</tr>
<tr>
<td>Max. speed*</td>
<td>154 km/h</td>
</tr>
<tr>
<td>Charging time</td>
<td>10 h</td>
</tr>
<tr>
<td>Type of battery</td>
<td>LiFeMgPO4</td>
</tr>
<tr>
<td>Number of modules</td>
<td>21</td>
</tr>
<tr>
<td>(of cells)</td>
<td>(50p x 6s = 300)</td>
</tr>
<tr>
<td>Capacity</td>
<td>27,8 kWh</td>
</tr>
<tr>
<td>Battery nom. power (Max.)</td>
<td>48,4 kW (80,6 kW)</td>
</tr>
</tbody>
</table>
Test Equipment of FAST
Test Vehicles: Battery Electric Vehicle

Wiring diagram – Components of the electric drive train

- Low voltage
- High voltage (intern)
- High voltage (extern)

---

Charger
3.3 kW
260...520 V
max. 12.5 A

Traction battery
28 kWh
nom. 48 kW
max. 81 kW
Test Equipment of FAST
Test Vehicles: Battery Electric Vehicle

Modeling and Simulation

Model of electric powertrain

Simulation of battery electric drive

Development of vehicle control software
e.g.: software sequence for regenerative braking

Hardware modification for regenerative braking
Contact

Please feel free to contact us:

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Further information's can be found at:

http://www.fast.kit.edu/