Trends in Vehicle Performance Testing

- Safety Requirements Increasing
  - Electronic Stability Control (ESC)
- Global competition requires differentiation
  - Vehicle Handling
  - Ride Comfort
- Fuel Efficiency Standards Adoption

New regulations and globalization drive the need for new testing tools and methods.

Market Driver – Globalization

- Improving Ride Comfort
  - Key factor in customer satisfaction and purchasing decisions
  - Lower background noise from engine (EV/HEV) and steering (EPS) expose passengers to more aerodynamic and suspension acoustics in the cabin
  - Semi-Active and Active suspensions have made tuning more complex

Typical Vehicle Interior Noise Spectrum

From: Jun Lu, Passenger Car Interior Noise Reduction by Low-Impedance Side Glass, Proceedings of Inter-Noise 2002, Institute of Noise Control Engineering
Market Driver – Globalization

» Increased global competition pushes OEMs to differentiate platforms with performance

» Improving Vehicle Handling
  – Move from Suspension/Tire Characterization to more Vehicle Based Maneuver Simulation

![Tire Characterization](image)

Vehicle based maneuver simulation

![Series Information](image)

Series Information:
- Series 1: Fz = -9283 N
- Series 2: Fz = -7547 N
- Series 3: Fz = -5804 N
- Series 4: Fz = -4655 N
- Series 5: Fz = -2915 N
- Series 6: Fz = -1125 N

Market Driver – Safety Requirements

» Electronic Stability Control (ESC)
  – Active vehicle intervention for safety

» 2012 Requirement in the US on all new passenger vehicles under 10,000 lbs (4536 kg) – (FMVSS) No. 126


» OEMs need limit tire data for ESC Maneuver to go into vehicle models

» Electronic Power Steering (EPS) is increasingly used in ESC assistance
Flat-Trac® Roadway

» With a vehicle on a laboratory rig:
  – Measure static and dynamic handling performance
  – Study the effects of vertical road motion on maneuvering, vibration, and durability
Handling Roadway – Function

» Restraint in only 3 axes (x, y, yaw)
» No restraint in suspension directions
» Determine instant road acceleration and velocity
» Present correct road velocity to each tire
» Repeat fast enough to minimize simulation lag
» Measure vehicle response

The vehicle is in the loop, it reacts the same as on the real road, for all maneuvers

Handling Roadway – Features

» Flat Surface
» 230 kph
» All 3 Road Motions
» Free Suspension
» Road Speed or Road Load
» Vertical Vibration to 20 g
» Body Force Simulation System
» 6 Component Tire Force
» Autopilot
» Automated routine tests

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Handling Roadway – Applications

» Open Loop
  – Steer Step
  – Throttle Off in Curve
  – Sine Steer
  – Straight Acceleration
  – Brake in a Curve

» Closed Loop
  – Constant Radius Skid Pad
  – Constant Velocity Skid Pad

» Durability
  – Rough Road
  – Driving Cycles

Handling Roadway – Results

» Skid Pad
  – steer vs. ay
  – 40 tests repeated

» J Turn
  – Ay vs. time
  – 26 tests repeated

be certain.
Suspension Kinematics and Compliance (K&C) Deflection Measurement Systems

<table>
<thead>
<tr>
<th>System</th>
<th>Operation Limits</th>
<th>Use</th>
</tr>
</thead>
</table>
| K&C (Base System) | • Quasi-static to 5 Hz  
• 0.6 m/sec velocity | • Static K&C Tests  
• Chassis Torsional Rigidity Testing  
• Cornering Simulation  
• Time History Playout  
• Vehicle Inertia Measurement (option) |
| K&C (with Dynamic Simulation Option) | • Quasi-static to 20 Hz  
• 0.6 m/sec velocity | • Additional Capability:  
• Dynamic K&C Deflections  
• mHIL Capability  
• Lower Frequency Transient Replication |
| DK&C | • Quasi-static to 30 Hz  
• 2 m/sec velocity | • Additional Capability:  
• FRF Analysis  
• Degradation  
• Higher Frequency Transient Replication |

Dynamic Kinematics and Compliance (DK&C) Deflection Measurement System

» Functions
  - Static K&C Tests
  - Dynamic K&C Deflections
  - Frequency Response Function (FRF) Analysis
  - Degradation
  - Maneuver Analysis
  - Inertia Measurement
Dynamic Kinematics and Compliance (DK&C)
Deflection Measurement System

» Applications
  - Suspension Development
  - Benchmarking
  - Dynamic Model Verification
  - Maneuver Analysis
  - Vehicle in the Loop Maneuvering

» Benefits
  - Precision
  - Throughput
  - Flexibility

K&C Data Examples
Safer Vehicles through advances in Tire Testing

- Increased range of tire testing conditions
  - Improve models with greater range of empirical data
  - Extend range of dynamic modeling and simulation
Flat-Trac® Tire Test System

- Measure tire force and moment properties
  - data used for CAE
- Establish the tire’s contribution to vehicle dynamic performance
  - Cornering characteristics
    - Lateral Force (Fy) vs. Slip Angle
    - Aligning Torque (Mz) vs. Slip Angle
  - Camber stiffness characteristics
    - Lateral Force (Fy) vs. Camber
    - Aligning Torque (Mz) vs. Camber
  - Traction Characteristics
    - Slip ratio testing
    - Combined lateral with slip

Data used with Empirical and Analytical models.

- Controlled
- Repeatable
- Eliminates uncertainty of curved drum
- Emulates flat roads
- Test data correlation with real roads

Flat-Trac CT Plus F&M Measurement System

Flat-Trac® CT Plus Tire Testing System

- Featuring new electric spindle torque drive
- Perform a full range of steady-state and dynamic tire force and moment measurements including:
Example: Steady-State F&M Test

Example: G-Spline Analysis Report - Fy
Example: G-Spline Analysis Report - Mz

Mz vs SA and Fz

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**Force and Moment - Carpet Plot**

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Example: Dynamic Sweep Test

**Fy vs. Slip Angle**

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Example: Dynamic Sweep Test

Mz vs. Slip Angle

- Inclination Angle = 6 degree
- Tire Load: 11570.33, 9256.264, 6942.198, 4628.132, 2314.066
- P205/60R15, Speed = 88.5 km/h

Example: Combined Fx and Fy Test

Friction Ellipse Fy vs Fx

- Tire Load = 5780 N
- Speed = 65 km/h
- Inflation Pressure = 260 kPa
- Slip Angle = -2 degree
- Slip Angle = 4 degree
Example: Slip Ratio Test

Fx vs SR

<table>
<thead>
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<th>Condition 5</th>
<th>Condition 6</th>
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<tbody>
<tr>
<td>SR (%)</td>
<td>SR (%)</td>
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<tr>
<th>Condition 5</th>
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<tr>
<td>Pt</td>
<td>261 kPa</td>
</tr>
<tr>
<td>Vr</td>
<td>65 kph</td>
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</tbody>
</table>

Condition Information

Flat-Trac® LTRe

» Located at the National Tire Research Center, owned and operated by Virginia Tech, opening January 2013 in Southern Va.
  » 200 mph, torque at full speed.
  » ESC Maneuver simulation for improving stability control on vehicles.
  » Advanced control improve Slip Ratio control and enable (mHil)
  » Only test system that can test NASCAR tires at high speeds
Steering System Testing in Research and Product Development

- Durability
- Characterization
  - Vibration, noise
  - Kinematics and Compliance (linearity, backlash, stiffness)
  - Driver feedback
  - Efficiency
  - Steering tuning
- Comparison/Evaluation
  - Testing to a Standard
  - A:B comparison
  - Benchmarking
  - Characterization
  - Specification, target setting
  - New technology evaluation
  - Cost reduction idea generation
- Performance, validation, fault testing
  - Steering tuning
  - Simulation
    - Testing to real world responses
    - Customer (or usage) correlated
  - Evaluate safety issues

New EPS Technology

- Rapidly evolving electronic steering systems (EPS) are replacing the hydraulic (HPS) technology.

- EPS systems enhance the overall driver experience by improving vehicle efficiency, handling, comfort and safety.
- Technology is more complex and presents new challenges as it continues to develop.
Component Test Examples

- Steering Column
- EPAS Components
- Intermediate Shaft
- Upper Ball Joint
- Steering Knuckle
- Rack End
- Inner Tie Rod
- Tie Rod End
- Wheel Spindle

Vehicle Bus Interface Capability

- Integrated CANbus 793.25
- Integrated HIL Simulator

be certain.
Steering System: Mechanical Hardware-in-the-Loop (mHIL)

Real Vehicle System

Simulated Vehicle System

Steer Hardware in an MTS Loading Rig

Vehicle Model

Maneuver

Road Surface

Vehicle Response

Maneuver

Road Surface

Vehicle Response

Allows vehicle level evaluations with model of vehicle and real parts
Hybrid Simulation combines physical and virtual components, inputs, and constraints to create an integrated simulation system.

Hybrid Simulation Benefits

Hybrid Simulation offers advantages for both Analysis & Testing.

- **Analysis**: Real physical parts can be substituted for difficult-to-model components when performing virtual simulations.
  - Example: using actual vehicle dampers as part of a virtual handling simulation.

- **Testing**: Generate correct test loads by surrounding physical test parts with virtual components and generic inputs.
  - Example: using virtual tires and digital roads as part of a full-vehicle durability test.
Spindle Coupled Road Simulation

¼-Suspension Bi-Axial Test System

- Tire-coupled suspension evaluation test system
  - Floating or controlled sprung mass
- Applications
  - Suspension development & validation
  - Wheel control
  - Ride Quality
  - Isolation
  - Road holding
  - NVH
  - Component Degradation
  - Suspension Transmissibility
  - Vertical Durability
Driving Simulation for Safety and Driver Response

Providing Solutions to Meet Changing Industry Needs

- Testing Electronic Stability Control (ESC) components and systems
- Tools to evaluate and design for advanced vehicle handling
- Pioneering advanced ride comfort testing solutions
- Systems for continued development of energy efficiency in vehicles
THANK YOU

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