Validation of Vehicle Drive Systems with Real-Time Simulation on High-Dynamic Test Benches

Albert Albers, Martin Geier, Steffen Jaeger, Christian Stier     V&V2013-2391
Matthias Behrendt
Topics

- Research topics at KIT and IPEK
- Conflict of aims in development of automotive drive systems
  - Trends in development of ICE and transmission
- Development of a validation environment for rotational vibration reduction systems
  - X-in-the-Loop using Top-down modelling
  - New test bench for physical clutch system setups
  - Examplary results
- Conclusion & Outlook
Karlsruhe Institute of Technology
One Institution. Two Missions.

Located at South-Germany
Validation of Vehicle Drive Systems with Real-Time Simulation on High-Dynamic Test Benches

Karlsruhe Institute of Technology
One Institution. Two Missions.

Staff: 8,980
Professors: 373
Students: 22,552

12 km - 20 min

8.980
373
22,552

Million Euros Budget

732
IPEK - Institute of Product Engineering Karlsruhe

Facts

- 2 professors and 1 managing director
- 8 research fields
  - 5 chief engineers
  - 65 scientists
  - 20 administration & technical staff
- Education
  - Since 1996 over 60 Ph.D.
  - 21 lectures
  - Over 300 student assistants
  - ~1700 coached students
- Equipment
  - Automotive test labs
  - High performance computing
  - Test vehicles
  - Mech. & Elec. workshops
IPEK Research Approach

Research Fields

Research Designs the Future

Drive Systems

Tribology Systems

Development and Innovation Management

Design Methods for Mechatronic Systems

Validation of Technical Systems

Lightweight Design

Human-Machine-Integration

Competence-based Education
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Optimizing of standard drive systems

- **Efficiency optimizing** for internal combustion engines and drivetrain:
  - increasing **engine excitation**
  - increasing **vibration sensitivity**
Optimizing of standard drive systems
Influences of ICE Downspeeding

Maximum relative angle of DMF increases.

Engine spec:
- capacity: 1,0 L
- 3 cylinders
- Turbo charged otto engine
- $P_{\text{max}} = 90 \text{ kW}$
- $T_{\text{max}} = 190 \text{ Nm}$

Decreasing isolation of torsional vibration
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IPEK research approach

x-in-the-loop framework

Maneuver and Test Cases

Driver

Rest System

X-in-the-loop

Environment

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IPEK research approach
x-in-the-loop framework

System „Vehicle“

- Virtual X-in-the-Loop
  - Model-in-the-Loop
  - Hardware-in-the-Loop

- Real

Vehicle-in-the-Loop
- Complete Vehicle
- Road Test
- Roller Test Bench

Subsystem-in-the-Loop
- Level 1 (e.g. powertrain)
- …
- Level i-1 (e.g. gearbox with clutch)
- Level i (e.g. clutch)

WSP-in-the-Loop
- e.g. friction systems, software code,
Top-down modeling within XiL validation

System under development

Rest system

Virtual

Physical

Vehicle

Manöver

Environment

Driver behaviour

IPEK

Istitut für Produktionstechnologie

11.04.2013

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XiL Approach Top-down model example: damper potential analysis for next ICE & gearbox
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Powerpack Testbench XiL Top-down model example: damper potential analysis for next ICE & gearbox
Powerpack Testbench
for drive components such as clutch & DMF

- power each 209 kW
- Max. speed 9000 1/min
- Max. torque 500 Nm (static)
- Rotor inertia 0,029 kgm²
- Max. excitation frequency 500Hz
- IPEK Engineering & automatization
- UNICO power electronics
- Krebs & Aulich engines
Implementation on Powerpack-Testbench clutch engagement (with judder), virtual powertrain
Sensitivity and benchmark study

basic approach

Validation of Vehicle Drive Systems with Real-Time Simulation on High-Dynamic Test Benches
Sensitivity and benchmark study
modal analysis (analytical)
Sensitivity and benchmark study
Exemplary results

- **Cherk maneuvers**
  - Sweep 5Hz to 10Hz (input motor)
  - Variation of **powertrain damping in real-time model** (50% / 100% / 300%)
  - **Amplitude response** input torque – rotational speed

- **Gearbox**
  (measured value)

- **Differential gear**
  (RT simulation)

- **Wheel hub**
  (RT simulation)
Sensitivity and benchmark study

Exemplary results

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Sensitivity and benchmark study

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Sensitivity and benchmark study
Exemplary results

- **ICE isolation**: transfer analysis of engine excitations
  - Excitation:
    - frequency sweep 10 – 100Hz
  - Amplitude response
  - Consistence with theoretical resonance frequencies
    - DMF(14Hz)
    - Wheel (55Hz)

variation of damping of wheels and sideshafts → see next slide
Sensitivity and benchmark study
Exemplary results

■ ICE isolation: damping influence
■ Variation of wheel and sideshaft damping

Amplitude response wheel damping: 100% wheel / 100% sideshaft
Amplitude response wheel damping: 50% wheel / 100% sideshaft
Amplitude response wheel damping: 100% wheel / 50% sideshaft
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Conclusion

High-performance closed loop validation framework
- high-dynamic rest system simulation
- top-down modeling of full vehicle system
- combination of physical and virtual models
- variety of applications
  - damper systems
  - gearbox
  - hybrid modules
  - ...

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Validation of Vehicle Drive Systems with Real-Time Simulation on High-Dynamic Test Benches
eDrive-in-the-Loop Test Bench

**use cases**

- **Pure electric drive testing:** Powertrain-in-the-Loop consisting of physical powertrain and vehicle control unit with virtual battery model (see figure left)

- **Traction engine testing in back-to-back configuration** (up to 20,000 rpm)

- **Full hybrid system testing** with virtual generation of critical ICE excitation and battery simulation for electrical powertrains

- **Investigation of physical high speed gearboxes** in virtual electric vehicle context