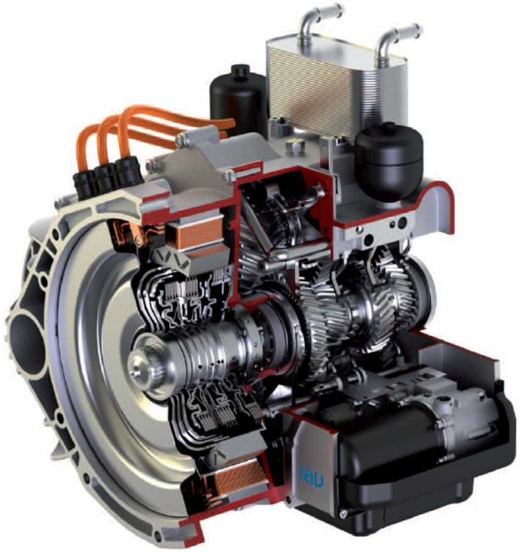
Model-Based Test of an Electro-Hydraulic Transmission Control Unit

MATLAB EXPO 2016 DEUTSCHLAND
Dr. R. Knoblich, Munich, May 2016



Content

Introduction
Vehicle Transmissions in General

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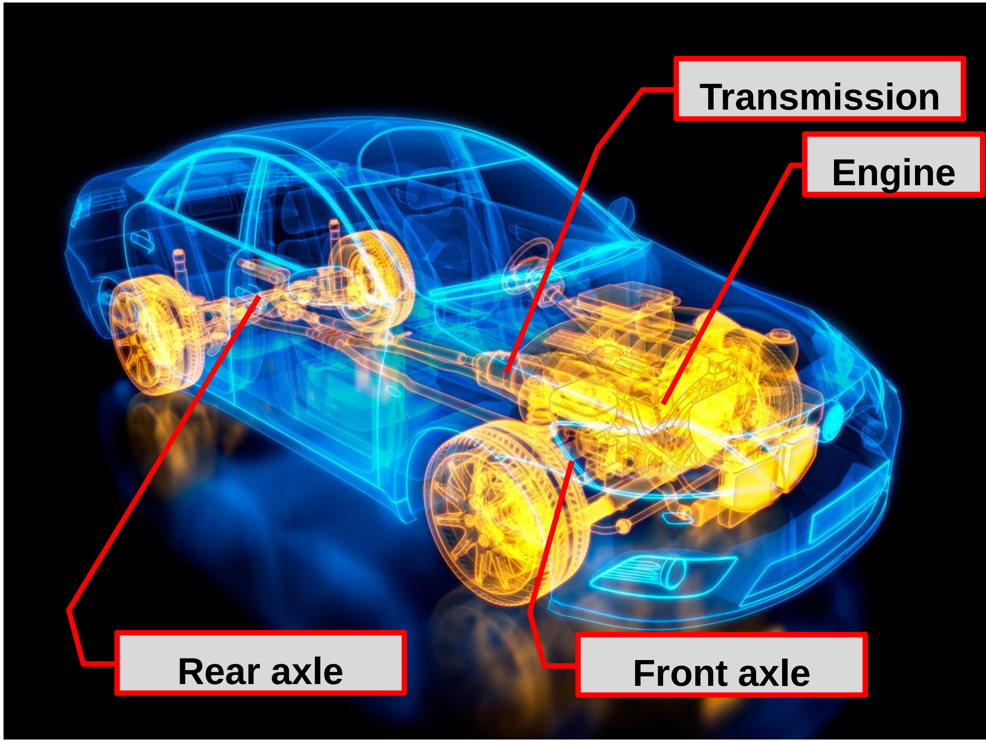
Vehicle transmission

- **Component between combustion engine and wheel**
- **Controls power delivered to road**
- **Influences comfort & performance judgement**
- **Various system configurations**
  - Automatic transmissions
  - Automated manual transmissions
  - Continuous variable transmissions
  - Double clutch transmissions



→ Vehicle transmission as integral part in power and efficiency considerations

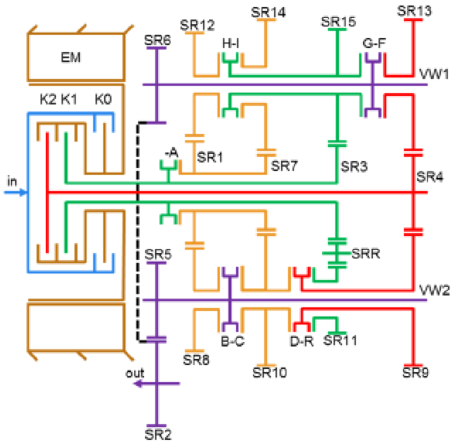
Introduction
Double Clutch Transmissions (DCT)

Key components

- **Clutches**
  - enable launching
  - realize power shifts
- **Gear shifters (GS) & synchros**
  - enable change of ratio
  - synchronize difference speeds
- **Electrical machine (EM)**
  - Additional power source

Features

- **Reduced weight, power losses, smaller package size**



Introduction
IAV‘s 8H-DCT 450 Concept

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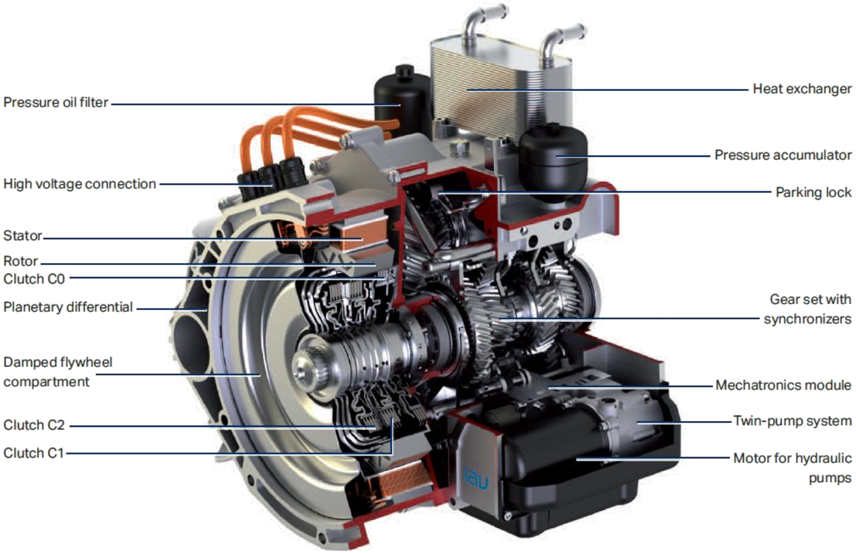
Development topic

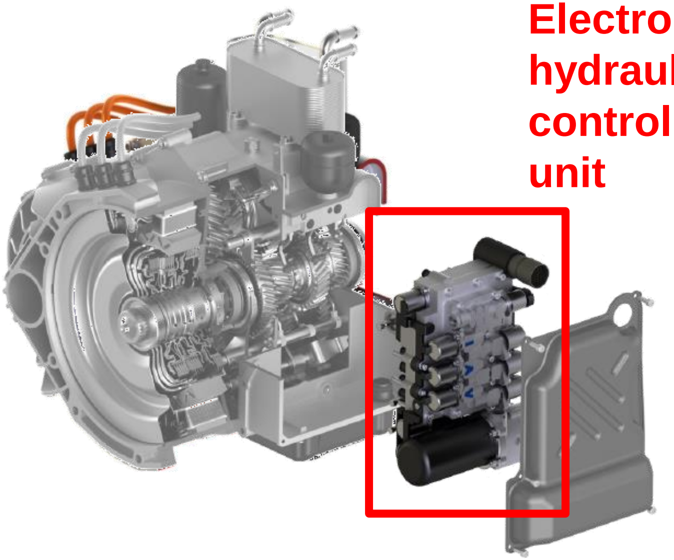
- **8-Speed-Hybrid-DCT for passenger cars**
- **Adaptable total ratio 8,0..12,0**
- **450 Nm drive torque, 7,500 min^{-1}**
- **Full hybrid with coaxial EM**
- **Additional separation clutch (K0)**
- **High efficiency hydraulic double pump concept**
- **One oil (ATF) for cooling & actuation**



Introduction
System under Test

Completely new design

- **Simultaneous design of**
  - mechanics
  - hydraulics
  - electronics
- **Early development stage**
  - electro-hydraulic control unit (CU) realized
  - remaining components are still in development



How to realize a CU test under real conditions with missing components?

→ Realization of a Hardware-in-the-Loop (HiL) system that enables judgement of fluidic behavior!

Testing Environment
Technical Background

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Two folded solution

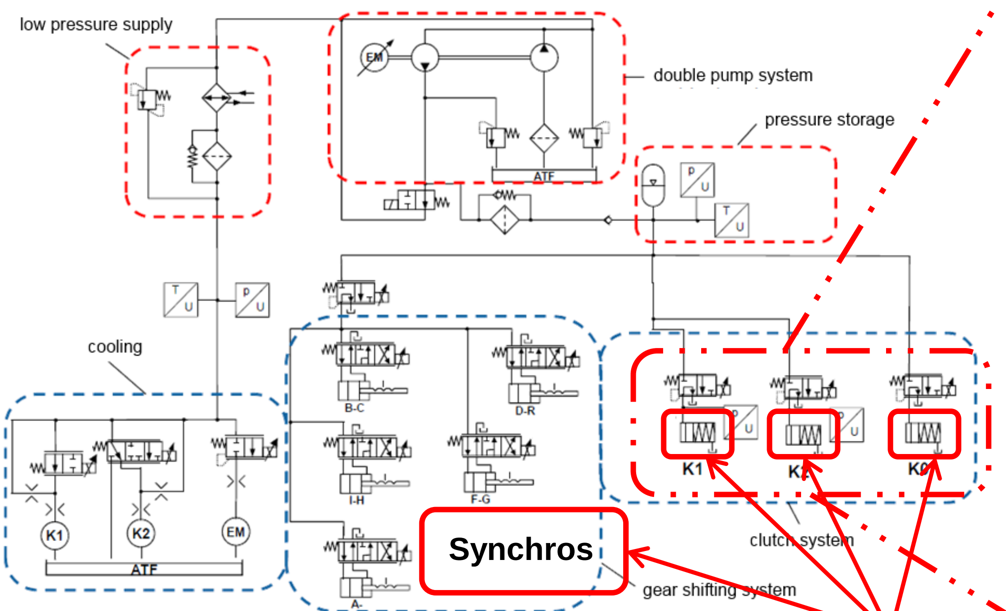
Specialized *hydraulic test rig*	**Environmental simulation by *software***
• **realizing hydraulic fluid hand over between CU and environment,** • **supplying installation space for additional actuators and** • **allowing integration of sensors for measurement data acquisition**	• **enabling „close-to-vehicle“ measurement circumstances and** • **driving cycles (FTP, WLTP, etc.),** • **generating control signals for CU** • **Generating stimulation of additional actuators to simulate behavior of missing transmission components (Clutches, Synchros)**

→ Idea: Usage of MATLAB®, Simulink® with Simscape™ Driveline™, Simscape™ Fluids™ in conjunction with dSPACE MicroAutoBox & RapidPro hardware and IAV Velodyn Simulation Framework

Testing Environment
Technical Challenges

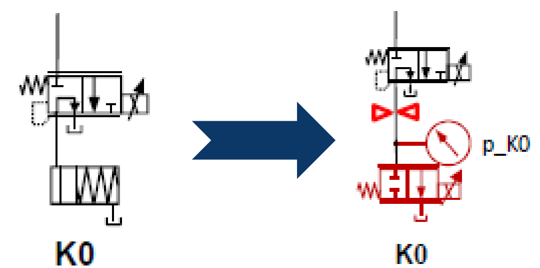
Generation of a highly flexible testing environment to

- **react on latest changes in hardware concept and**
- **increase reusability of testing concept**



no hardware representation

How to compensate missing hardware (HW) ?



Replacement of clutch hardware by

- **proportional valve and**
- **software control**

Testing Environment
Importance & Advantages

Why is it so important to simulate missing components in such a complex way?

- **Achieve realistic flow and pressure conditions during tests**

  → derive hardware revisions to improve system behavior at an early development stage

  → estimate hydraulic power consumption, especially in relevant driving cycles

- **Simulate realistic filling and leakage behavior**

  → accurate estimation of fill durations and losses

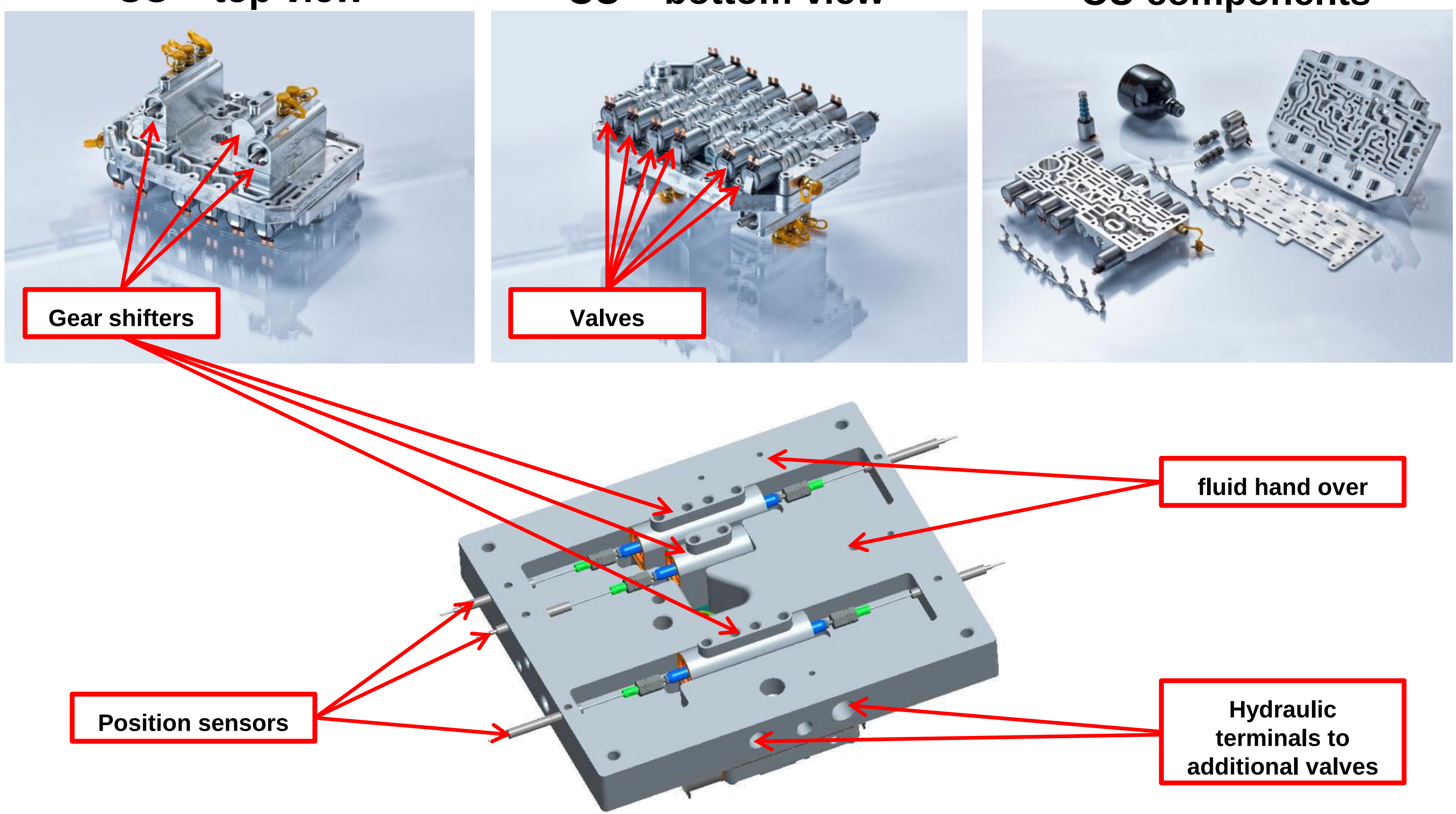
- **Easy adaption of testing environment to changes in mechanic concept**

  → smaller or bigger clutch systems are subjects of software parameter changes

→ Increased significance of HiL measurement data, more flexibility when testing different hardware concepts

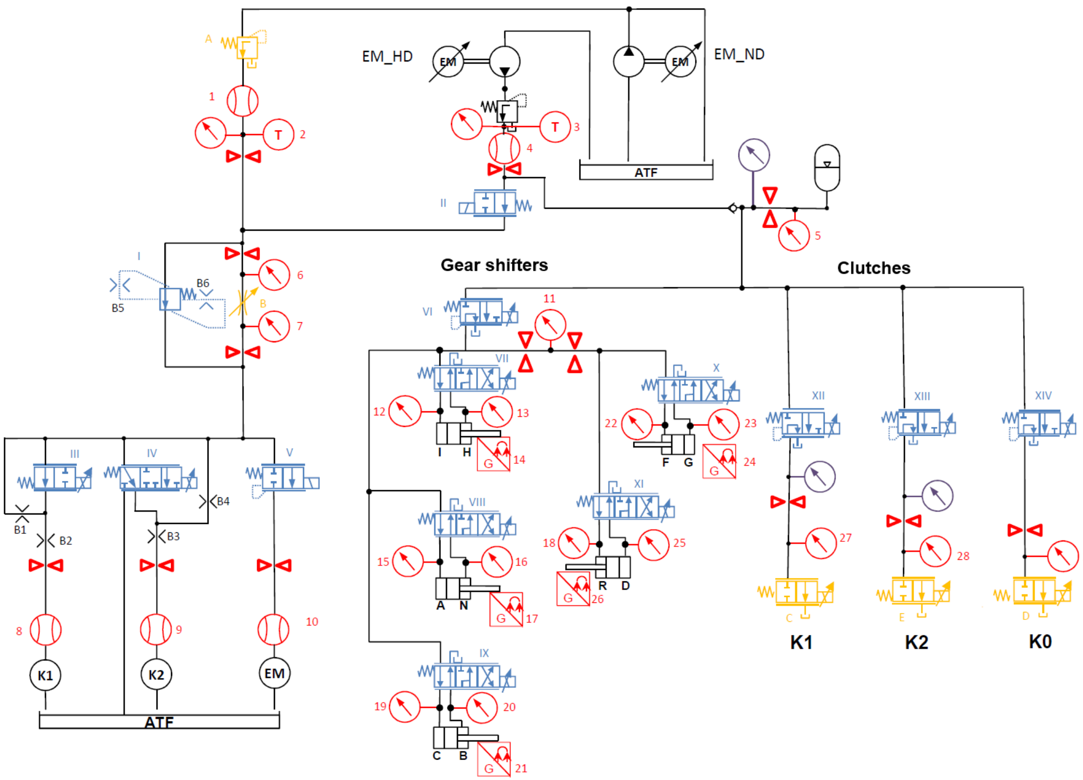
Testing Environment
Hardware I

CU – top view **CU – bottom view** **CU components**



Test rig – bottom view

Testing Environment
Hardware II



Additional instrumentation

- 3 internal pressure sensors
- 19 additional pressure sensors
- 5 sensors for volume flow rate measurement
- 2 temperature sensors
- 5 displacement sensors

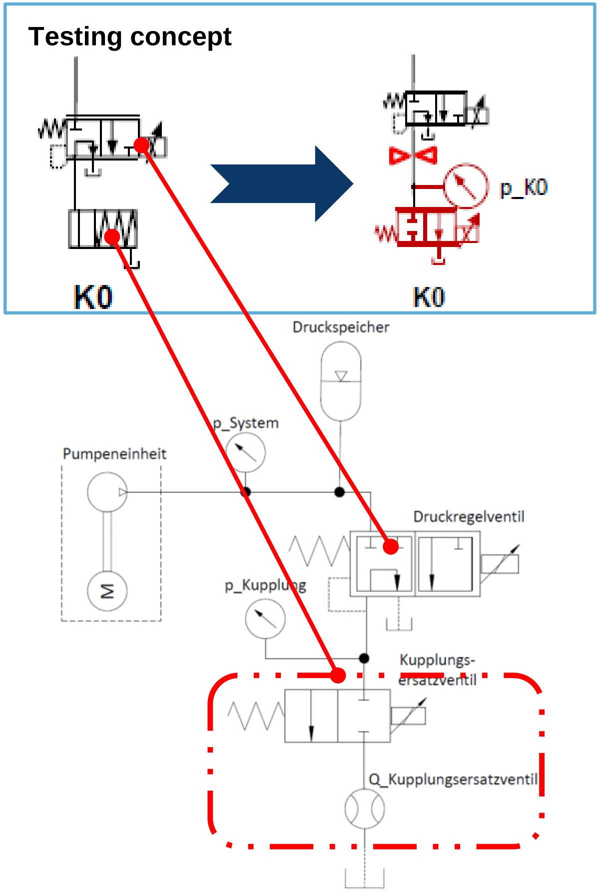
→ **Complete evaluation of electro-hydraulic control unit becomes possible**

Testing Environment

Validation of Testing Concept with Simscape™ Fluids™

Prior to realization of HW a proof of concept has to be done

- **Usage of Simscape™ Fluids™ components for modelling of hydraulic supply, clutch valves and test rig components reduced development time significantly**
- **Simscape™ Fluids'™ easy representation in comparison to modelling with nonlinear differential equations enabled quick understanding and transfer of models**
- **Accurate simulation models allowed precise estimations of system characteristics**

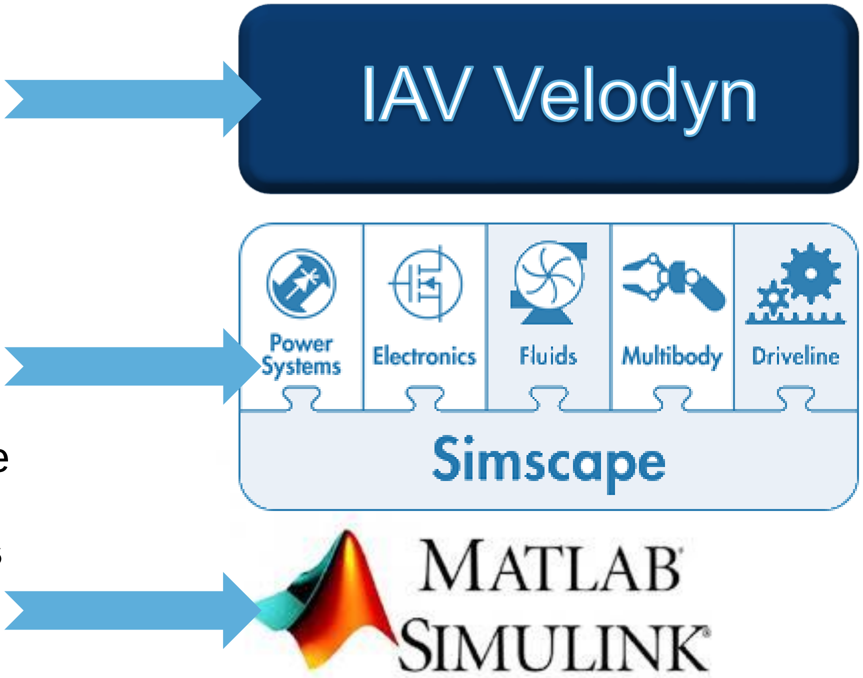


→ Simscape™ Fluids™ allowed proof-of-concept in approximately 2 days

Testing Environment
Software Concept

Software requirements

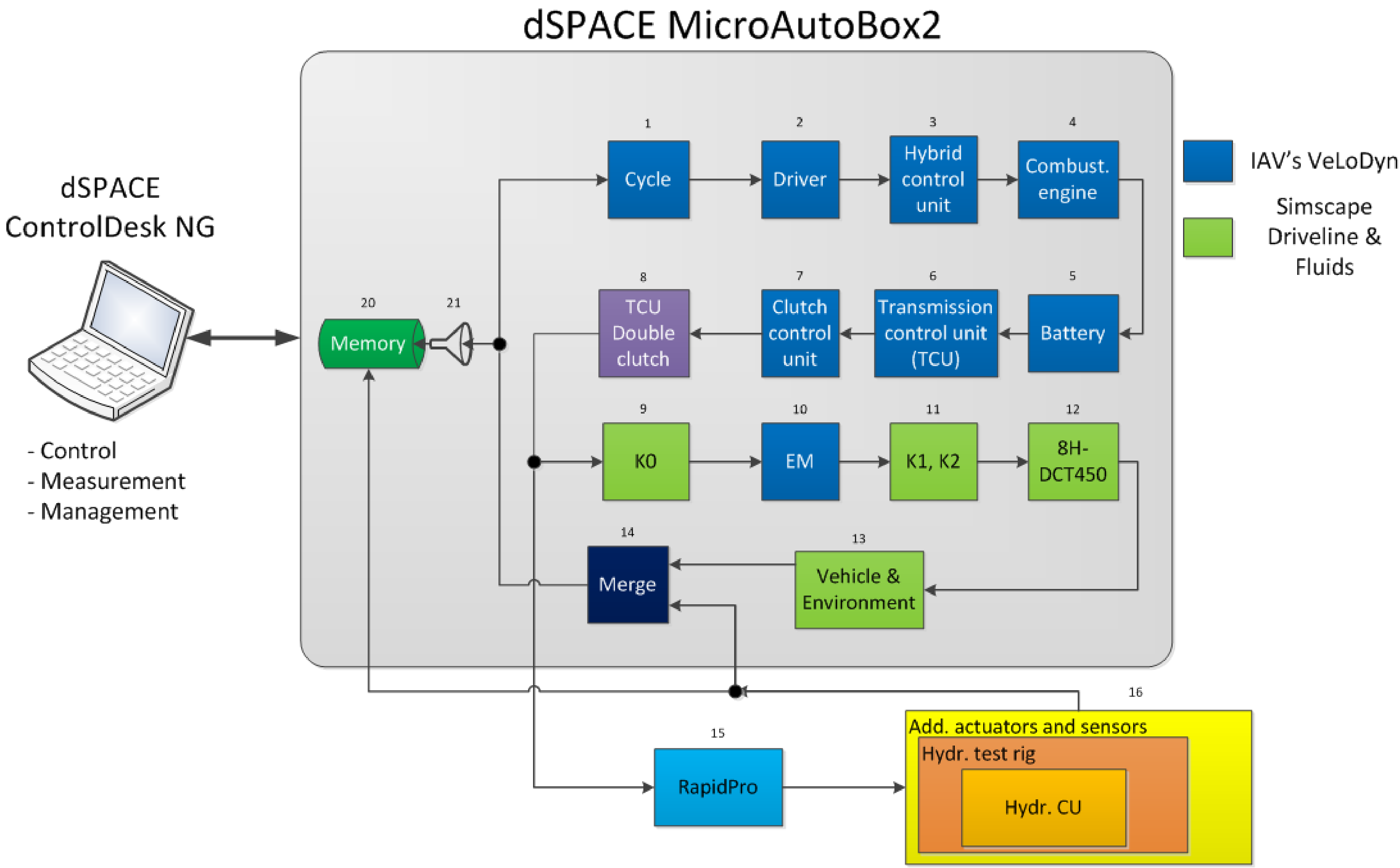
- **Simulation of environment**
  → Generating necessary signals (driver requests, speeds, slopes etc.)
- **Simulation of missing HW components & vehicle**
  → Generating control signals for proportional valves & current override
- **Computation of CU‘s control signals**
  → Implementation of control algorithms,
  → computation of control signals:
    - valve currents, switch signals



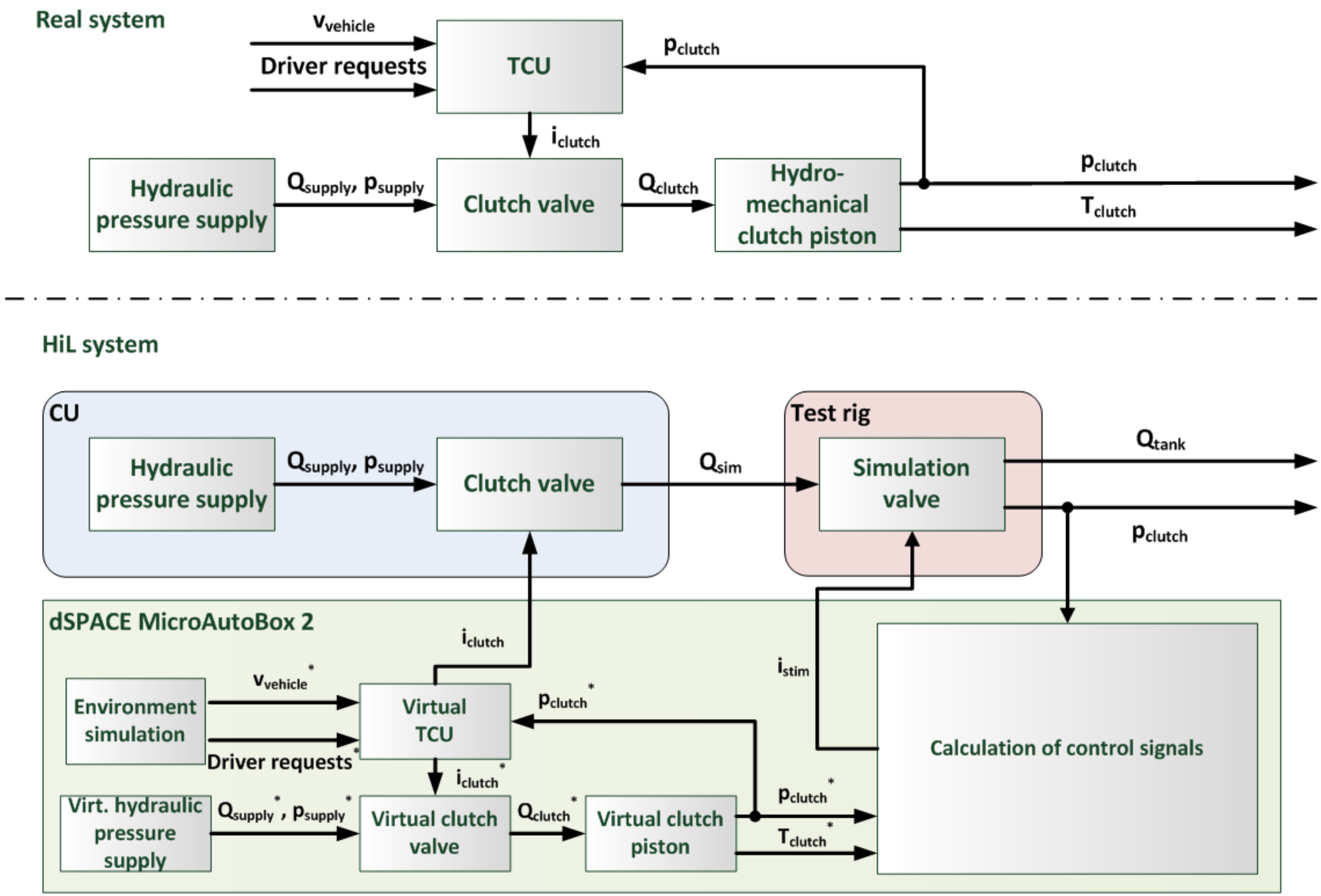
→ Usage of different tools: MATLAB®, Simulink®, Simscape™ Driveline™, Simscape™ Fluids™, IAV Velodyn

Testing Environment

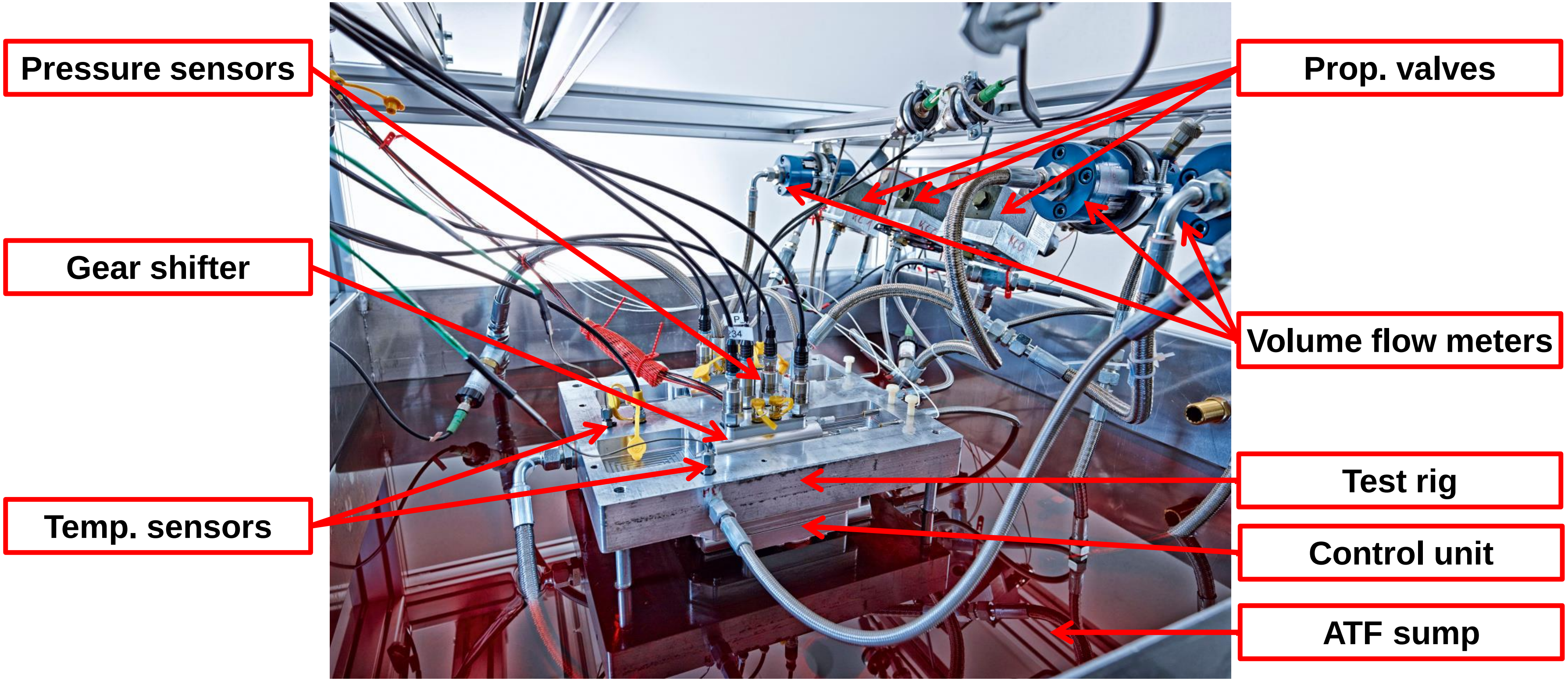
Software Architecture & HW-Integration I



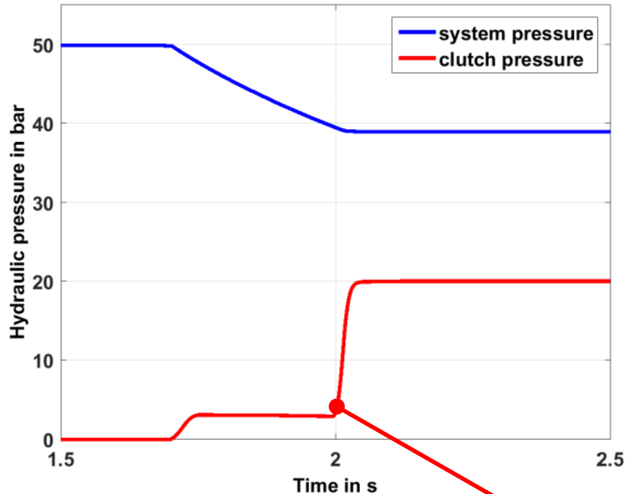
Testing Environment
Software Architecture & HW-Integration II

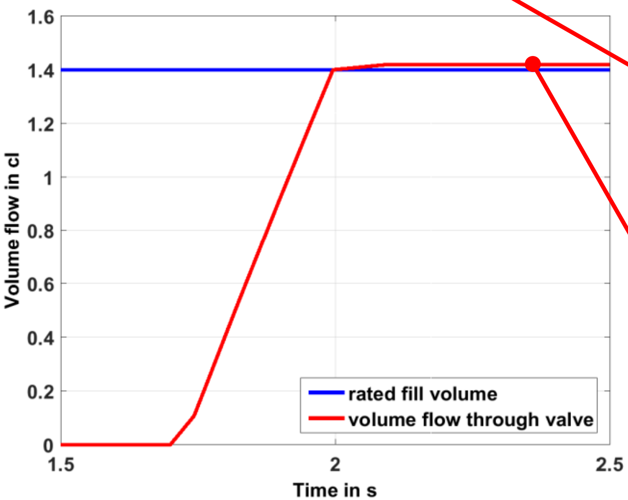


Results
Test Rig



Results
Filling Behavior





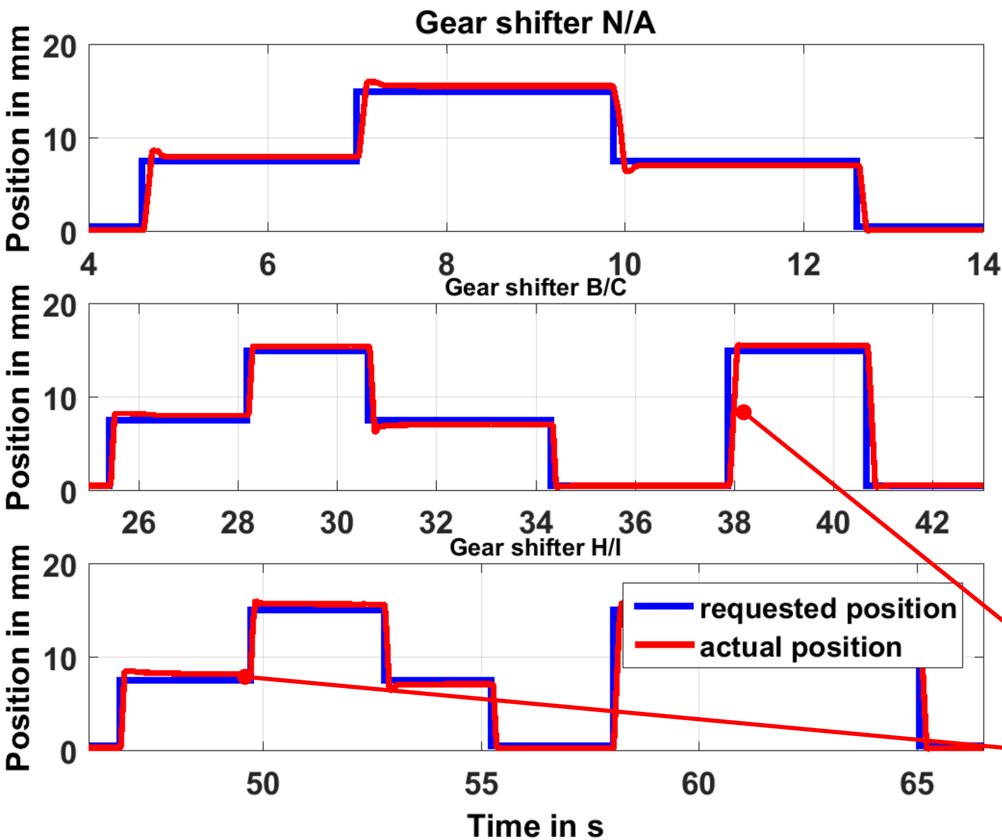
Measurement conditions

- bang-bang system pressure control (35/50 bar), smoothed by pressure accumulator
- step-shaped stimulation of clutch valve (p_{req}= 20 bar)
- model-based control of prop. valve
- leakage is zeroed (q_{leak} = 0 cl)

Results

- realistic pressure behavior resulting from clutch piston movement can be realized (compared to real clutch systems)
- model-based control achieves fill volumes near to rated values

Results
Gear Shift Behavior



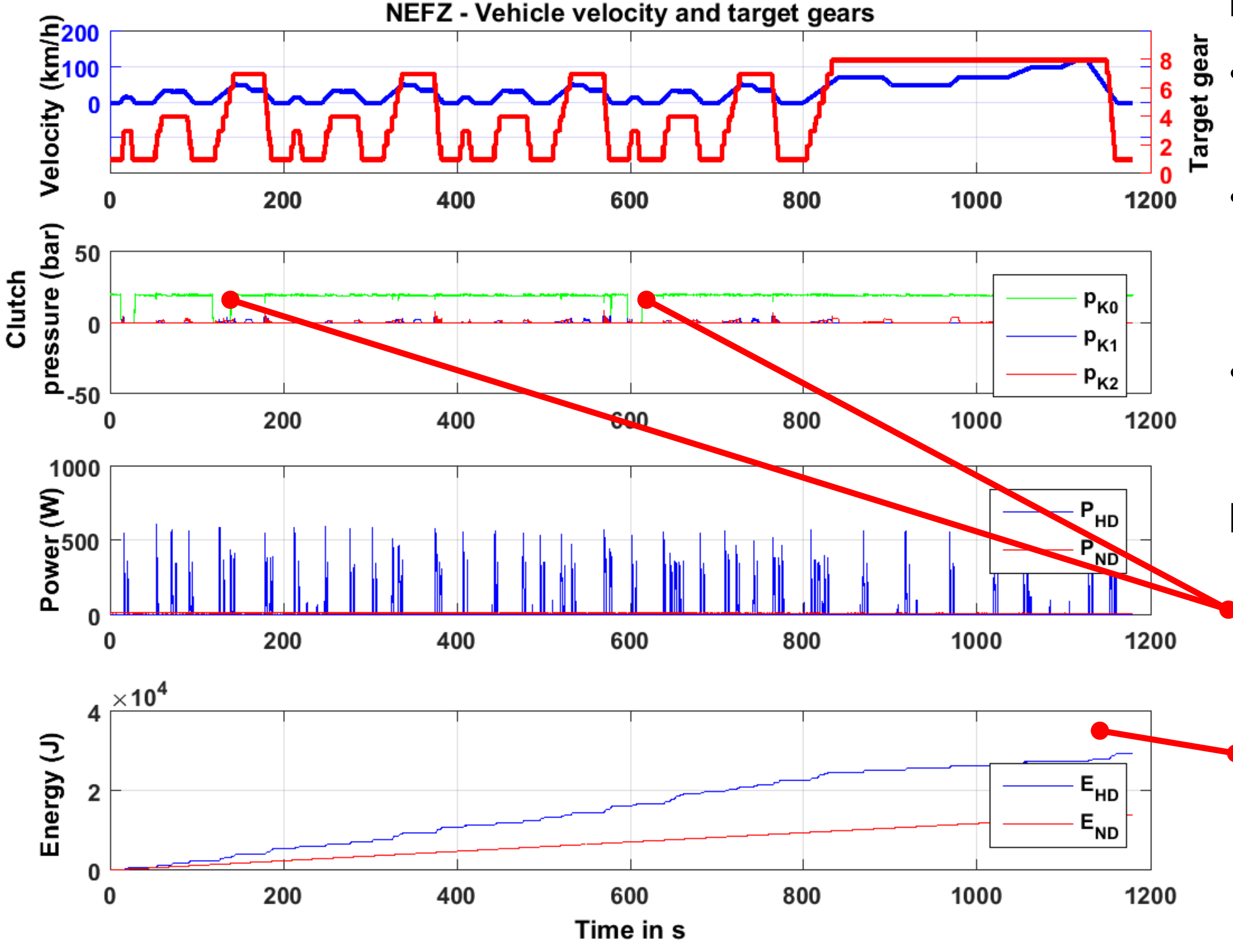
Measurement conditions

- bang-bang system pressure control (35/50 bar)
- shifting requests derived from driving cycle & environmental simulation
- model-based override of GS valve currents to achieve sync. behavior
- position forward control

Results

- detailed data for actuation velocities
- close to reality GS movement
  → important for energy considerations
- …

Results
Driving Cycle Behavior



Measurement conditions

- bang-bang pressure control
- shifting requests derived from driving cycle & environmental simulation
- model-based control of clutches & GS

Results

- evaluation of hybrid control algorithms
- reliable estimation of power consumption due to realistic volume flow and pressure characteristics

Summary & Conclusions
Summary

- **Short introduction into vehicle transmission systems**
- **Presentation of object of study: transmission concept and development stage with resulting problems**
- **Presentation of two folded problem solution**
- **Description of hard- & software approach**
- **Presentation of testing environment, acquired measurement data & results**

Summary & Conclusions
Conclusions

- **Simplified modelling of hydraulic and transmission system due to usage of Simscape™ Fluids™ and Simscape™ Driveline™**
- **Seamless interaction of software and plant models due to one unique simulation platform - Simulink ®**
- **More reliable measurement data due to realistic flow & pressure conditions**
- **Flexible testing environment: easily adaptable to new mechatronic and vehicle concepts by simple software changes (model)**
- **Reduced commissioning time:**
  - **Calibration on test rig: Dither, fill functions, shifting functions**

Outlook

- **Integration of additional actuators for stimulation of gear shifters (counter force)**
- **Optimization of hardware concept due to acquired measurement data**
- **Piecewise replacement of stimulation actuators with real components according to development progress**
- **After realization of mechanics: Comparison of gathered results for evaluation of testing approach**

Thank You

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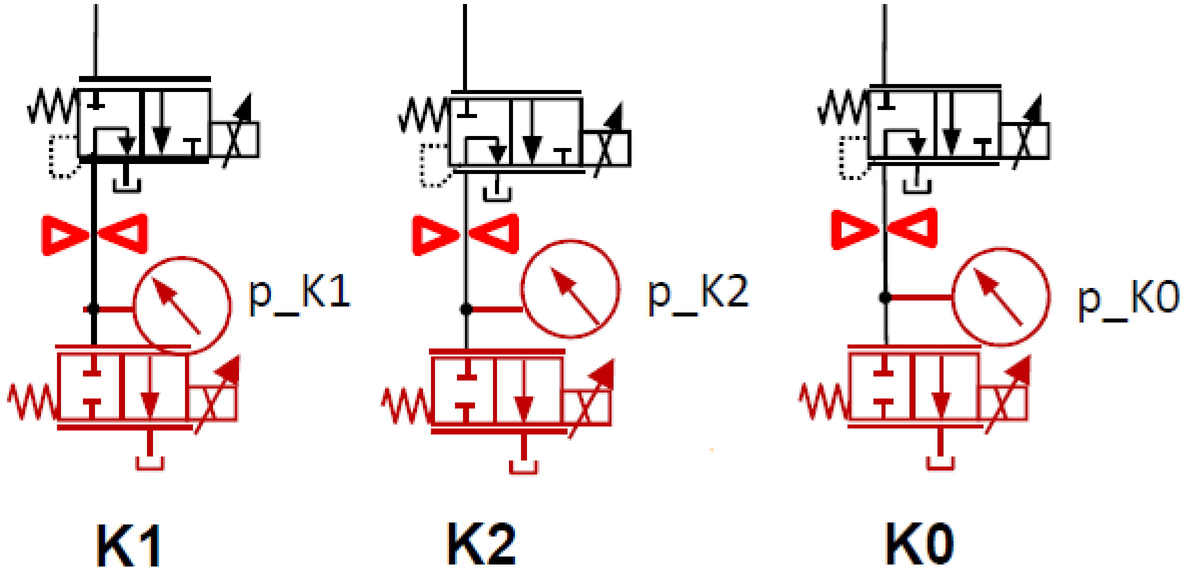
Abbreviations

ND	Niederdruck, low pressure
HD	Hochdruck, high pressure
DCT	Double clutch transmission
EM	Electrical machine
Nm	Newton meters
min^{-1}	Revolutions per minute
CU	Control unit
HiL	Hardware-in-the-Loop
SW	Software
HW	Hardware
GS	Gear shifter
ATF	Automatic transmission fluid
FTP	Federal Test Procedure
WLTP	Worldwide Harmonized Light-Duty Test Procedure
K0	Clutch 0
K1	Clutch 1
K2	Clutch 2
NG	Next Generation

Additional material



Additional material