UNITED

Engineering Knowledge Transfer Units to Increase Student´s Employability and Regional Development

Test Facilities of FHJ, it’s background and tasks

FH Joanneum Gmbh.

Co-funded by the Erasmus+ Programme of the European Union

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Test Facilities of FHJ, it's background and tasks

T. Lechner

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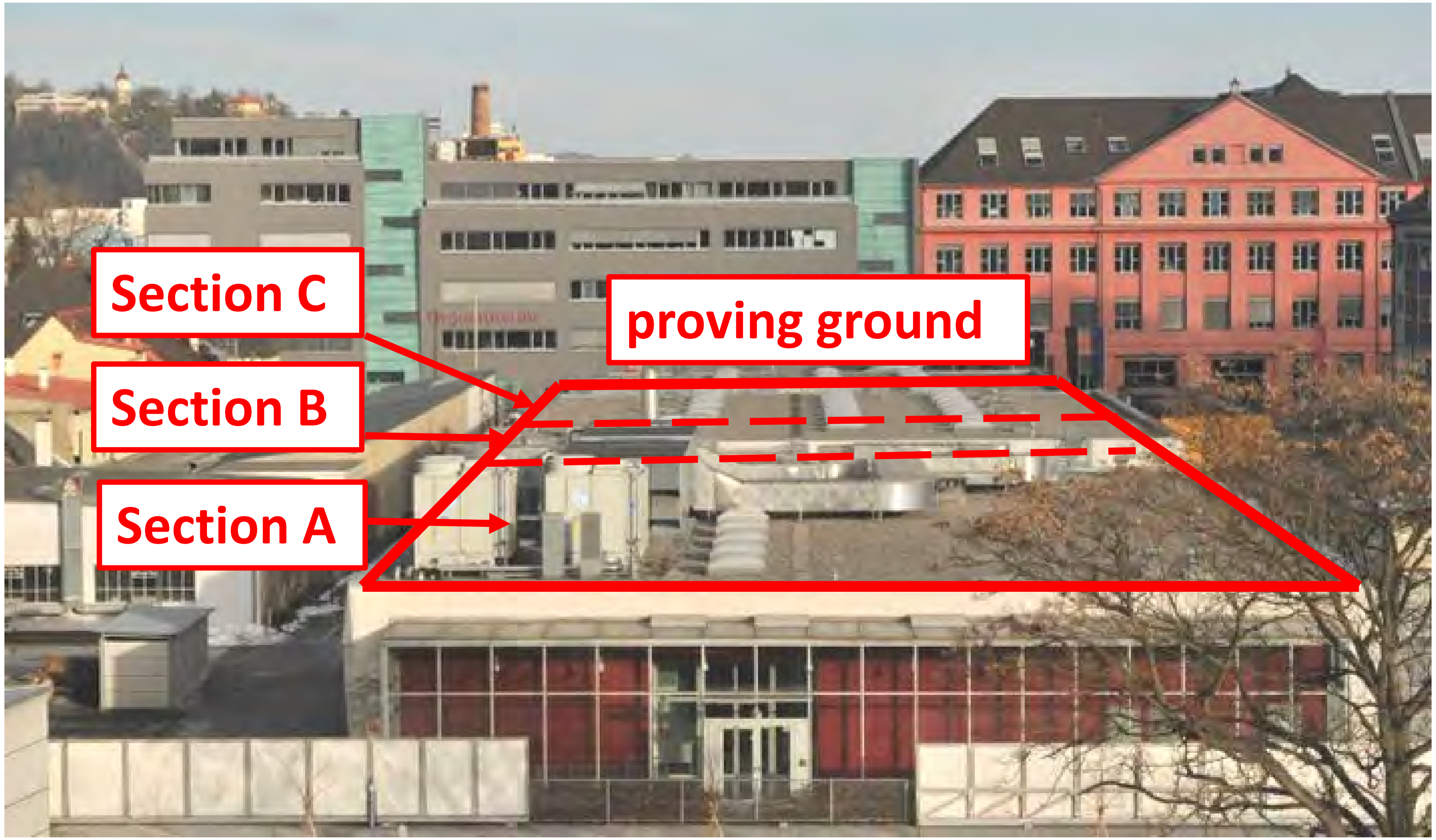
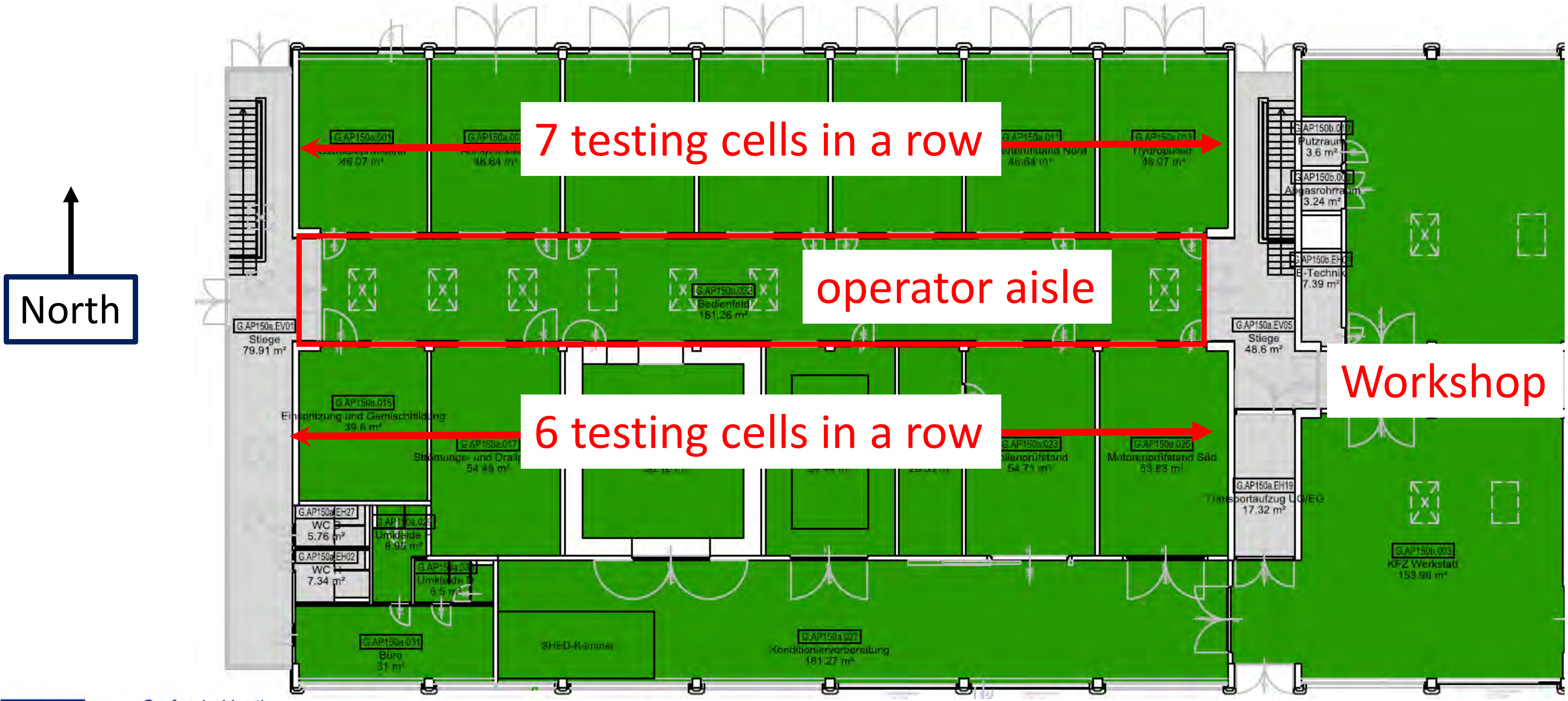
Introduction

- Section C: Laboratories for education
- Section B: Workshops
- Section A: Test bay area



Section A: Floor plan



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Operator aisle

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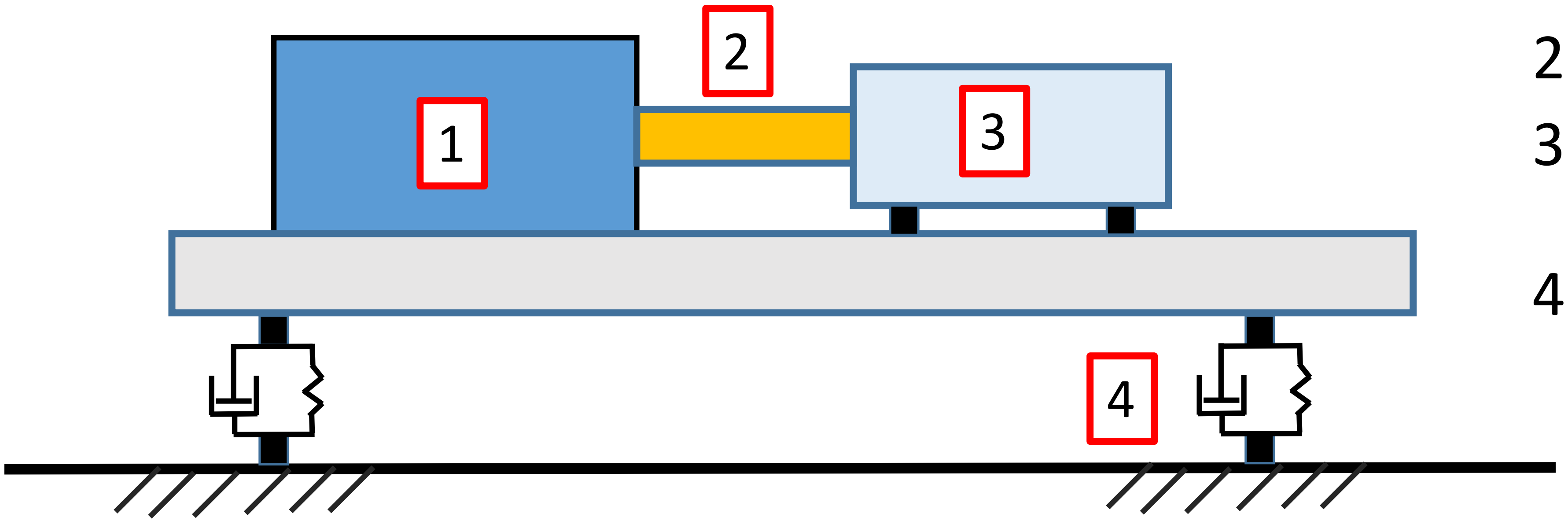
View to test cell

The operator have a view to the test cell through a pane of unbreakable glass.

Engine test rig principle



1 – power absorber

2 – shaft

3 – Unit under Test

4 – Damping system

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Engine test rig

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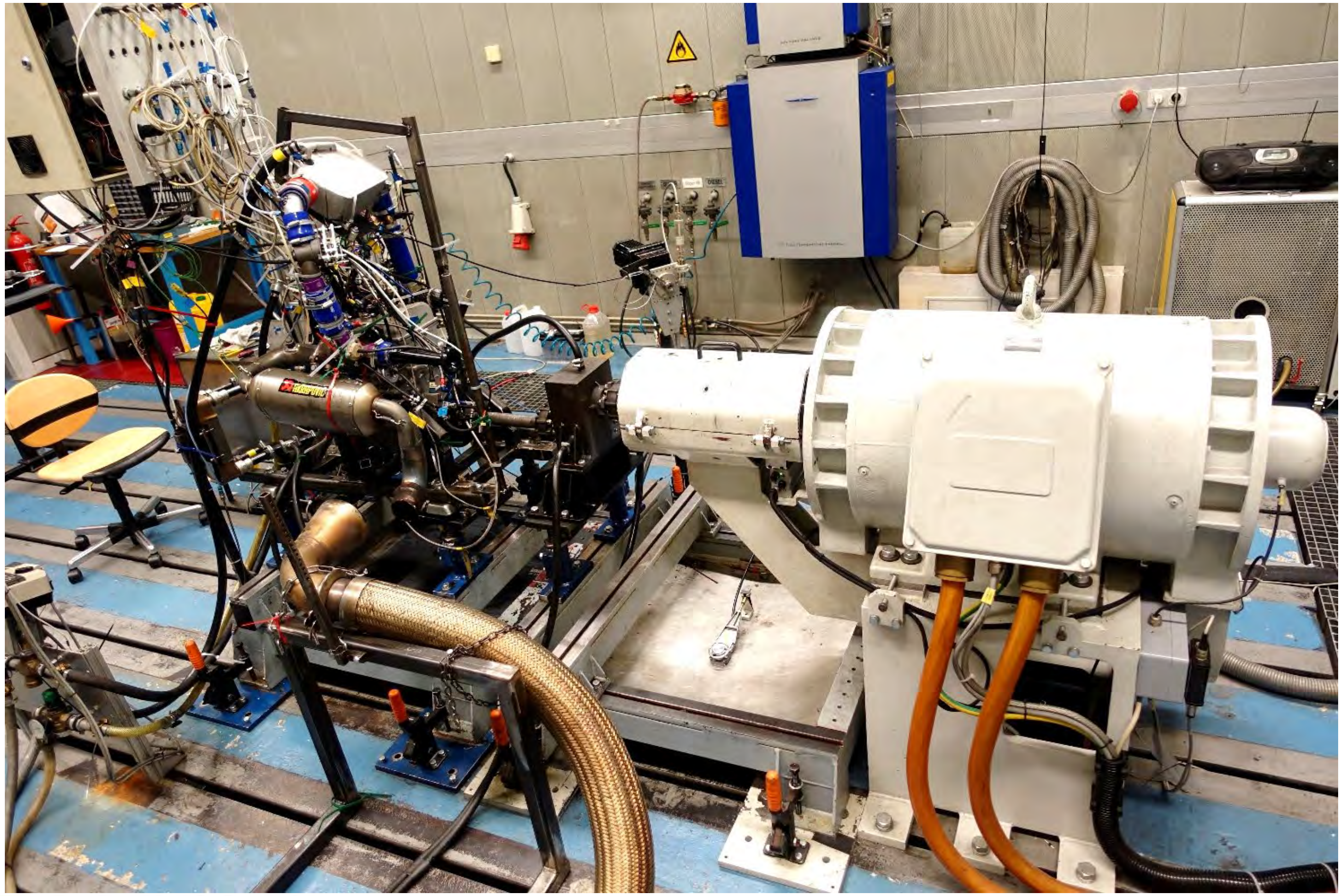

- Engine test bed south of UAS Graz with AC power absorber (white)

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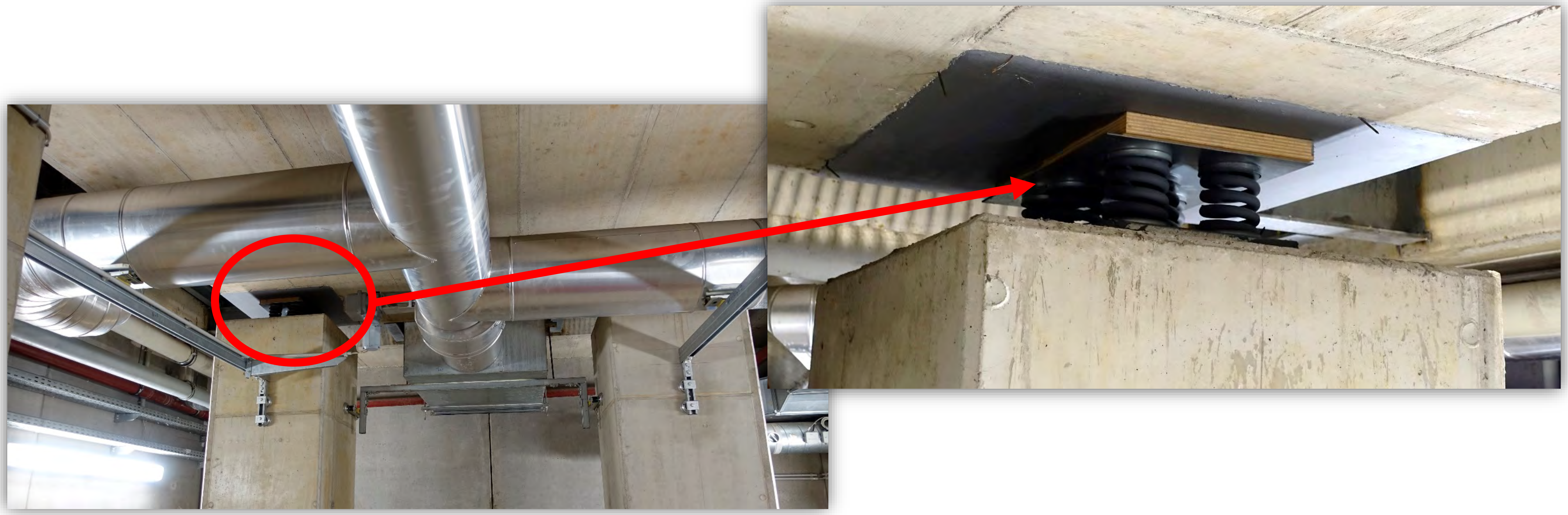
Vibration damping



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Vibration damping

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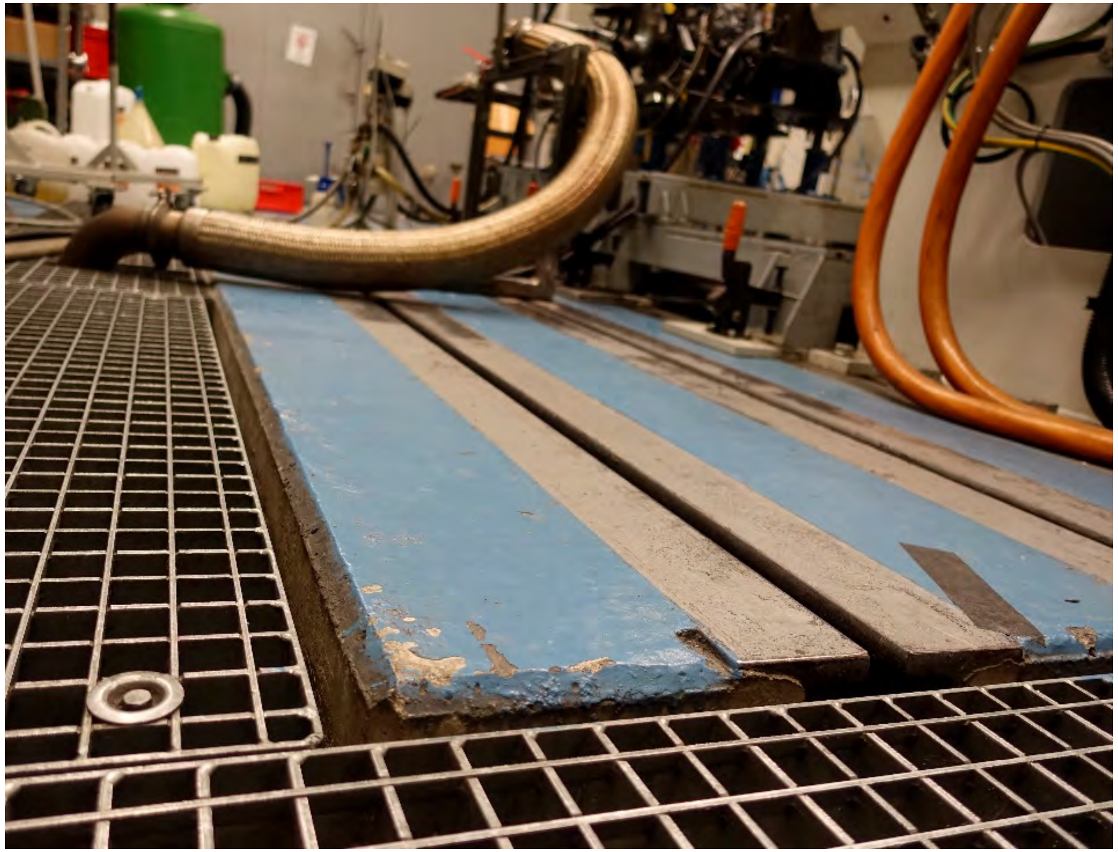
Base plate – T-nuts



- Massive Base plate out of concrete
- Track system for T-nuts
  - For easy installation and movement of DUT’s

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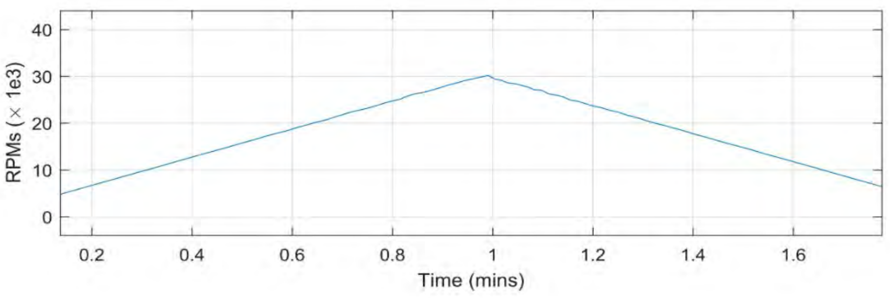
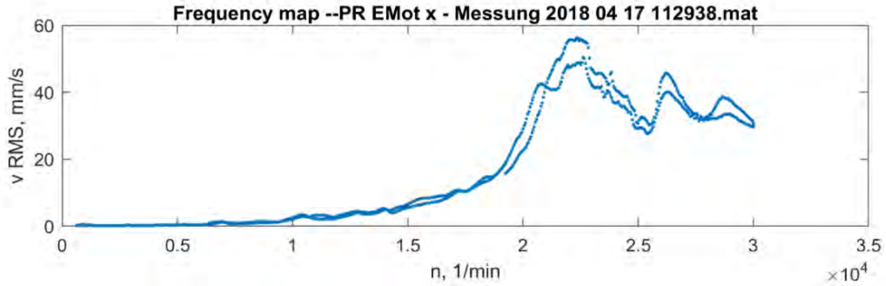
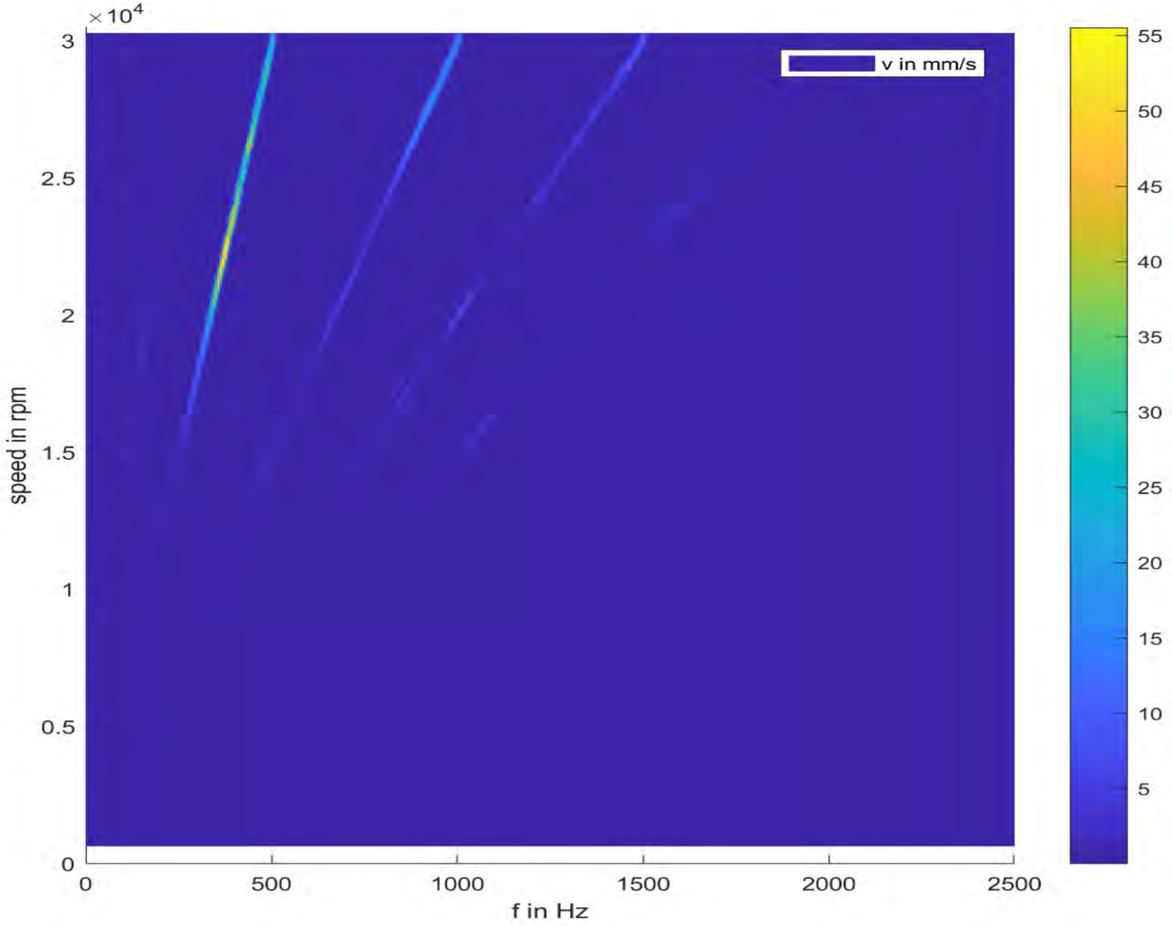
NVH Test at each new Set Up





- Slow speed up excites resonances
- We measure accelerations and integrate to grade the vibration velocity
- A Campel diagram allows to find sources



Campel diagram of a Device under test

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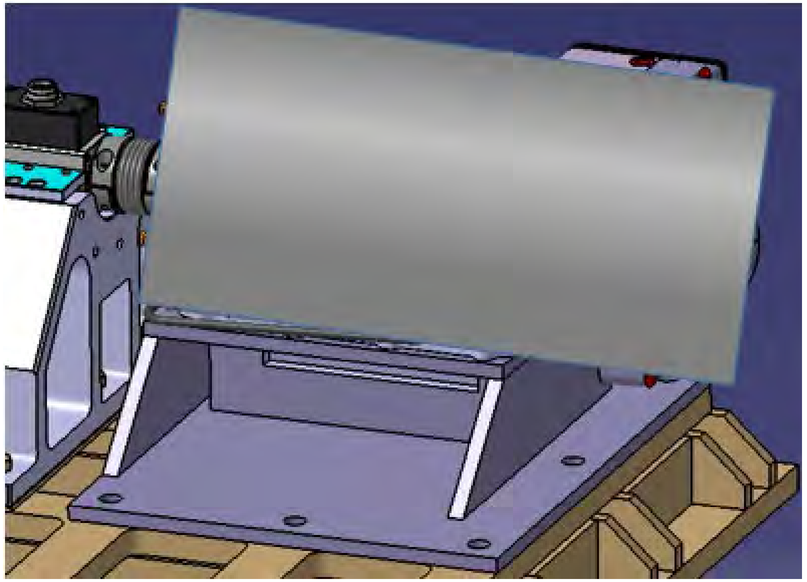
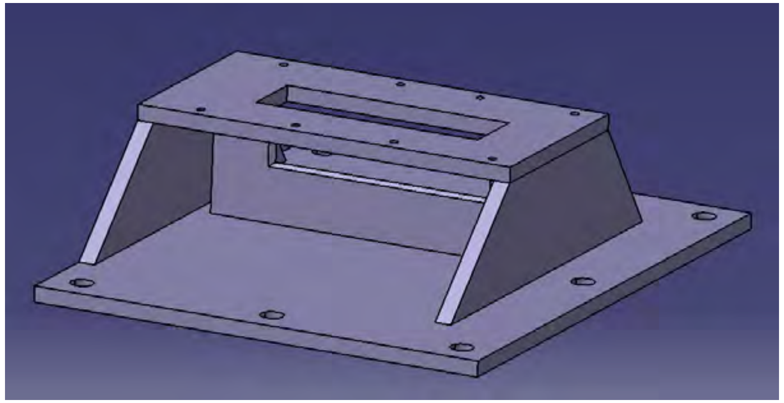
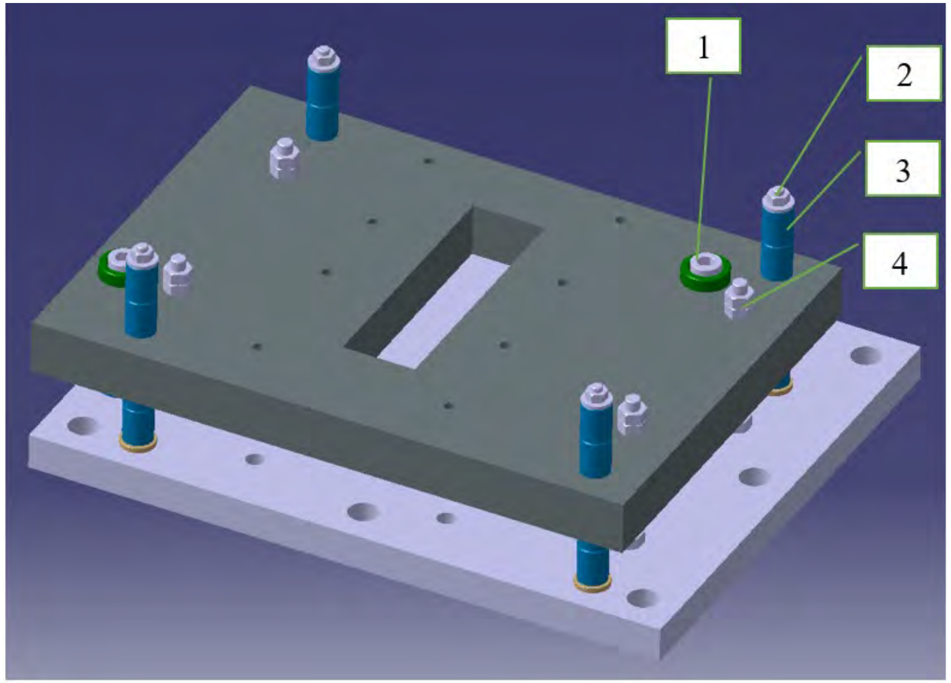
Separated isolation for high speed drives







1 .. Horizontal hard stop
2,3 .. Rubber spring, preloaded, adjustable
4 .. vertical hard stop

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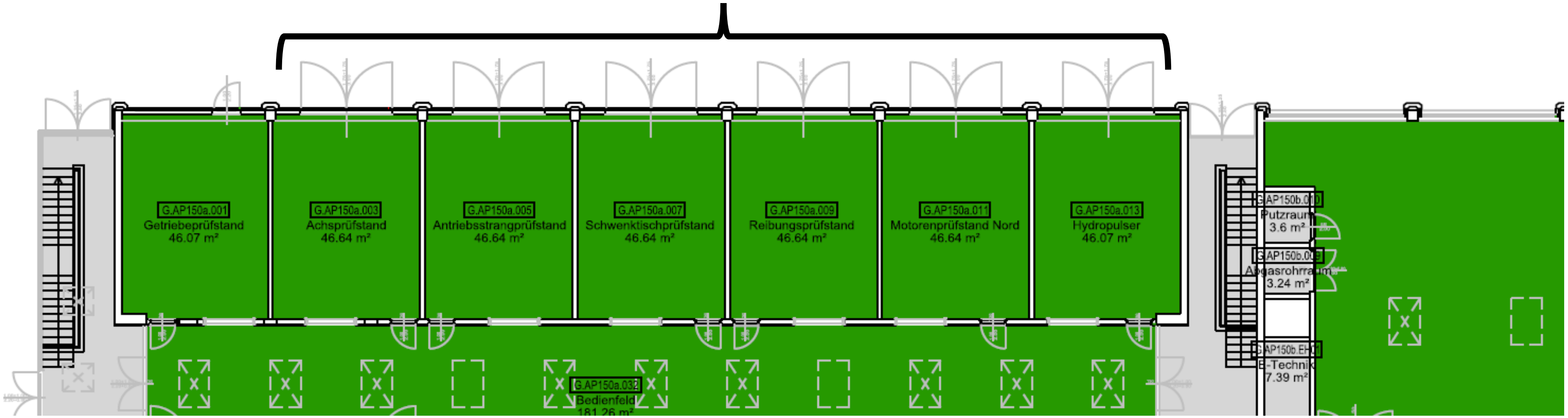
Testing cells entrance

- Doors for suppliers
- 1 door per testing cell



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Doors for suppliers

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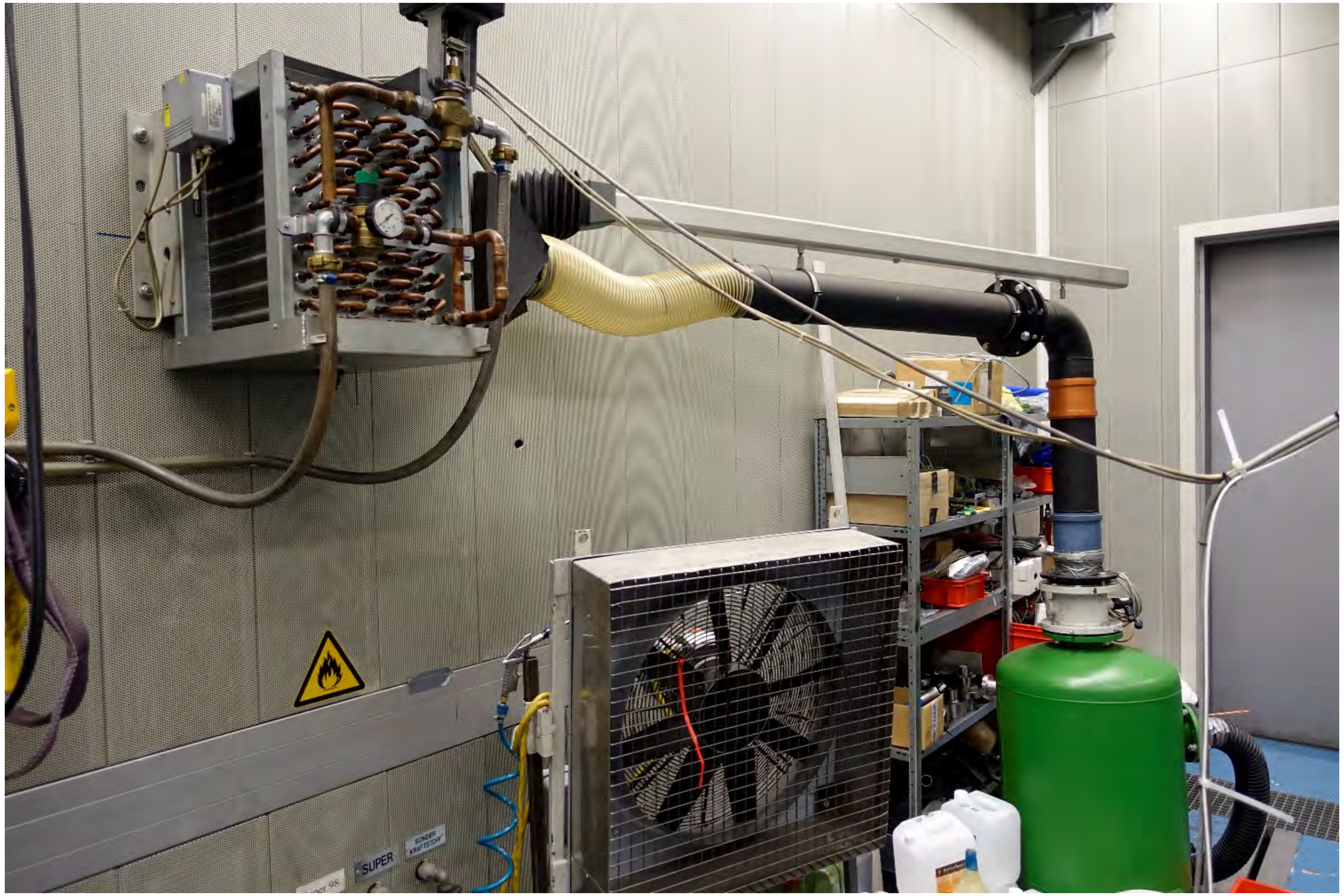
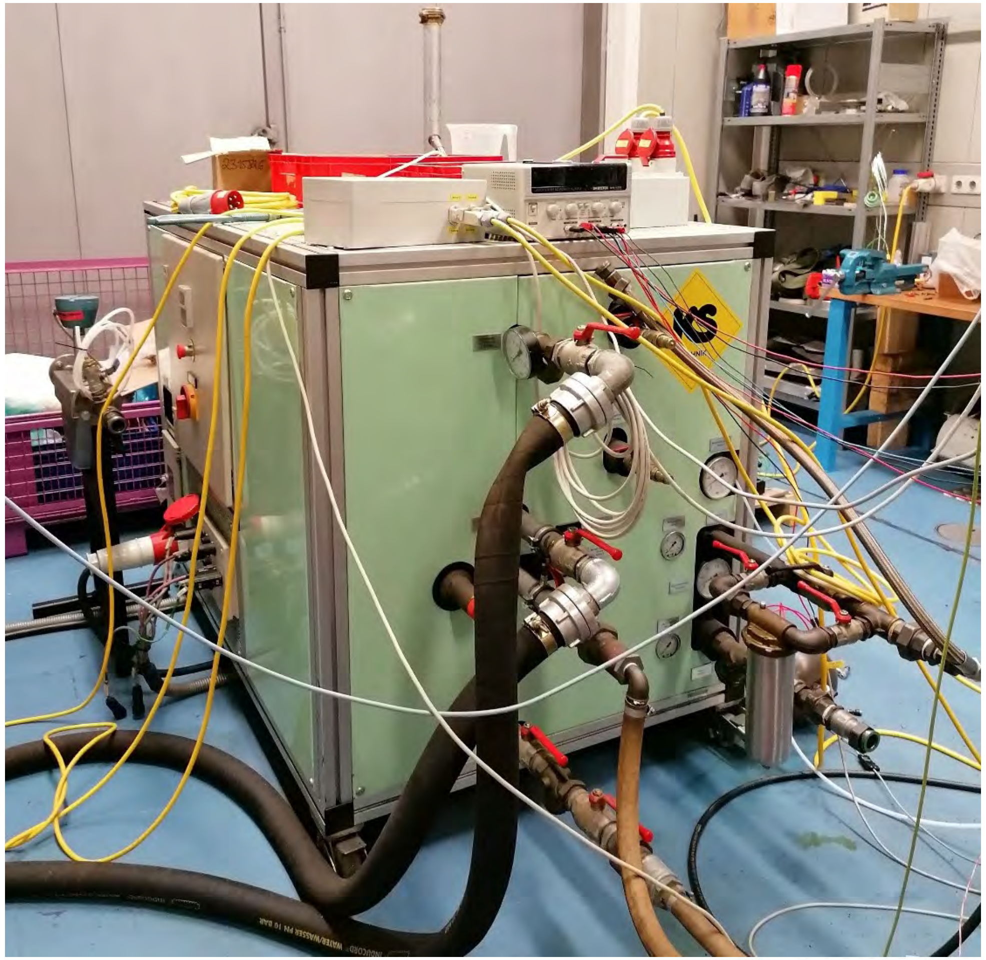
Facility equipment

- Air Supply for ICE
  - Water cooled air conditioner
  - Green: absorber to avoid inlet gas vibration
  - Mass flow meter



Facility equipment

- Cooling liquid and oil conditioning unit for ICE



Facility equipment

- Fuel storage

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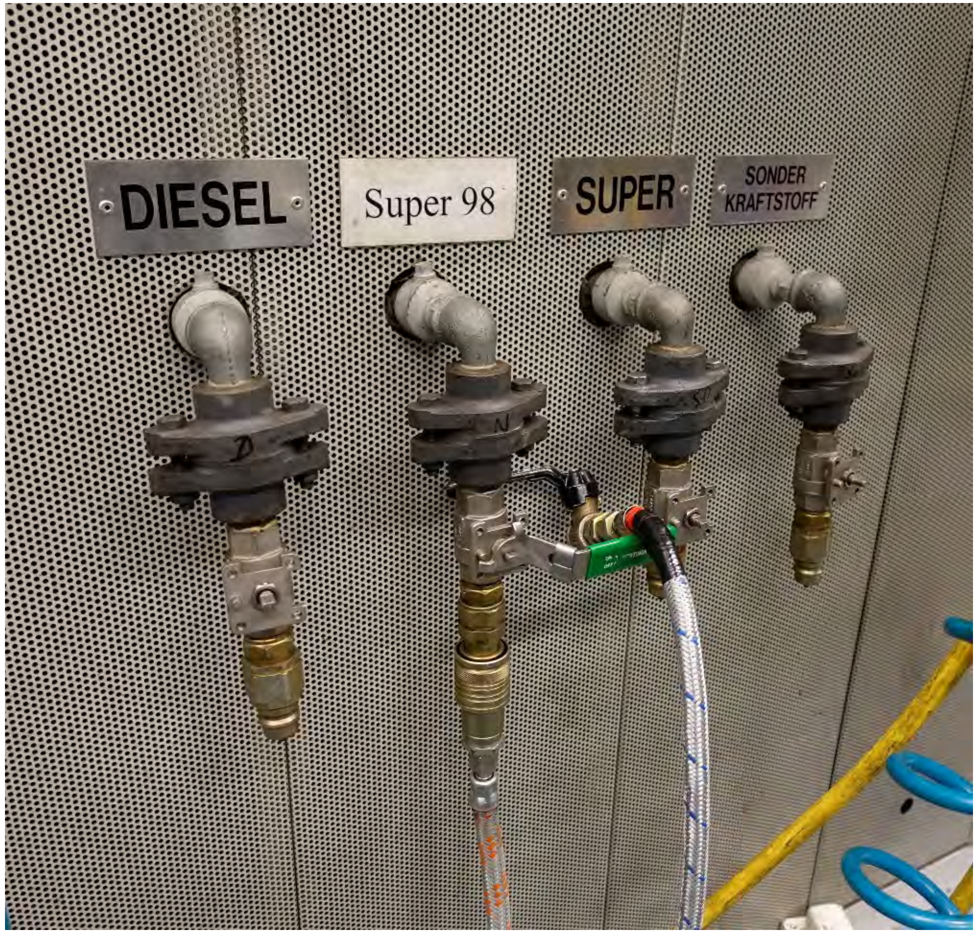
Facility equipment

- Fuel supply



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Facility equipment

- Gas storage and supply
  - Calibration gases
  - Zero gas
    - Synthetic air for FID
    - Nitrogen for IRD and CLD
  - Span gas
    - FID: Propane in synthetic air
    - IRD: CO and CO2 in nitrogen
    - CLD: NO in nitrogen

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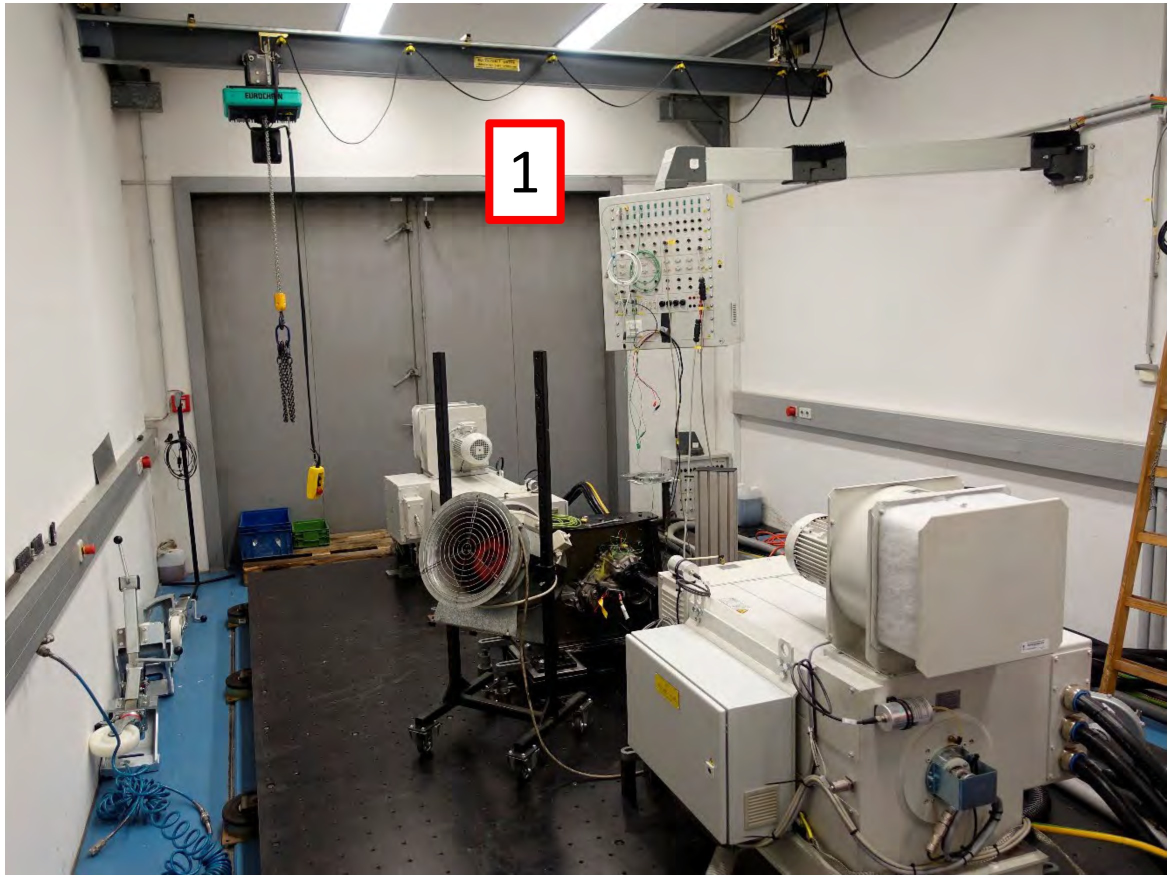
Measuring System



- Sensor Box (1)
  - Easy to connect sensors to the **d**ata **acq**uisition system (DAQ)
  - Temperature Sensors
    - Pt100 and Thermocouple
  - Pressure Sensors
  - Analogue input and output channels
  - Digital input and output channels
  - …

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Mechanical power measurement

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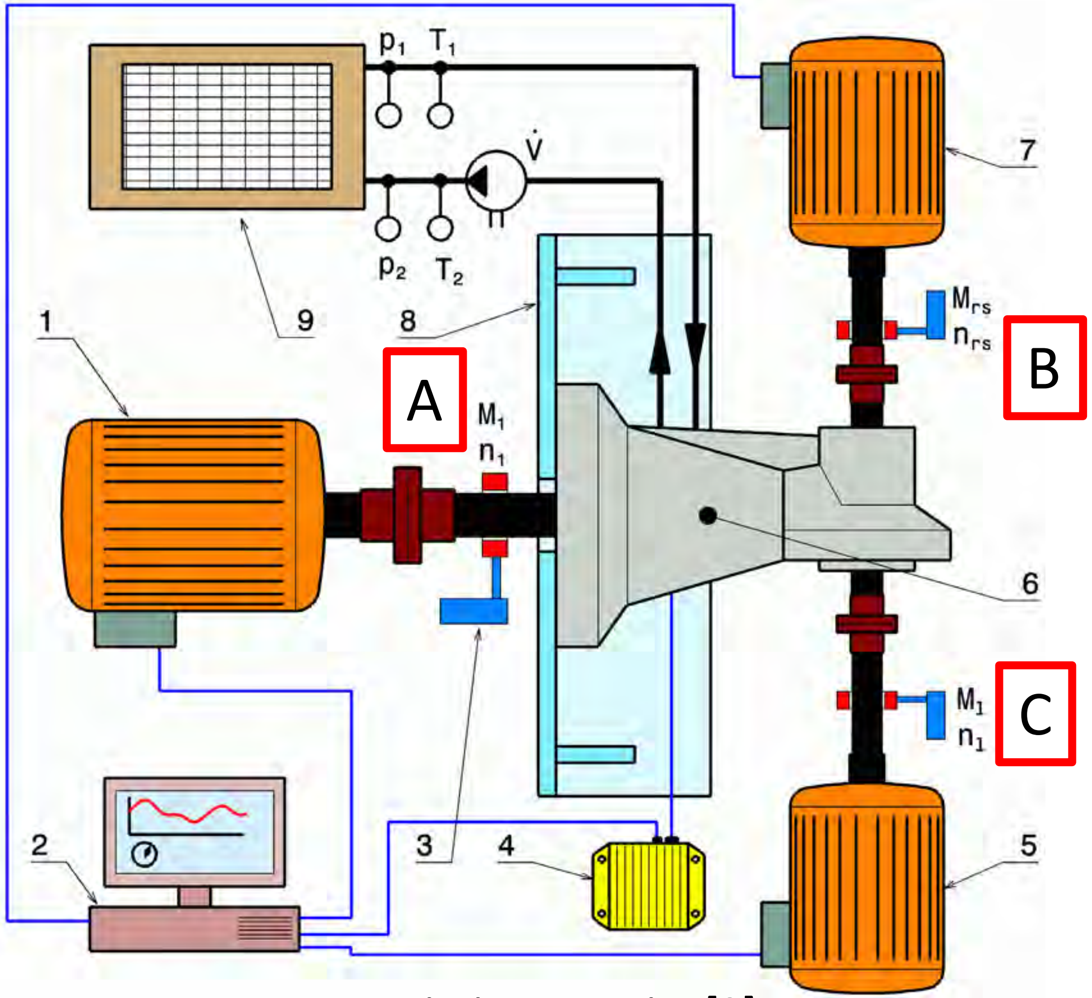
- Mechanical power:

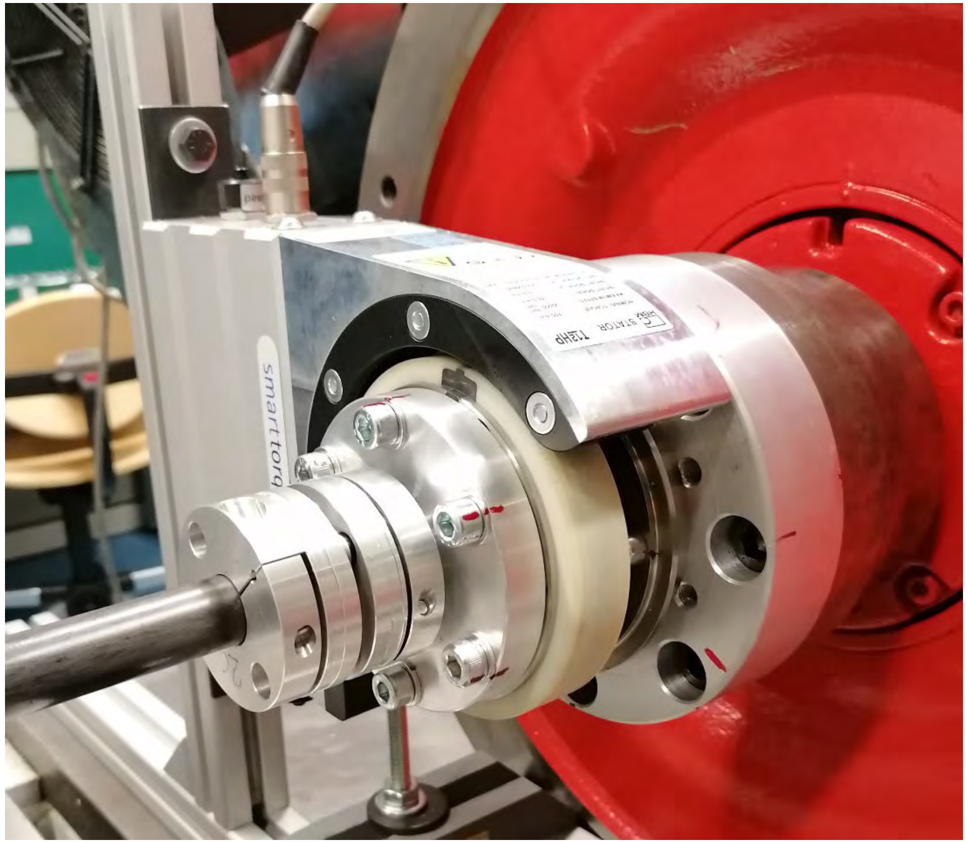
$$P_{\mathrm{mech}} = T \cdot \omega$$
$$\omega = 2 \cdot \pi \cdot n$$

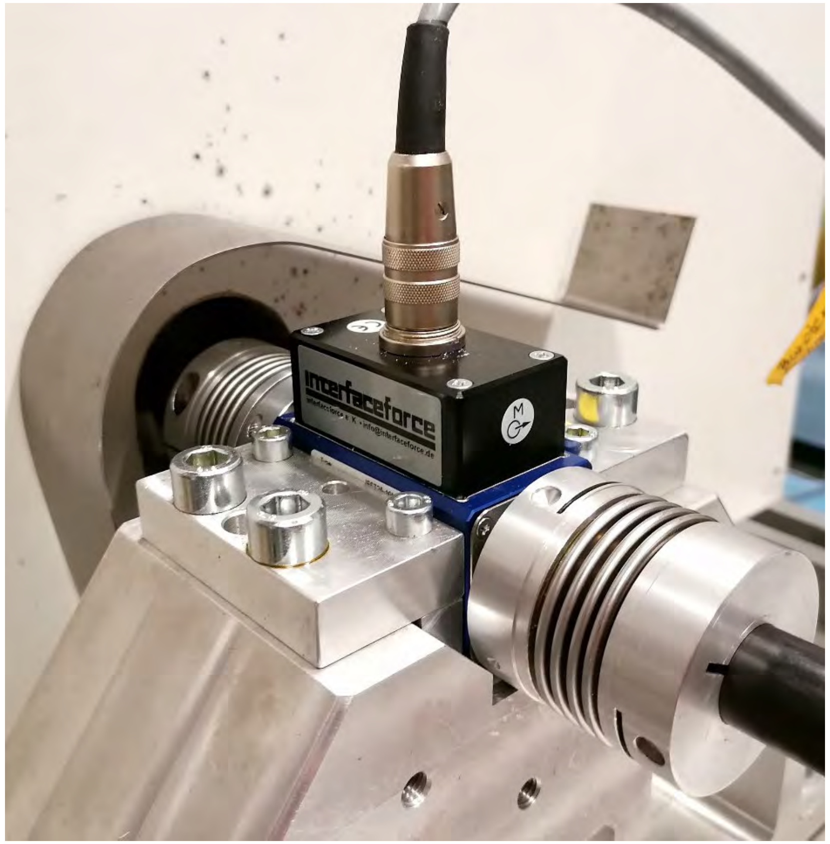
- Torque T and speed n must be measured to calculate P_{mech}
- To determine the efficiency of the Device under Test (DUT → 6), the power at A (input) as well as B and C (output) must be measured with high accuracy.



Transmission test rig: [2]

Sensors for torque and speed





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Quality Management, [1]

- Accreditation regarding to the standard ISO EN IEC 17025
- Scope of accreditation:
  - EGV 715/2007*ECR
  - 715/2007*CEReg 715/2007
  - EPA 40 CFR Part 86
  - 3 UN GTR No. 19

Bundesministerium
Digitalisierung und
Wirtschaftsstandort

Die Nationale Akkreditierungsstelle / *The National Accreditation Body:*

AKKREDITIERUNG AUSTRIA

bestätigt die Akkreditierung der Rechtsperson / *confirms the accreditation of*

FH JOANNEUM Gesellschaft mbH
Alte Poststraße 149, A-8020 Graz

Identifikationsnummer / *ID-number:* **0222**
als / *as* **Prüfstelle / *Testing Laboratory***
gemäß / *according to* **EN ISO/IEC 17025:2017**
Datum der Erstakkreditierung / *Initial date of accreditation:* **17.02.2004**

Standort/Organisationseinheit / *site/unit:*
Institut Fahrzeugtechnik / Automotive Engineering, Alte Poststraße 149, A-8020 Graz

Informationen zum Akkreditierungsumfang und zu Akkreditierung Austria / *Information about the accreditation scope and Akkreditierung Austria* http://www.bmdw.gv.at/akkreditierung

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Dipl.-Ing. Dr. Norman Brunner
Wien, am 11. Dezember 2019

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References

[1] https://www.fh-joanneum.at/labor/prueffeld-fuer-fahrzeuge/

[2] Michael Trzesniowski: *Rennwagentechnik: Datenanalyse, Abstimmung und Entwicklung*. Springer Vieweg, 2017

Engineering Knowledge Transfer Units to Increase Student´s Employability and Regional Development

Layouts for Drivetrain Testing

K. Reisinger

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Aim of testing

Functional Testing

e.g. calibration of automated gear shift operation; dynamic of a shift operation

- simulation of special subsystem states in car (engine speed, vehicle speed)
- development of functional software
- measuring systems behaviour

Characteristics

- same behaviour as in the car
- high flexibility to test different states

Fatigue Testing; Measuring Characteristics

e.g. durability of a gearbox; efficiency map of a drive

- simulation of defined subsystem states (engine speed, engine torque)
- loads for durability
- measuring systems properties

Characteristics

- defined load states, often steady state
- high automation to get high repeatability

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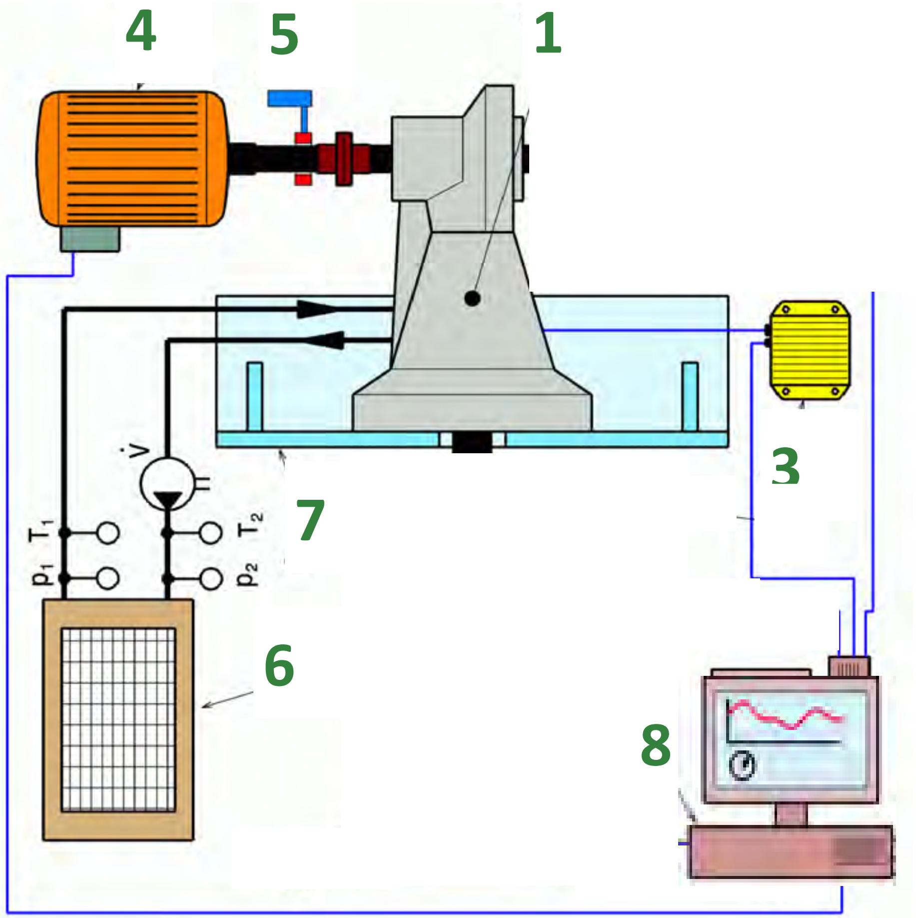
1-M Layout – for Spin Losses



- Spin Loss Test
- Strip Down Test

1+2 Device under test (DUT)

1 Gear Box
2 ECU of Gearbox (opt.)

3 … open

4 machine (speed control)

5 torque + speed measurement

6 conditioning unit for oil and/or cooling liquid

7 rig

8 rig control system

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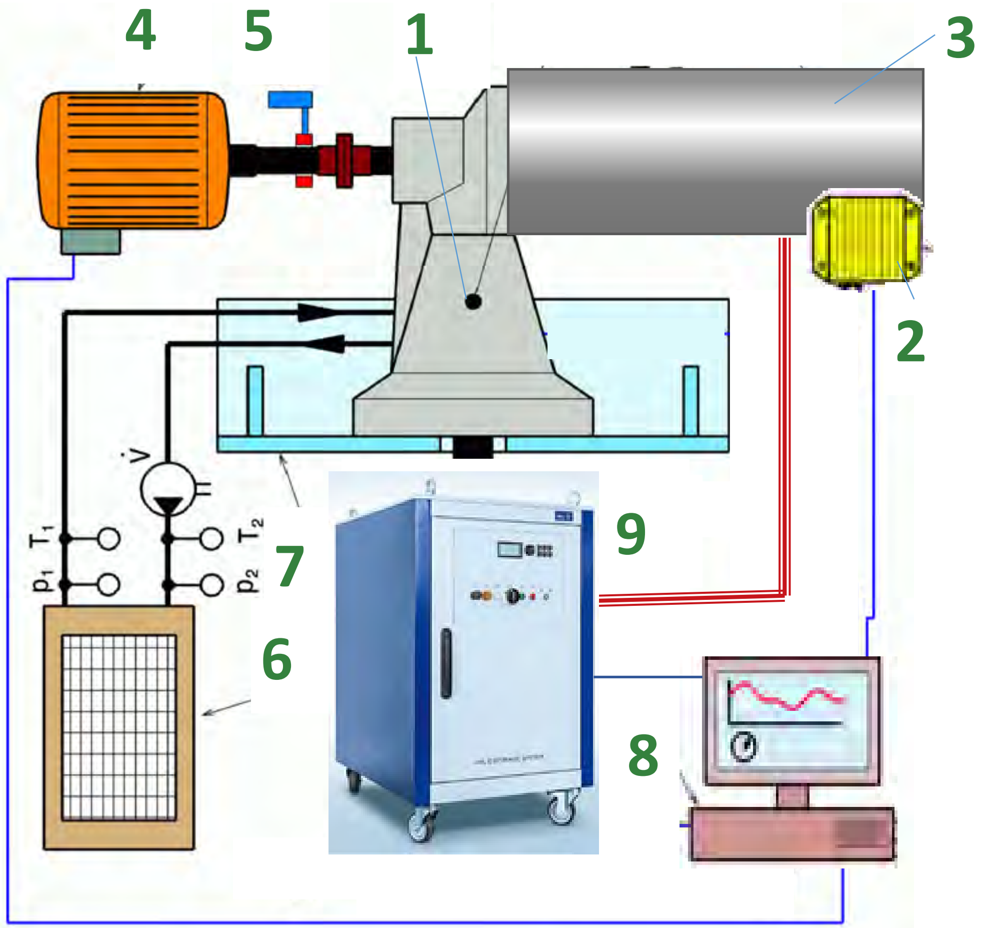
1-M Layout – for Drives



- **E-Drives, with/without gear box**
- **ICE with/without gear box**

1 gearbox or mounting rig

2 ECU

3 inverter + motor or ICE (accel. pedal control)

4 electrical machine (AC, 4-quadrant speed control)

5 torque + speed measurement

6 conditioning unit for oil and/or cooling liquid

7 rig

8 rig control system

9 battery emulator or fuel + exhaust gas connection

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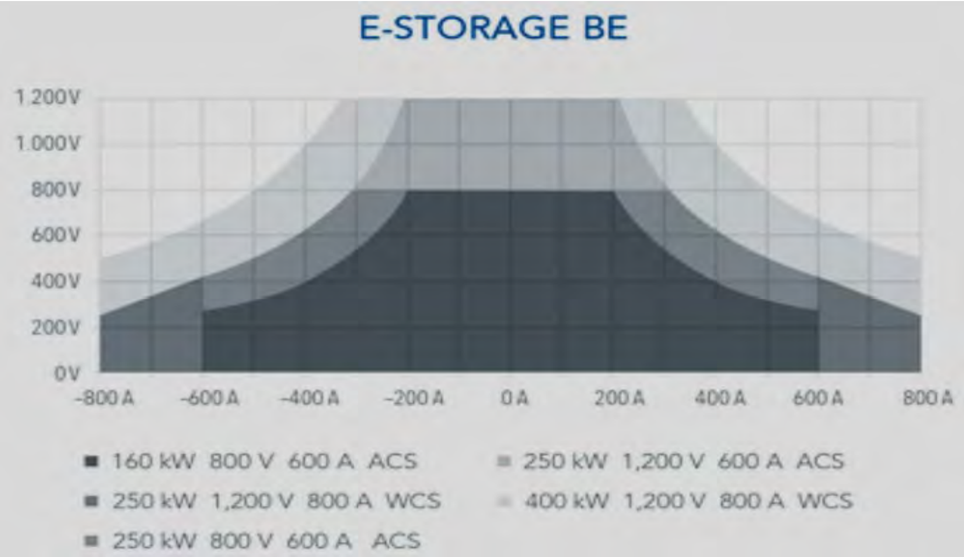
Battery Emulator

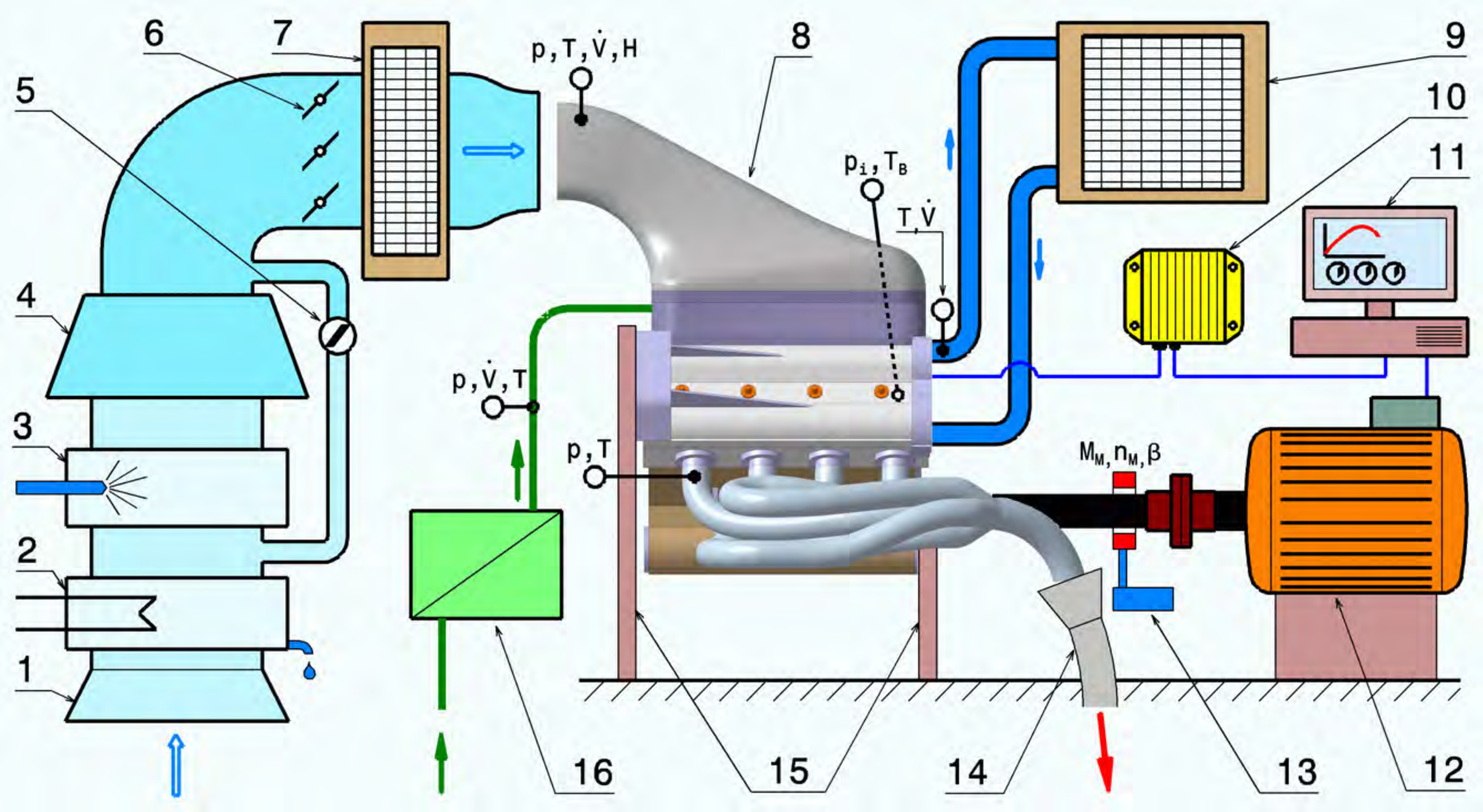
- Hazard of fire using pre-serial-production batteries in rooms.
- Different Systems for HV and LV needed (common GND at LV)
- Testing at a defined SOC, SOH and battery temperature



AVL E-Storage Systems 2019

Left: Power Distribution Unit ("plug")
Right AVL E-Storage HD 400 kW, 1200 V, 800 A in cellar of FHJ

ICE Engine Test Rig



1..7 air conditioning

8 engine

9 cooling water conditioning

10 ICE-ECU

11 rig control system

12 el. machine

13 torque + speed measurement

14 Exhaust gas analyser

15 rig

16 fuel conditioning

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[Trzesniowski: Rennwagentechnik: Datenanalyse, Abstimmung und Entwicklung. Springer Vieweg, 2017]

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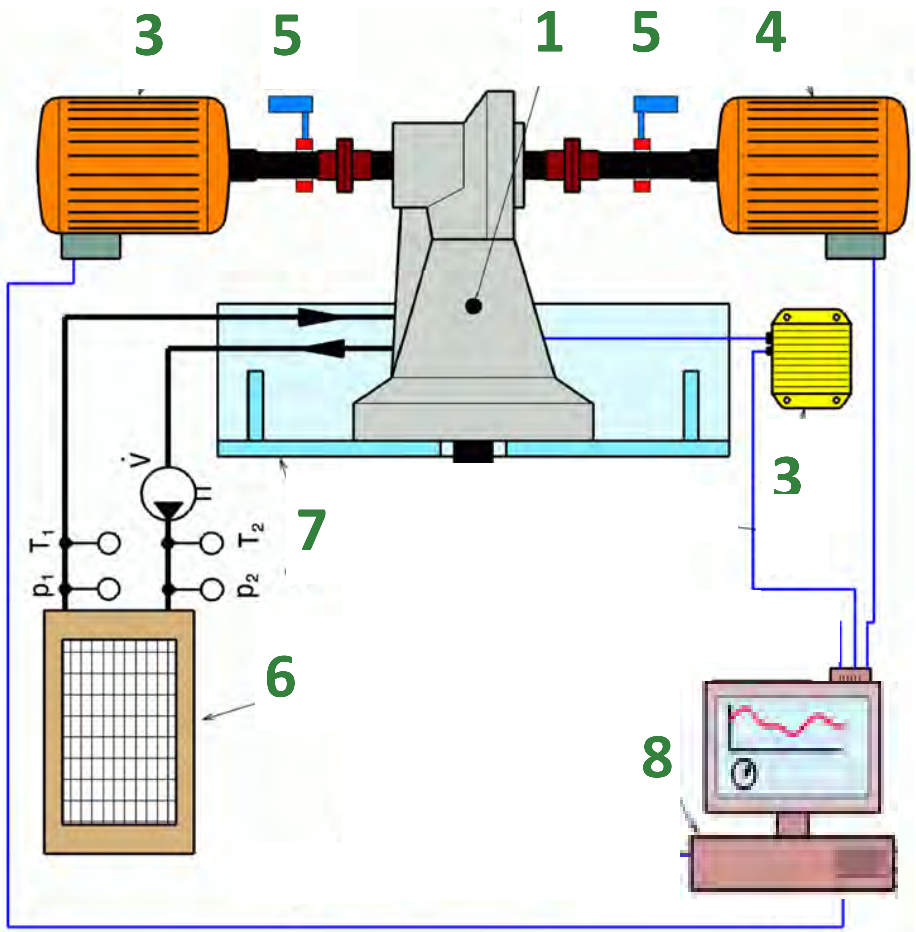
2-M Layout – for Gear Boxes



- automated/manual transmission gearbox
- single speed gearbox (for E-Drive)
- Efficiency

1 unit under test (UUT) = Gear Box

2 ECU of Gearbox (opt.)

3 el. machine (torque control)

4 machine (speed control)

5 torque + speed measurement

6 conditioning unit for oil and/or cooling liquid

7 rig

8 rig control system

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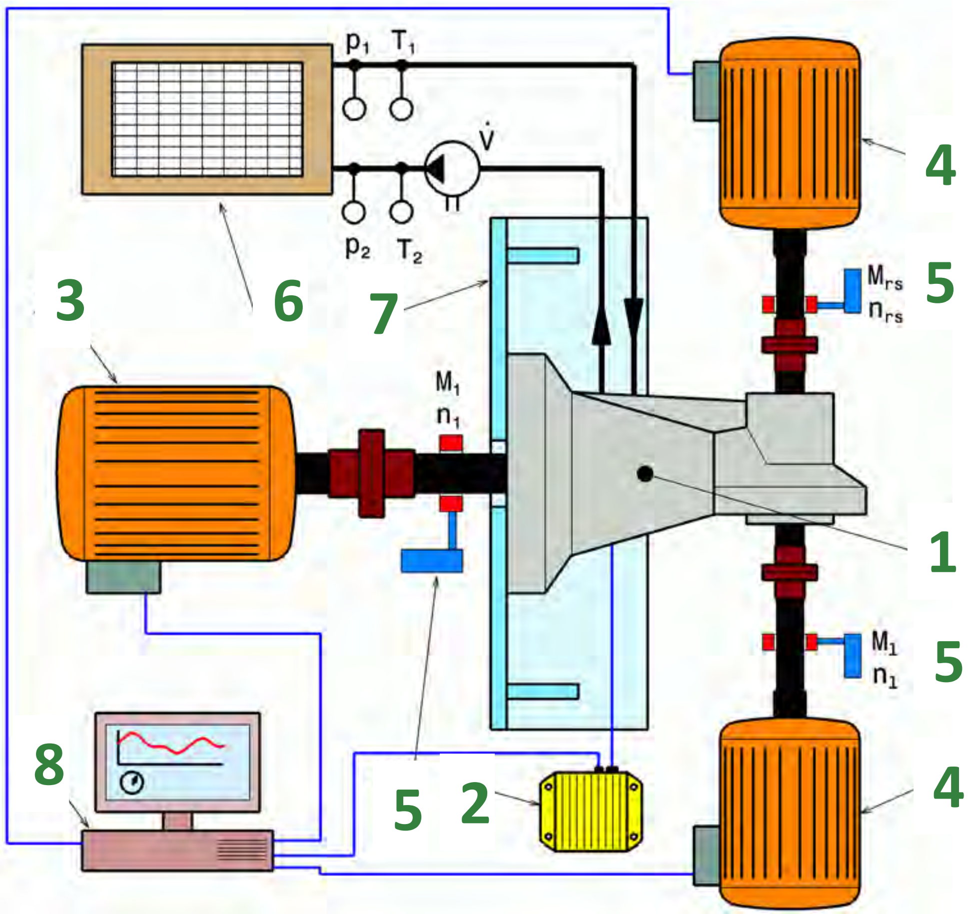
3-M Layout – for Axle Drive Gearboxes



- **Axle drive gearbox**
- **AWD centre differential gearbox**

1 unit under test (UUT)

2 ECU of UUT (opt)

3 el. machine (e.g. torque-control)

4 2x el. machine (e.g. speed control)

5 torque + speed measurement

6 conditioning unit for oil and/or cooling liquid

7 rig

8 rig control system

[Trzesniowski: Rennwagentechnik: Datenanalyse, Abstimmung und Entwicklung, Springer Vieweg, 2017]

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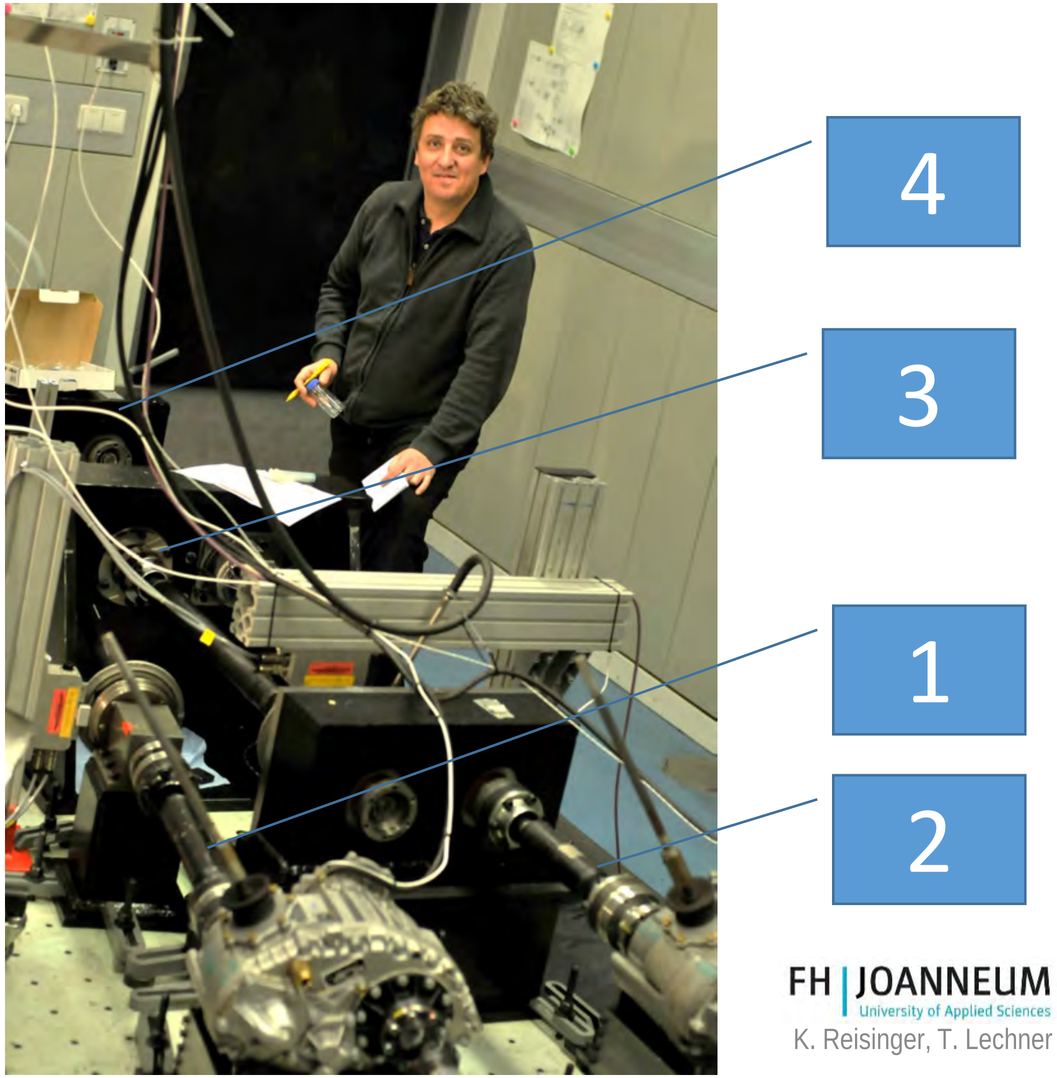
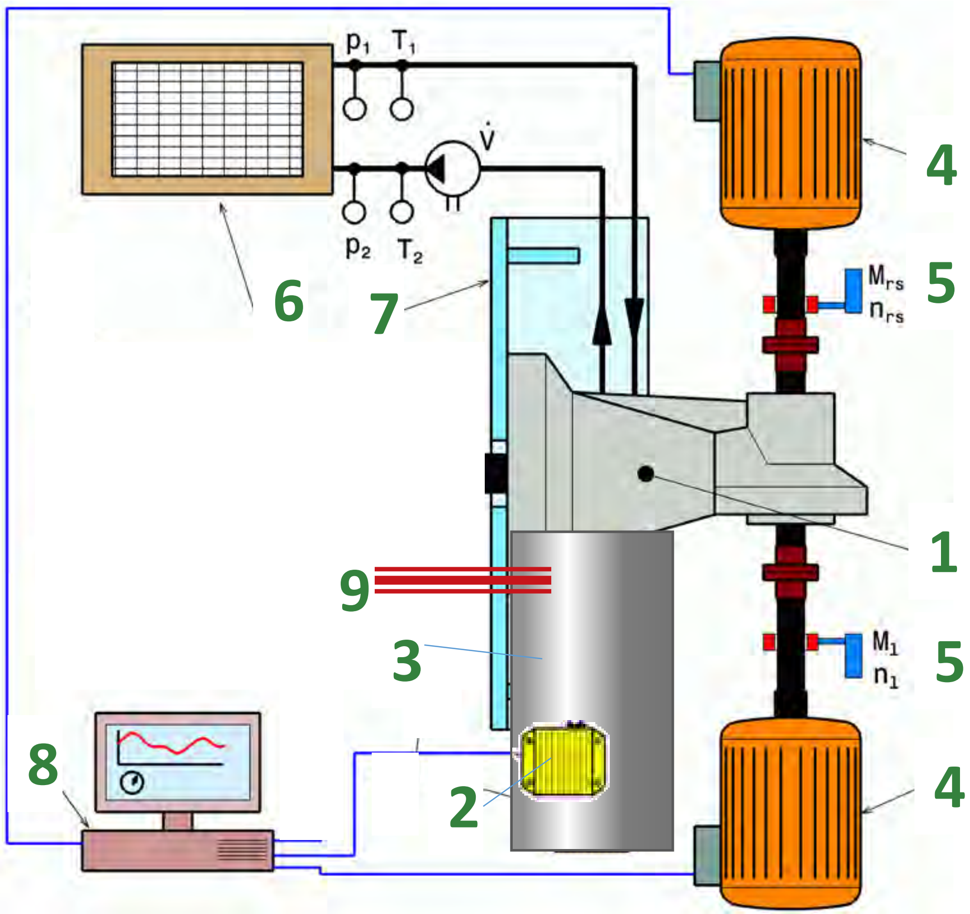
3-M Transmission Test Rig

- Arrangement for Centre Differential Gearbox
  - 1 .. Input shaft
  - 2 .. front output shaft
  - 3 .. DUT
  - 4 .. rear output shaft



Picture: [Trzesniowski]

2-M Layout – for Axle Drives



- **Axle drive units, E-Drive/HEV-drive/ICE**

1 gearbox

2 ECU

3 inverter, motor (accel. pedal control)

4 2x el. machine (e.g. speed control)

5 torque + speed measurement

6 conditioning unit for oil and/or cooling liquid

7 rig

8 rig control system

9 battery emulator or fuel + exhaust gas connection

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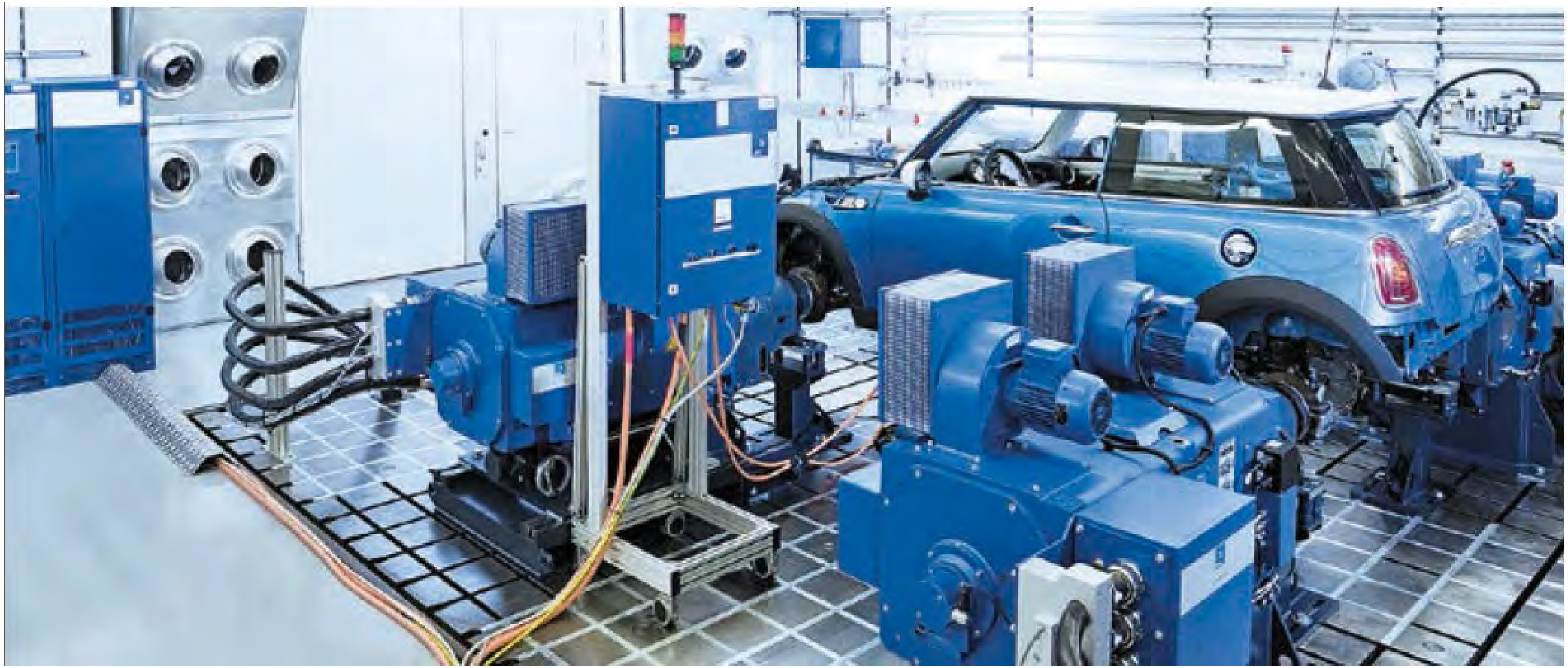
Vehicle Drivetrain Test
Advantage: Simple Interface



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see also https://www.avl.com/racing
[https://www.avl.com/de/-/vehicle-in-the-loop-test-system]

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e.g. Rear Drive Module at test bench

Objective: 6 DOF Unit motion due to torque

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Position sensors pick-up point B01 in x, y, z direction

Interfaces for inverter and data logger

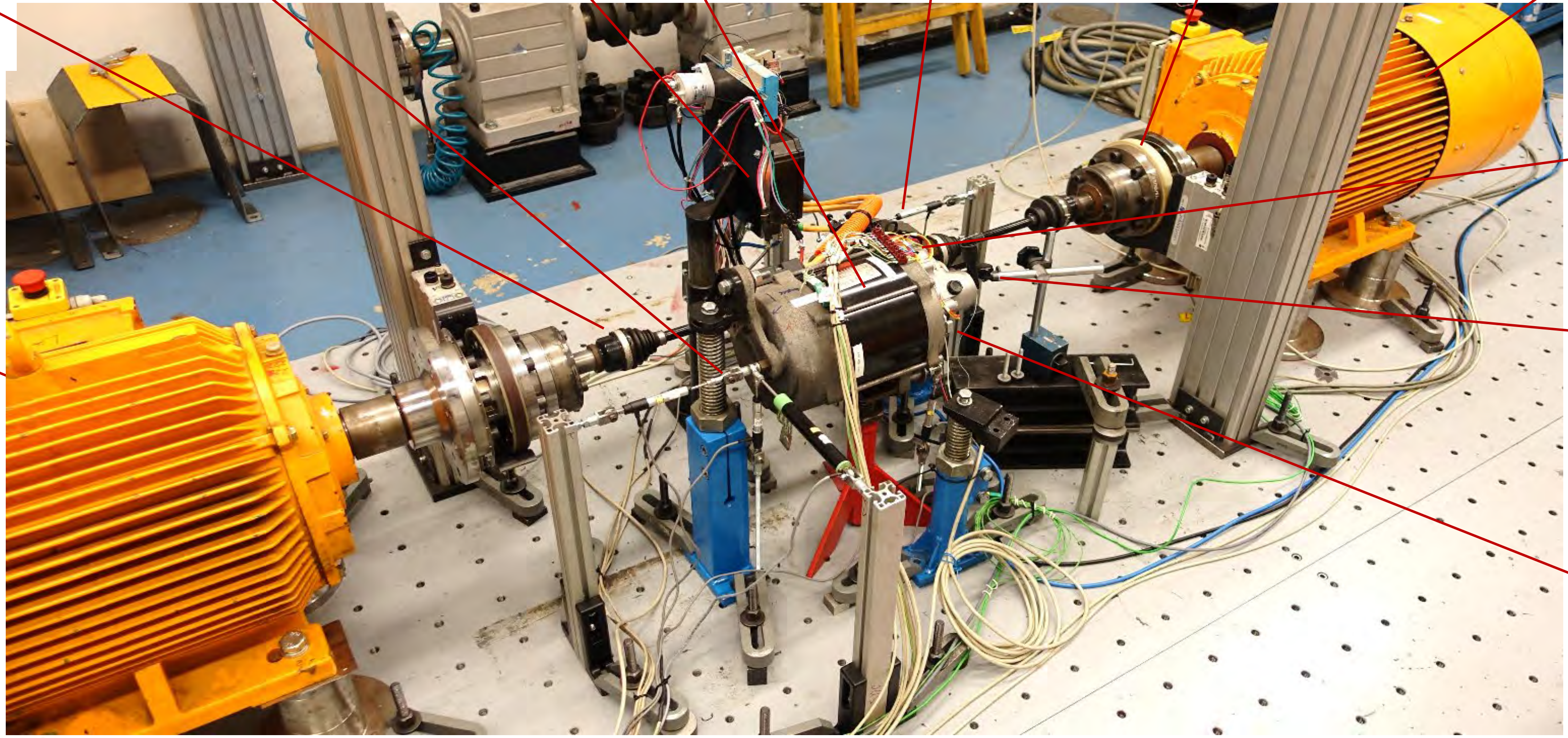
Complete Renault Twizy drive line

Position sensors B03 in x,y,z direction

Torque flange left-hand

e-machine left-hand wheel

Stock drive shafts



E-machine right-hand wheel

3 strain gauges on transmission case

Automotive angular sensor

Position sensor B02 in z direction

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Reisinger K. et al.: Endbericht Innovationsscheck Plus 2017, FH Joanneum , Mar. 2019. (*Final report of cooperation project*)

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Spin- and Power Losses

K. Reisinger

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Efficiency Description

Simple Approach

$$P_{out} = \eta \cdot P_{in}$$

- **No load, no loss.**
- We have "Spin Losses" also when transferring no power. They are small compared to max. power.
- **Efficiency approach is sufficient at high power**, when non-load-dependent losses are small, compared to load-dependent ones.

P .. power at subsystems' interface,
$\eta = \frac{P_{out}}{P_{in}}$ .. efficiency,
M .. transferred torque,
n ... speed, T.. temperature

Problem

- WLTC has a lot of low power phases. Small constant losses become important.
- They are in the focus of current drivetrain development.

Exact Solution

$$P_{Loss} = f(M, n, T),$$
$$P_{out} = P_{in} - P_{Loss}$$

Approach: Spin Losses

$$P_{Loss} = f_1(n, T) + f_2(M)$$
$$= f_1(n, T) + (1 - \eta) \cdot P_{in}$$

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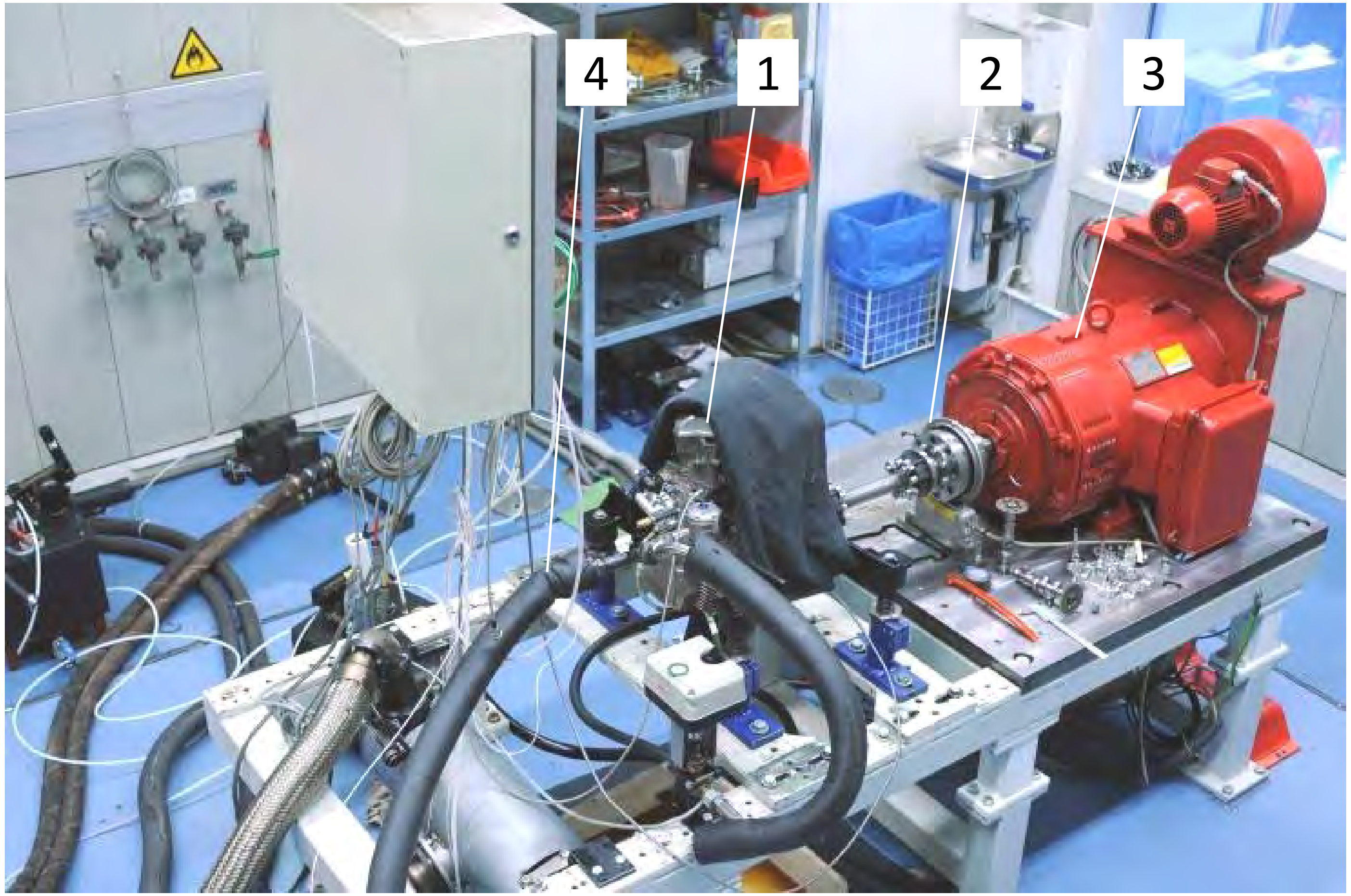
Spin Loss Measurement



1 Device Under Test
Gearbox, non fired ICE

2 sensitive torque measurement device
(2-10 Nm at gearboxes)

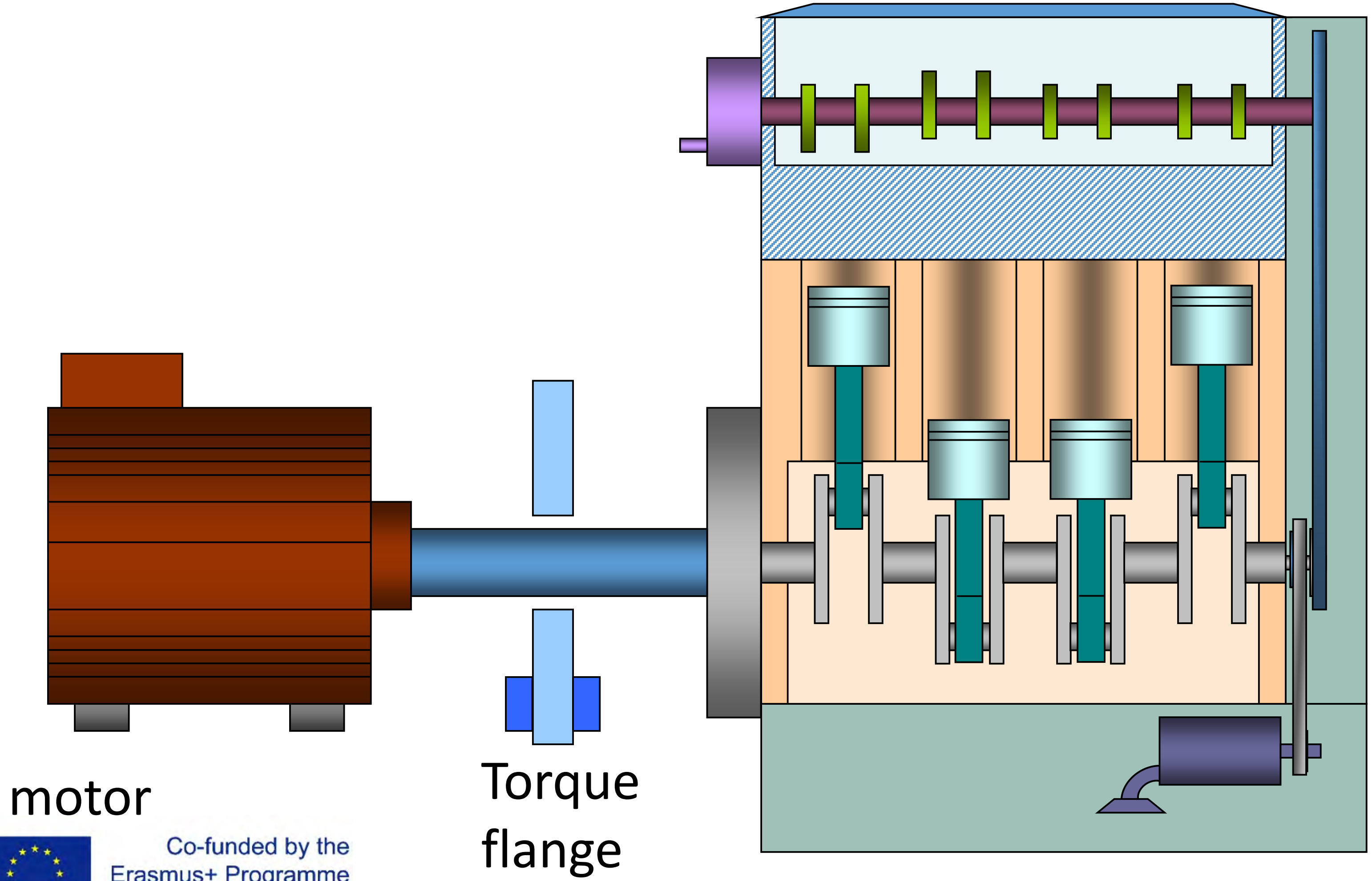
3 test bench motor
(speed control)

4 Conditioning of lubricant and /or housing air temperature

[Picture: Trzesniowski]

Cause – Effect – Analysis
Strip Down Test

UNITED



Strip-down method

[M. Trzesniowski]

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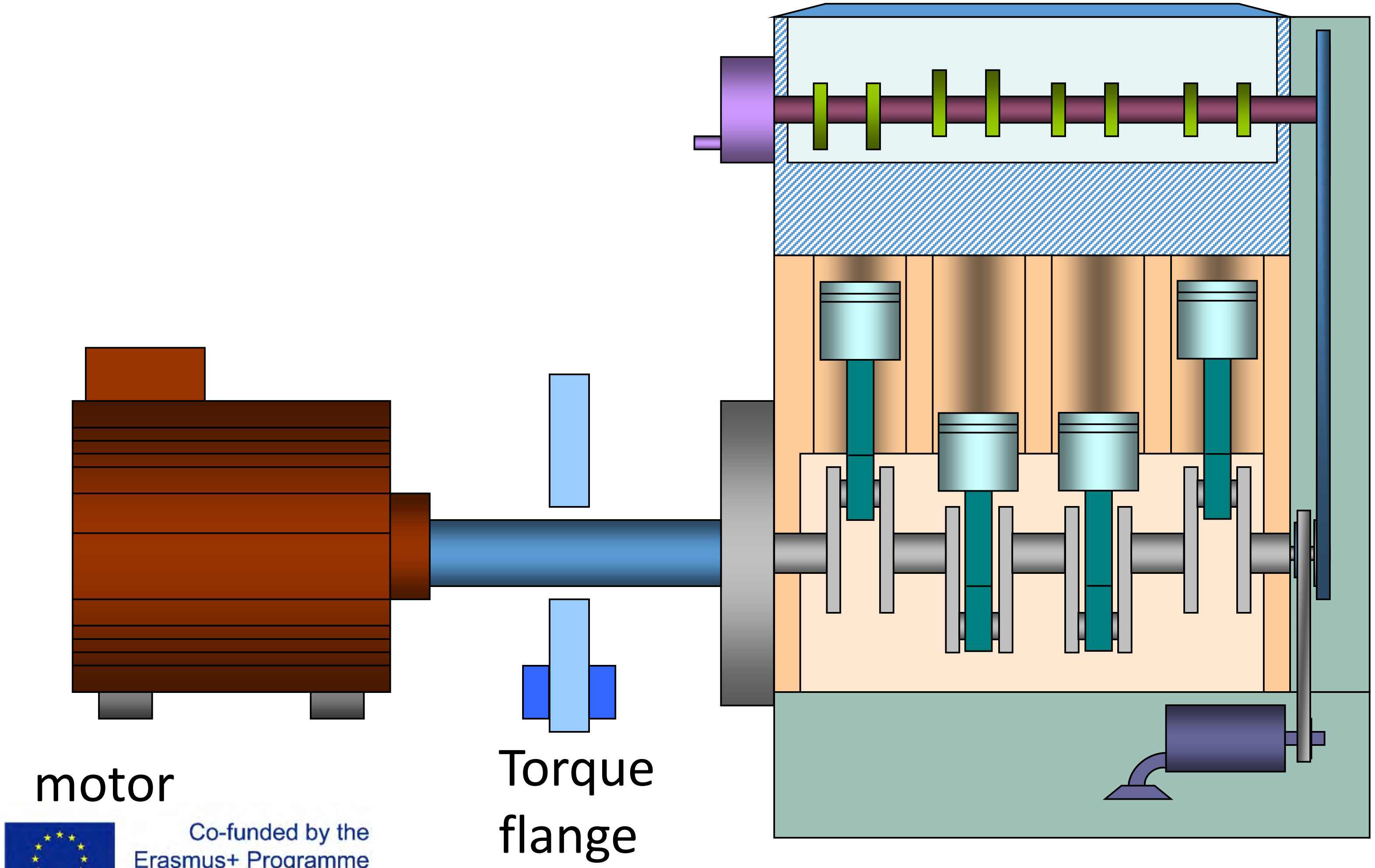
Cause – Effect – Analysis
Strip Down Test 2



[M. Trzesniowski]

Focus on

- reproducible temperature state
  - Box housing + heater/cooler
  - conditioning of all liquids
- reproducible, accurate torque measurement
  - Offset-Drift
  - smoothing torsional vibrations, avoid Aliasing!
- reproducible assembly influence

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Results of Spin Loss Tests

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1. Test matrix

Engine: xyz

Part / Filename	Crankshaft	Pistons & conrods	Oil pump	Cylinder head / valvetrain	Vacuum pump	Alternator	Power steering pump	A/C pulley	Idler pulley and tensioner	Oil level (l)	Oil temp (°C)	Valve lift (mm)
-000001	●	●	●	●	●					4	~ 90°	9,6
-000002	●	●	●	●	●					3	35	9,6
-000003	●	●	●	●	●					3	90	9,6
-000004	●	●	●	●	●					4	90	9,6
-000005	●	●	●	●	●					2	90	9,6
-000006	●	●	●	●	●					1	90	9,6
-000007	●	●	●	●	●					3	120	9,6
-000008	●	●	●	●	●					3	140	9,6
-000009	●	●	○		○					1	90	
-000010	●	●	○		○					2	90	
-000011	●	●	○		○					3	90	
-000012	●	●	○		○					4	90	
-000013	●	●			○					1	35	

- array of tests
- torque / power loss at each assembly state
- The difference between two assembly states is the component's contribution

But remember:
the losses are maps $P(n,T)$

→ highly automated test procedure is necessary

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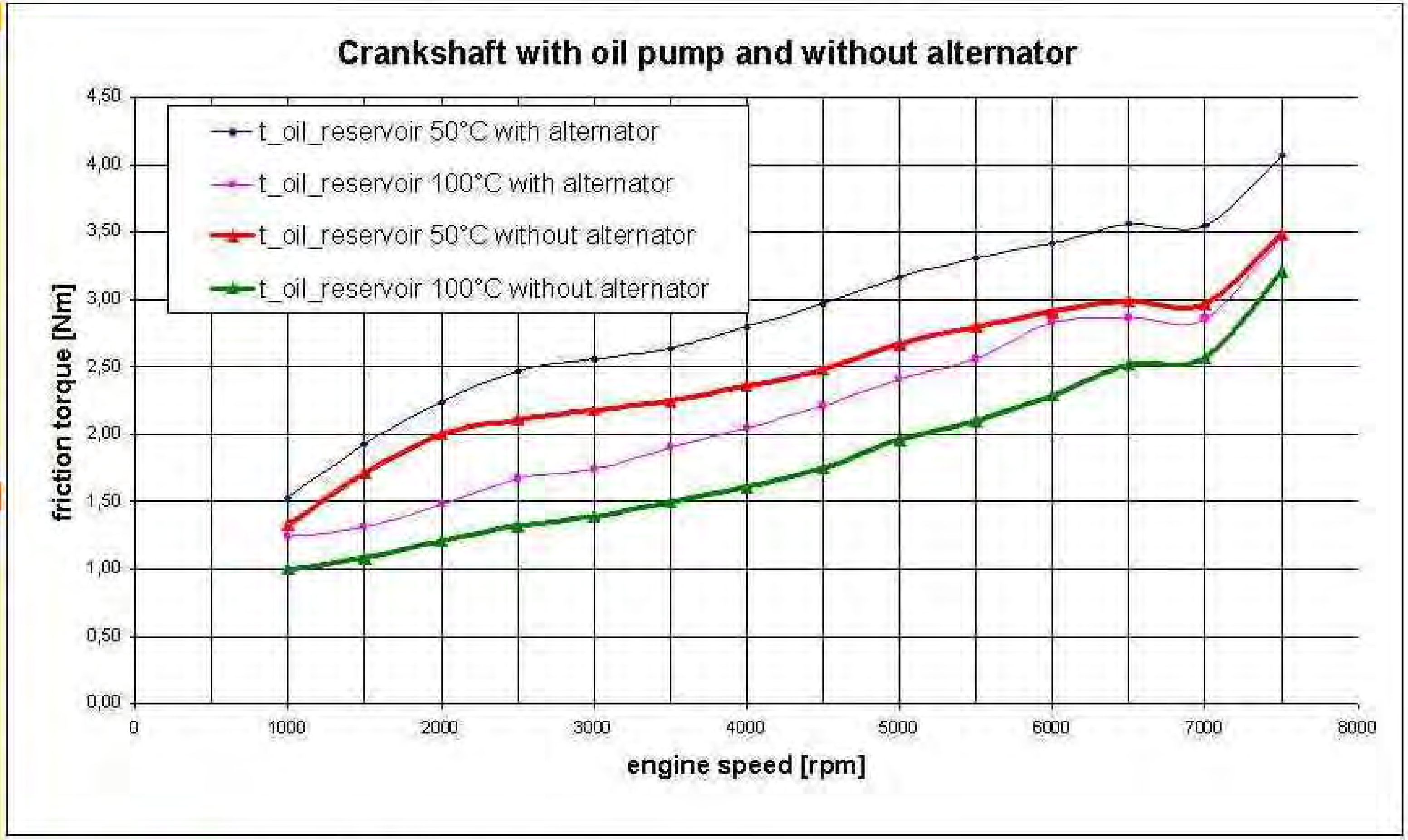
Losses of an ICE at an assembly state

t_oil_reservoir 50°C		
n	Md	Md
1000	1,53	1,33
1500	1,93	1,71
2000	2,24	2,00
2500	2,47	2,11
3000	2,56	2,18
3500	2,64	2,25
4000	2,80	2,36
4500	2,97	2,48
5000	3,17	2,67
5500	3,31	2,80
6000	3,42	2,91
6500	3,56	2,99
7000	3,55	2,97
7500	4,07	3,49

t_oil_reservoir 100°C		
n	Md	Md
1000	1,24	1
1500	1,31	1,08
2000	1,48	1,21
2500	1,67	1,32
3000	1,74	1,39
3500	1,9	1,5
4000	2,05	1,61
4500	2,21	1,75
5000	2,41	1,96
5500	2,56	2,1
6000	2,83	2,29
6500	2,87	2,52
7000	2,86	2,57
7500	3,47	3,21



Md Crankshaft with oil pump and alternator
Md Crankshaft with oil pump and without alternator

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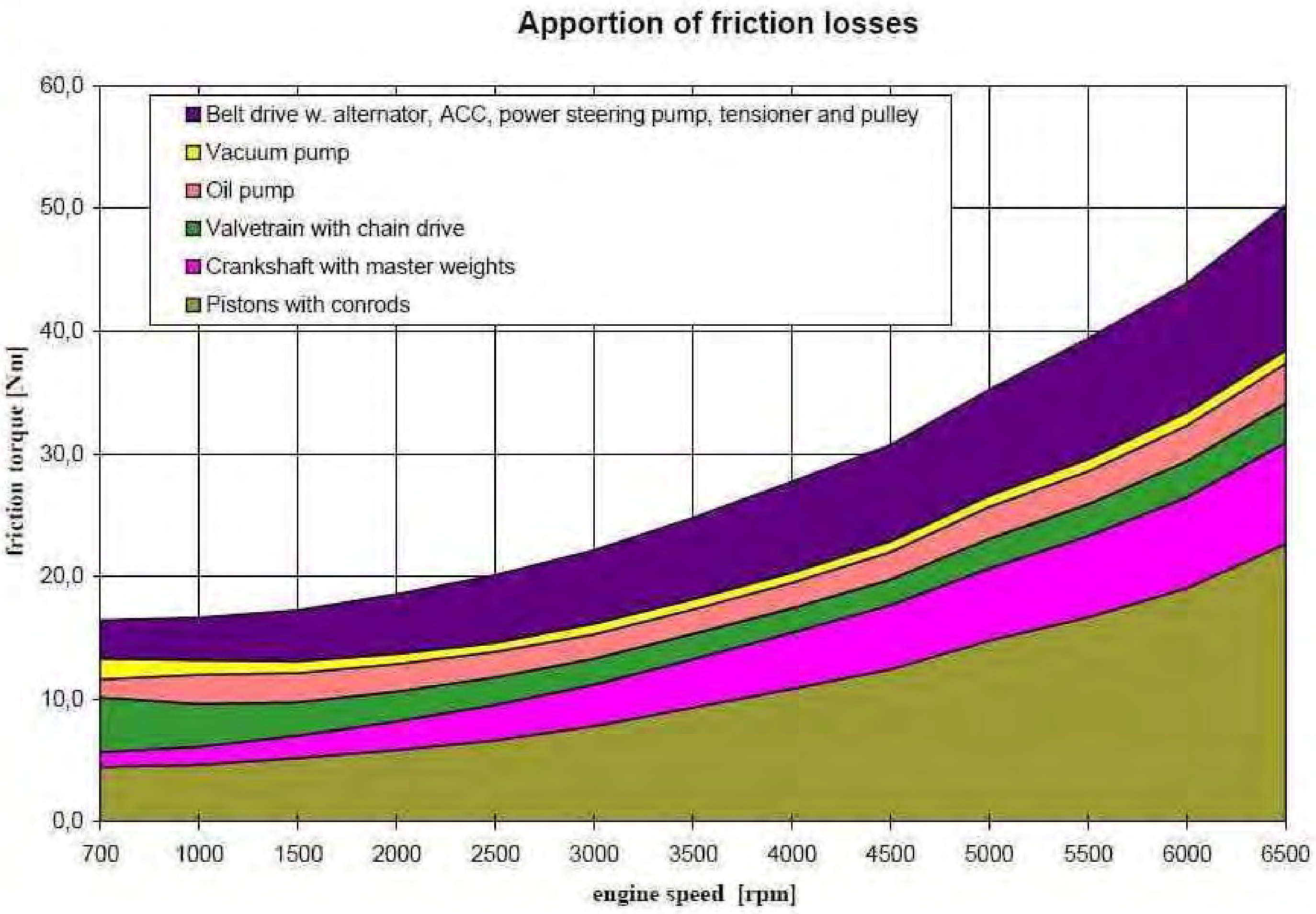
Losses of an ICE

n_KW U/min	Vacuum pump Md Nm	Pistons with conrods Md Nm	Crankshaft with master weights Md Nm	Valvetrain with chain drive Md Nm	Oil pump Md Nm	Belt drive w. alternator, ACC, power steering pump, tensioner Md Nm
700	1,7	4,5	1,2	4,5	1,5	3,2
1000	1,2	4,6	1,5	3,5	2,4	3,5
1500	1,0	5,2	1,9	2,7	2,4	4,2
2000	0,9	5,9	2,3	2,4	2,3	4,9
2500	0,8	6,6	2,8	2,3	2,1	5,5
3000	0,8	7,8	3,4	2,2	2,0	6,0
3500	0,8	9,3	3,9	2,1	2,0	6,7
4000	0,8	10,8	4,6	2,0	2,1	7,4
4500	0,8	12,4	5,2	2,1	2,3	7,9
5000	0,9	14,8	5,8	2,4	2,6	8,7
5500	1,0	16,7	6,6	2,6	2,7	9,9
6000	1,1	19,1	7,4	2,9	2,9	10,6
6500	1,1	22,6	8,3	3,2	3,3	11,8



Example: Total friction torque at 90°C and 0.5 l oil level of an 3.0l 6 Cylinder SI motor

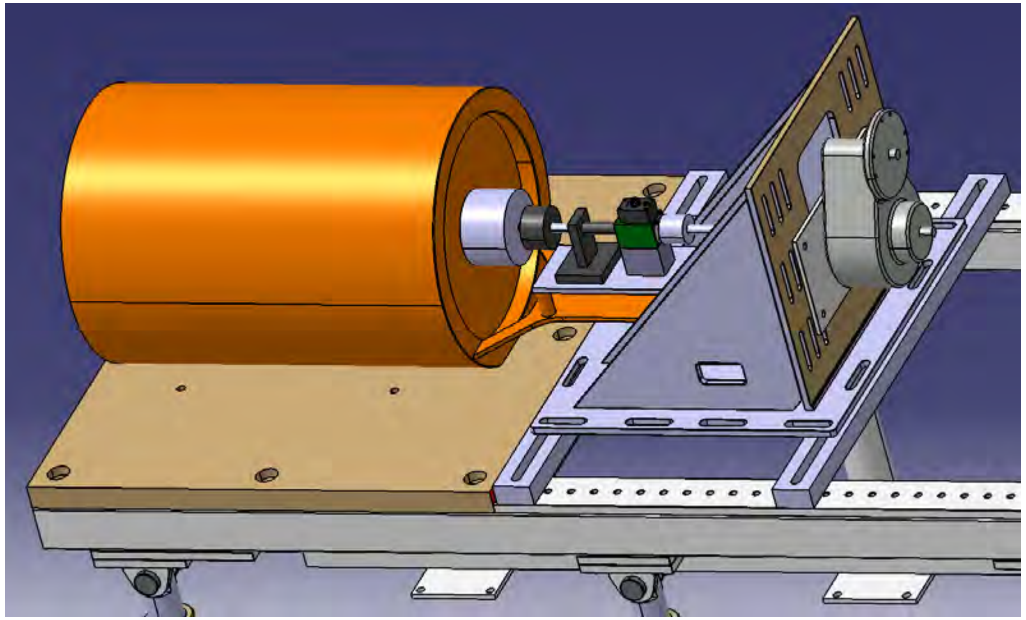
Friction in Gearboxes

Most important at medium speeds

- preloaded bearings
- shaft seals
- churning

At high speeds (> 20.000 RPM) watch also

- bearings and it's lubrication



Test Setup for Gearbox Spin Loss Tests (Housing for temperature conditioning removed)

[K. Laber, 2018]

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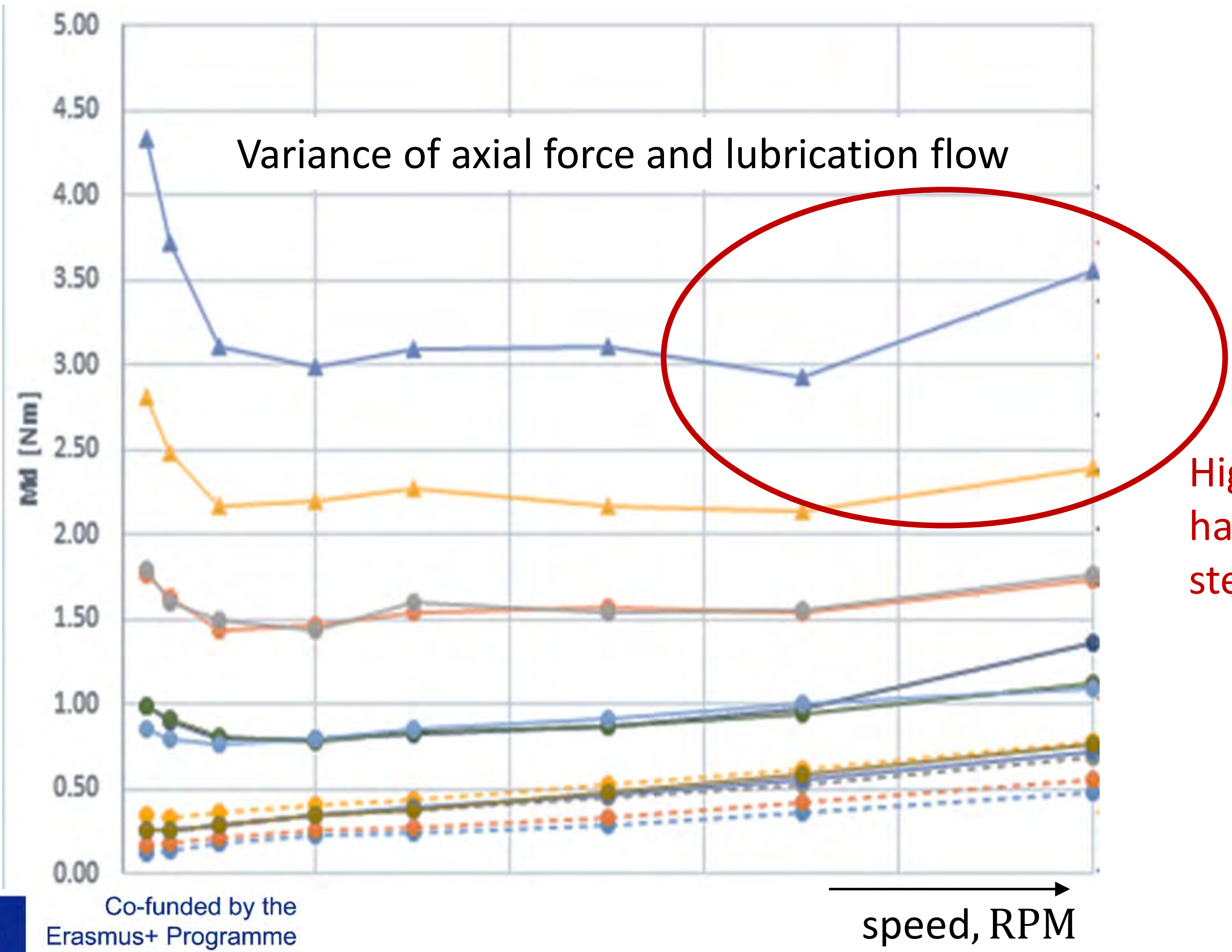
Example:
Losses of 2 Axial Needle Bearings at 80°C



- P_{loss} rises up to kW
- $M_{Loss} = \mathrm{f}(\mathrm{F}_{ax}, \mathrm{n}, \mathrm{T}, \mathrm{Lub.})$

High power input
hard to have (nearly)
steady state temperature

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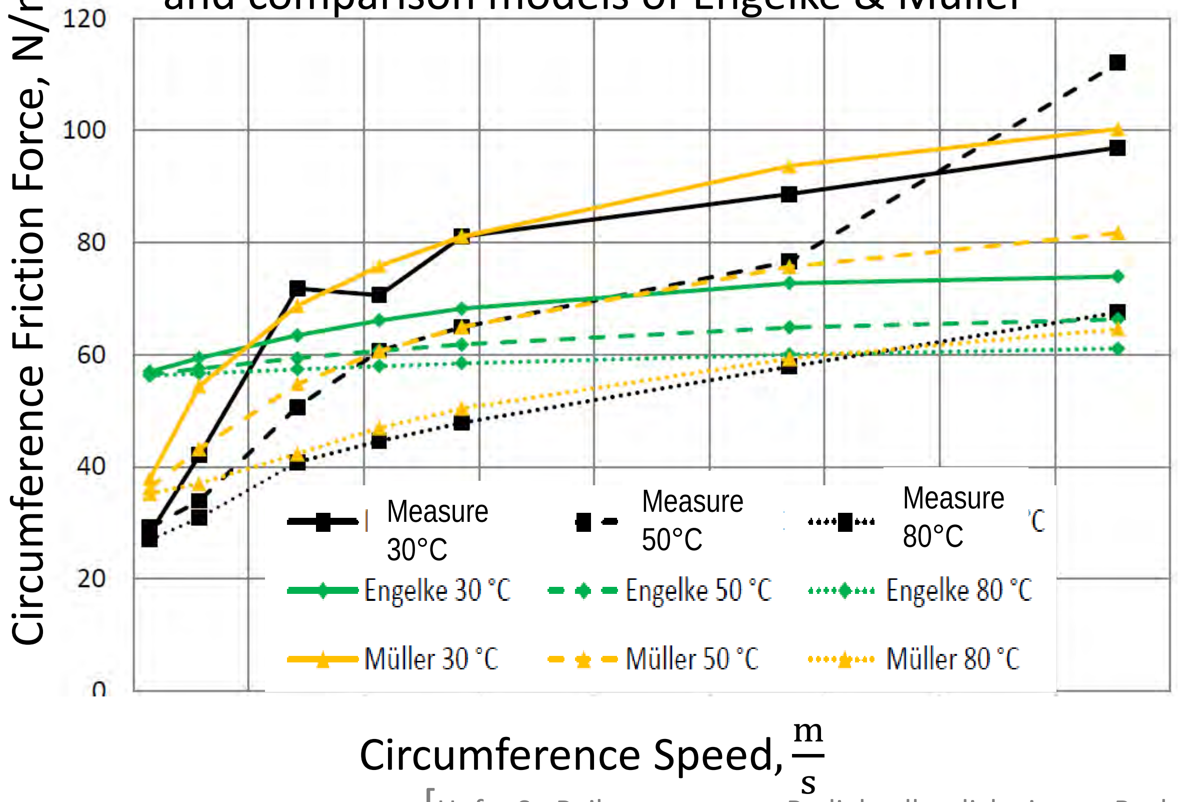
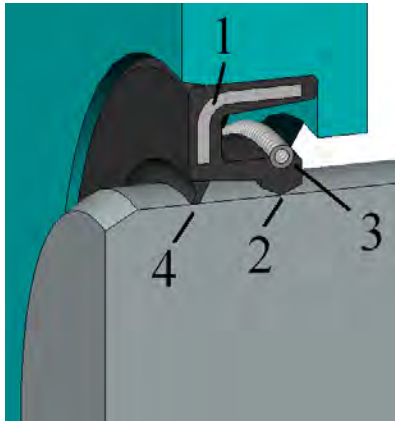
Example
Radial Shaft Seal

results for different housing temperatures
and comparison models of Engelke & Müller





1 .. steel brace
2 .. sealing lip
3 .. spring
4 .. dust lip
[https://de.wikipedia.org/wiki/Wellendichtring]

- Losses are important
- Depends on viscosity of lubricant at the sealing lip
  - depends on temperature at sealing lip
  - depends on thermal conduction
  - depends on timing of the test procedure

[Hofer S.: Reibmoment von Radialwellendichtringen, Bachelors Thesis, FHJ 2017]
[ENGELKE, Tobias: Einfluss der Elastomer-Schmierstoff-Kombination auf das Betriebsverhalten von Radialwellendichtringen. Hannover, Gottfried Wilhelm Leibniz Univ., Diss., 2011]
[MÜLLER, Heinz Konrad: Abdichtung bewegter Maschinenteile : Funktion, Gestaltung, Berechnung, Anwendung. Waiblingen : Medienverlag Müller, 1990

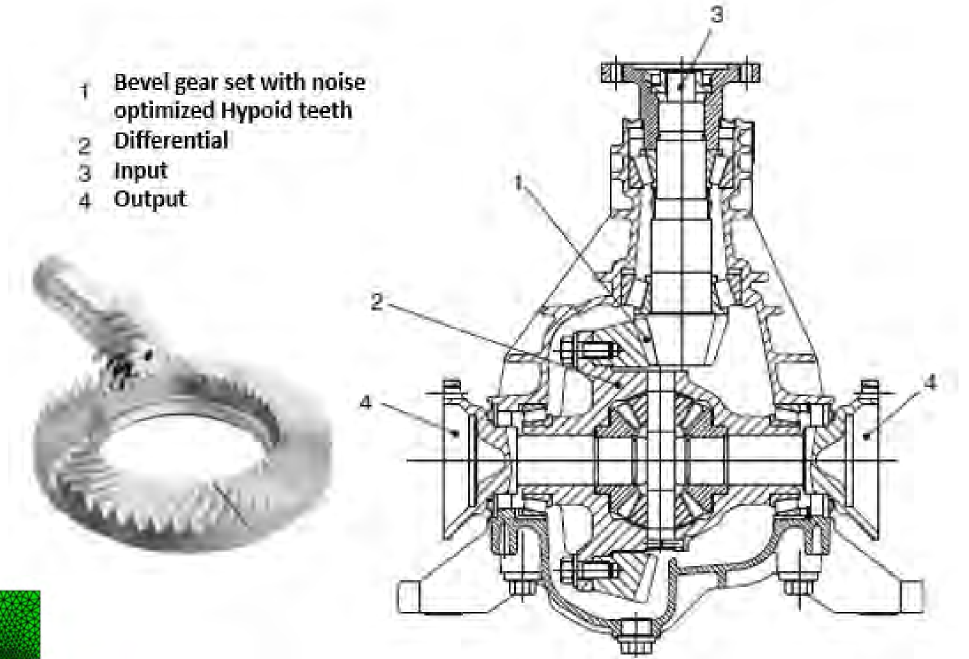
Connection to Student's Projects "Engineering Project" – Gearbox' Efficiency

Objectives

- estimate losses for a driving cycle
- compare to measured values

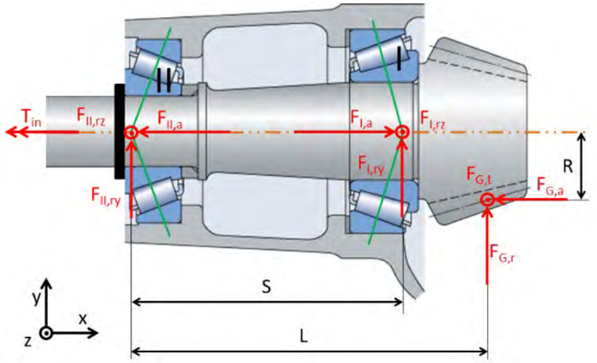
Tasks

- determine loads to components
- estimate losses
- weight them in driving cycle

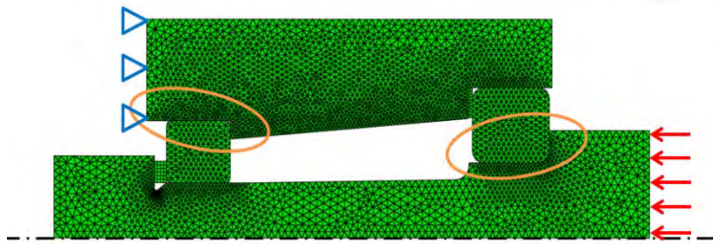


Rear differential gear box

[Platzer P.,Raffelsberger C.,Steinhäusler P.: Engineering Project Thesis, Poster at A3PS Conference, Vienna 2017]



Loads at gears



FEM-Model to determine bearing pre load

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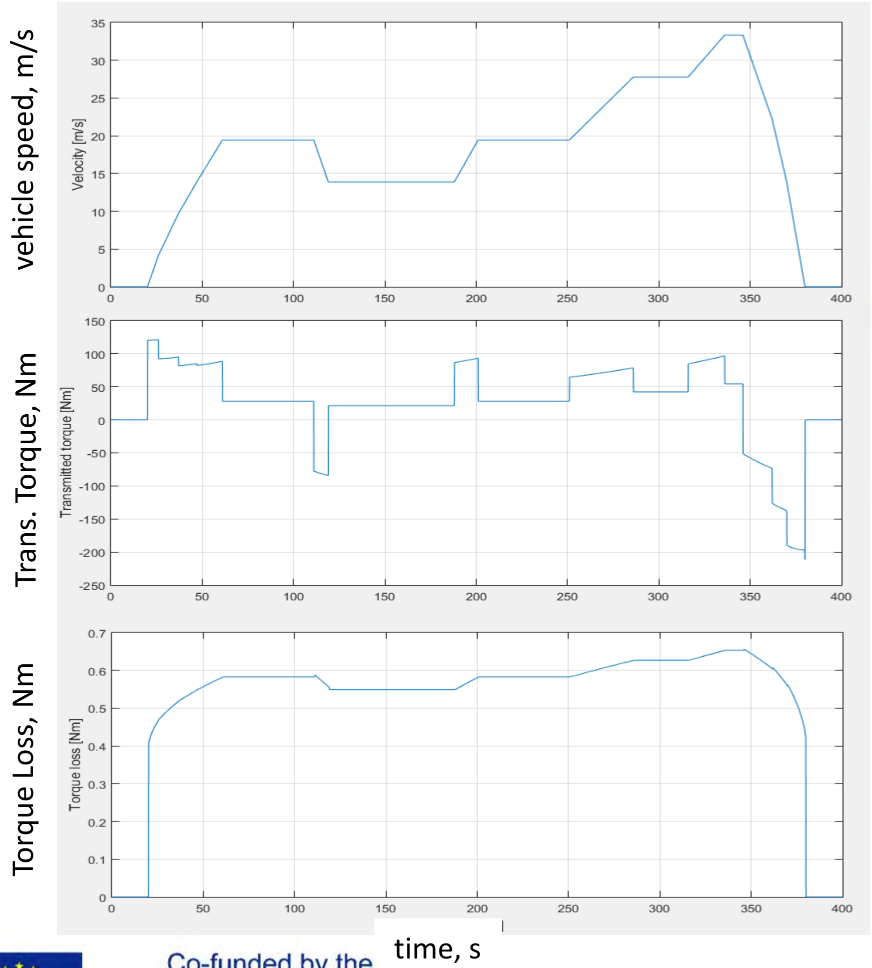
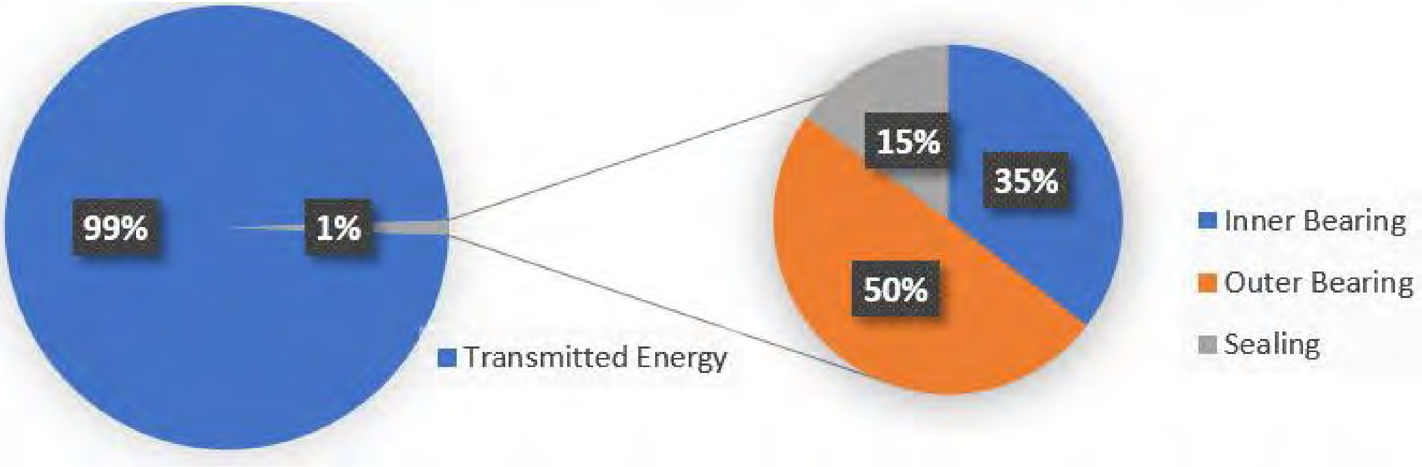
Connection to Student's Projects
"Engineering Project" – Gearbox' Efficiency





[Platzer P.,Raffelsberger C.,Steinhäusler P.: Engineering Project Thesis, Poster at A3PS Conference, Vienna 2017]

Model in Matlab

Engineering Knowledge Transfer Units to Increase Student´s Employability and Regional Development

Efficiency

K. Reisinger

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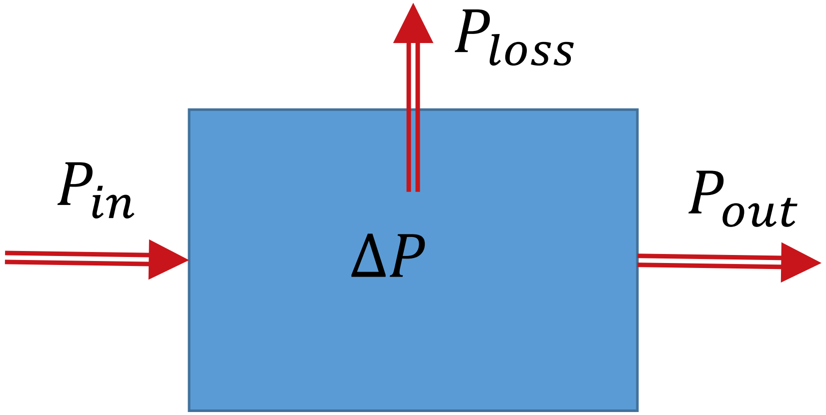
Power-Difference Method



P_{in} .. power effort
P_{out}.. power benefit
ΔP .. power stored in $E_{kin}, E_{pot}, \ldots$
P_{loss} .. losses (typ. thermal)

Power Losses from power effort and power benefit

$$P_{loss} = P_{in} - P_{out} - \Delta P$$

Steady State $\boldsymbol{\Delta P = 0}$

$$P_{loss} = P_{in} - P_{out}$$

E.g. Electric Drive

- Efficiency $\eta = \frac{P_{out}}{P_{in}}, \eta \cong 96\%$ in nominal speed and torque
  $$P_{in} = 1\,000\text{ W}, P_{out} = 960\text{ W}$$
- Accuracy 0.5% at 2 kW, $\pm 1\%$ at 1 kW
- Measured
  $$P_{in} = \binom{1\,010}{990}\text{ W}, P_{out} = \binom{970}{950}\text{ W}$$
  $$P_{loss} = \binom{60}{20}\text{ W} = 40 \pm 20\text{ W} = 40\text{ W} \pm 50\%$$
  $$\eta = \binom{0.98}{0.94}$$

- **Accurate Measurement especially at low power**
- **Consider energy stored in system**

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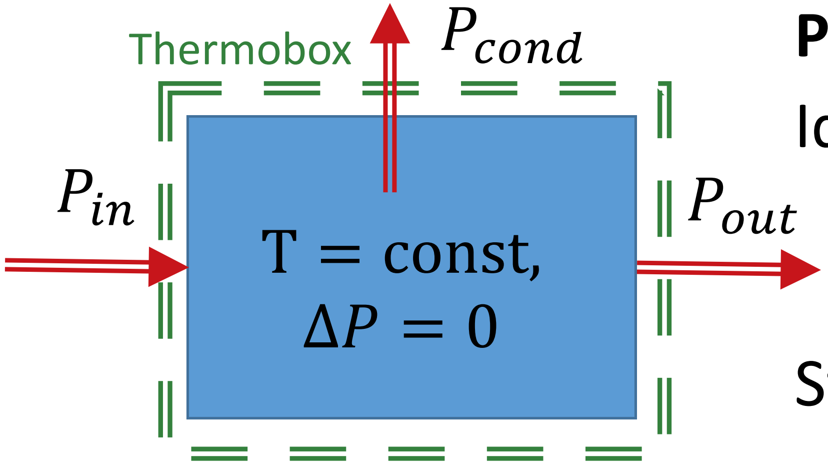
Calorimetric Method



Power Losses using Conditioners Heat Flow

Idea: Losses will be changed to heat

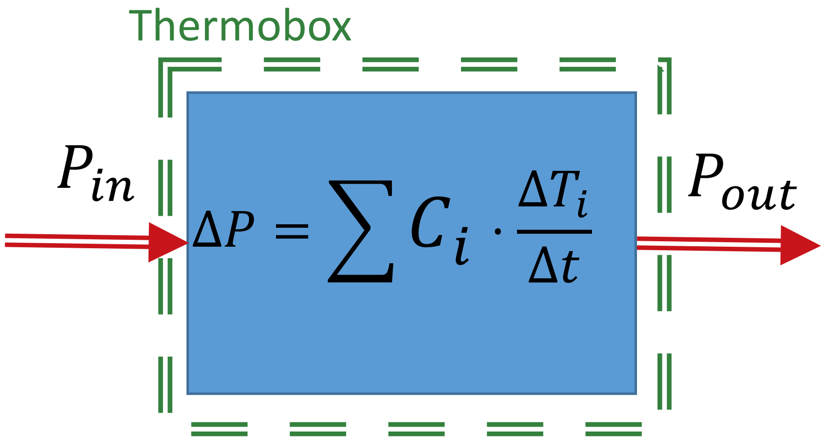
$$P_{cond} = P_{loss} = P_{in} - P_{out} - \Delta P$$

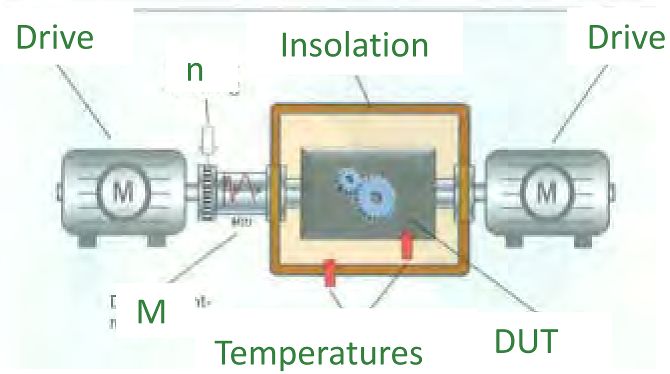
Steady State: $\Delta P = 0$

- Conditioning of gear box oil
  - unnatural oil distribution
- Gearbox put in cooling liquid
  - unnatural temperature distribution

Homann/Eckstein, (ika RWTH Aachen):
too high influence of unnatural temperature state.

Short-Time Calorimetric Method





Power Losses using Heat Capacity

Idea: Losses will be changed to warm up

Adiabatic Box:

$$\mathrm{P}_{\mathrm{cond}} = 0, P_{in} - P_{out} - \Delta P = 0$$

$$P_{Loss} = \frac{\Delta U}{\Delta T} = \sum C_i \cdot \frac{\Delta T_i}{\Delta t}$$

- Determine heat capacity of each part
- measure temperatures T_i
- Test process
  - heat up to uniformly temperature
  - speed up by accelerating both machines synchronously
  - impress torque
  - measure time and temperature difference of parts with different temperatures

[Homann J., Eckstein L.: Kalorimetrisches Verfahren zur Wirkungsgradbestimmung von Getrieben, ATZ 11/2014, 116. Jahrgang, P. 68-73]

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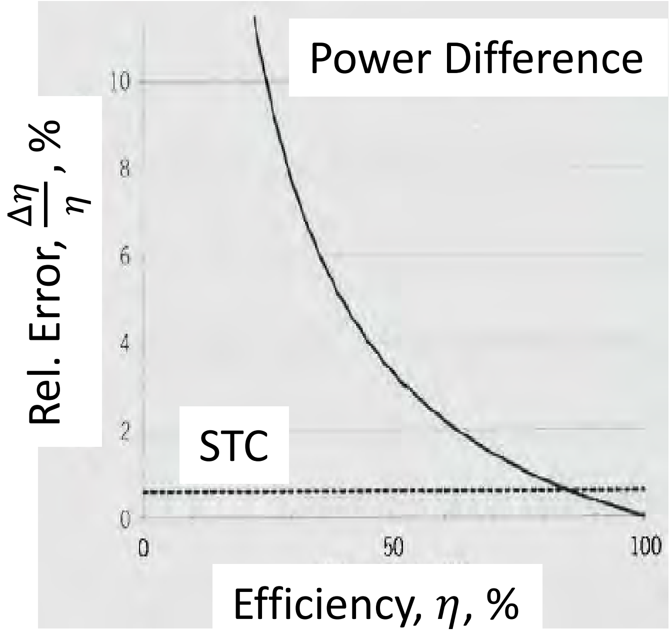
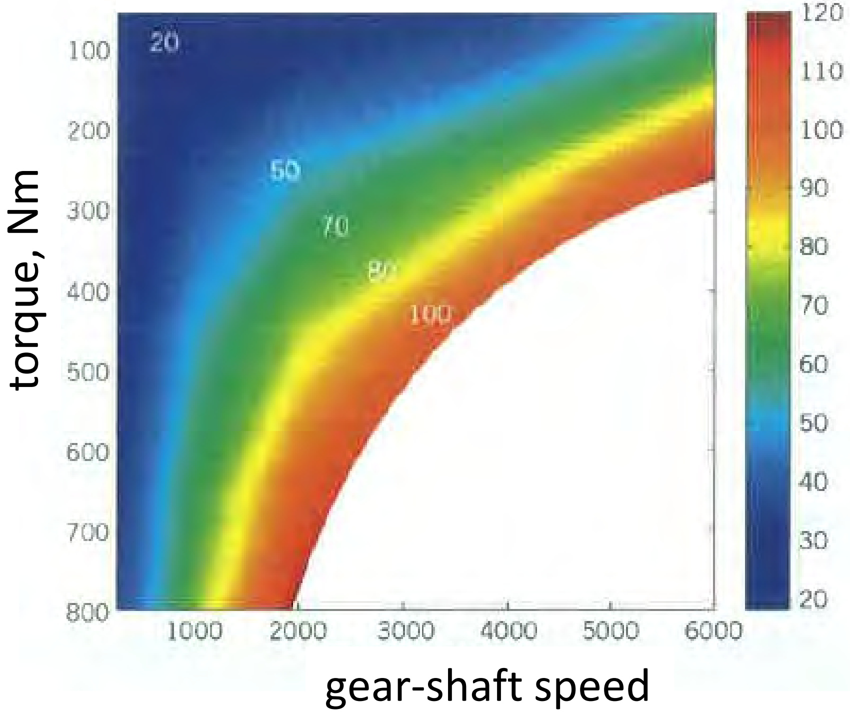
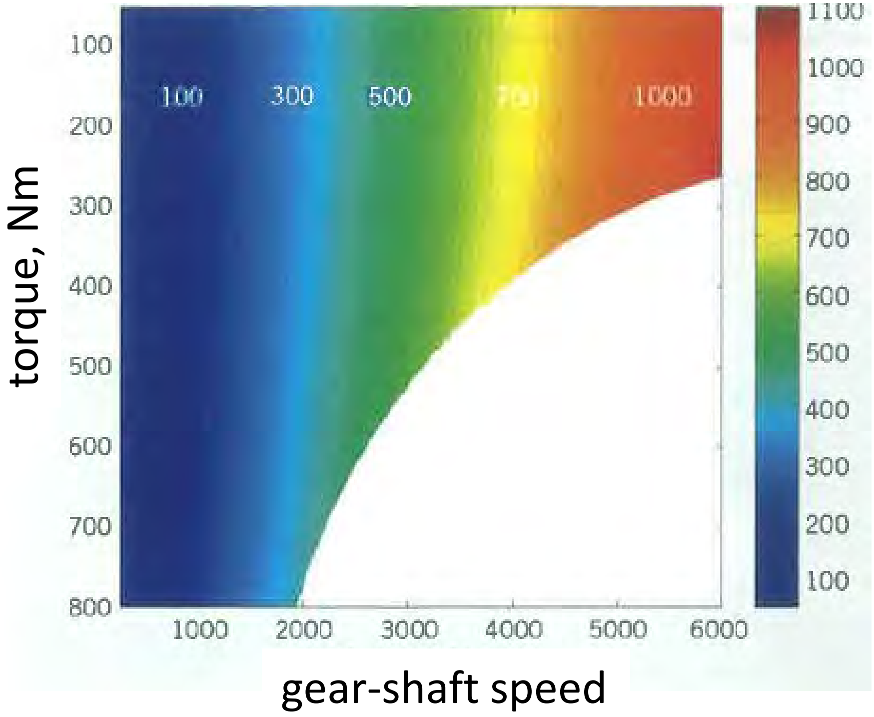
Short-Time Calorimetric Method (STC)



Abs. Error STC , W



Abs. Error Power-Difference-Meas. , W



Homann/Eckstein say: good results, especially at low power

[Homann J., Eckstein L.: Kalorimetrisches Verfahren zur Wirkungsgradbestimmung von Getrieben, ATZ 11/2014, 116. Jahrgang, P. 68-73]

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UNITED

Engineering Knowledge Transfer Units to Increase Student´s Employability and Regional Development

Electrical Power Measurement

T. Lechner

Co-funded by the Erasmus+ Programme of the European Union

Electric power measurement

- **Motivation**
  - For vehicles with combustion engines, the fuel consumption can be measured with exhaust gas analysers.
  - The fuel consumption is a measure for the used energy.
  - Due to the increasing electrification of powertrains, the electric energy consumption must be ascertained.
  - Therefore, an accurate electric power measurement is needed.
  - For drivetrain development, the efficiency of used components must be measured.

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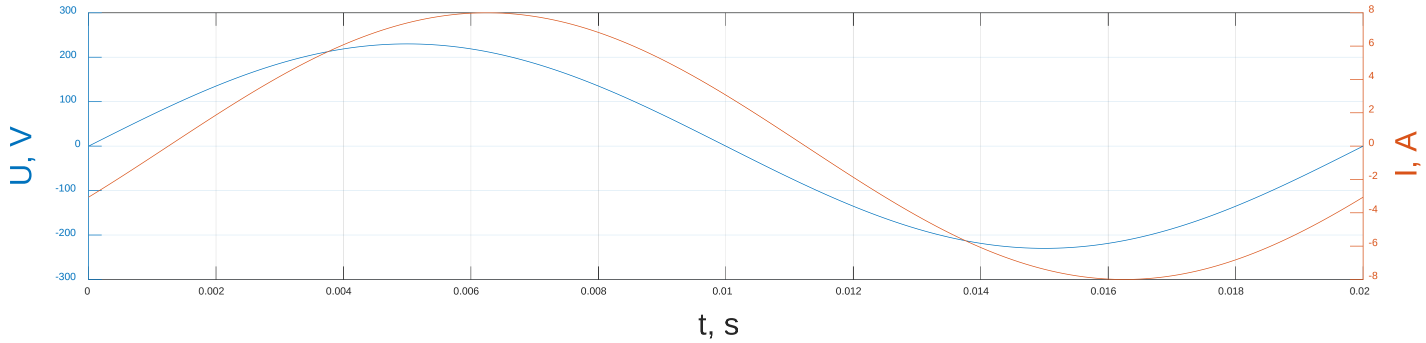
Electric power measurement

- Introduction
  - Easy to measure in case of:
    - Slow changing direct current or voltage
    - alternating quantities with perfect sinus shape



Active, reactive and apparent power can be easy calculated out of the effective values

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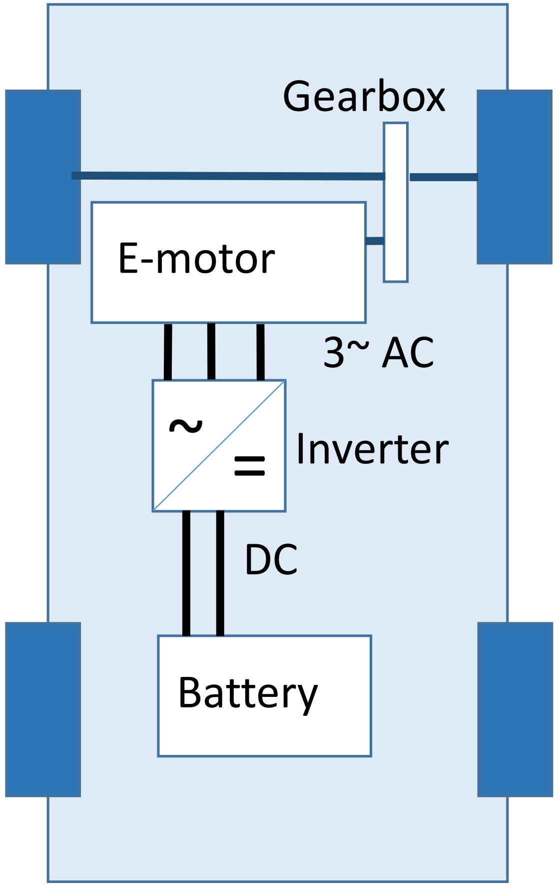
Electric power measurement

- For drivetrain development and determining the efficiency of inverters, the power on the DC as well as at the AC side must be measured.
- Inverter:
  - Transfers DC to 3-phase alternating current
  - The goal is to generate 120 degree shifted sinusoidal phase currents.
  - A pulsed voltage generates this with the help of the E-motor’s inductance.
  - → Voltages are not sinusoidal, currents are only approximated sinusoidal



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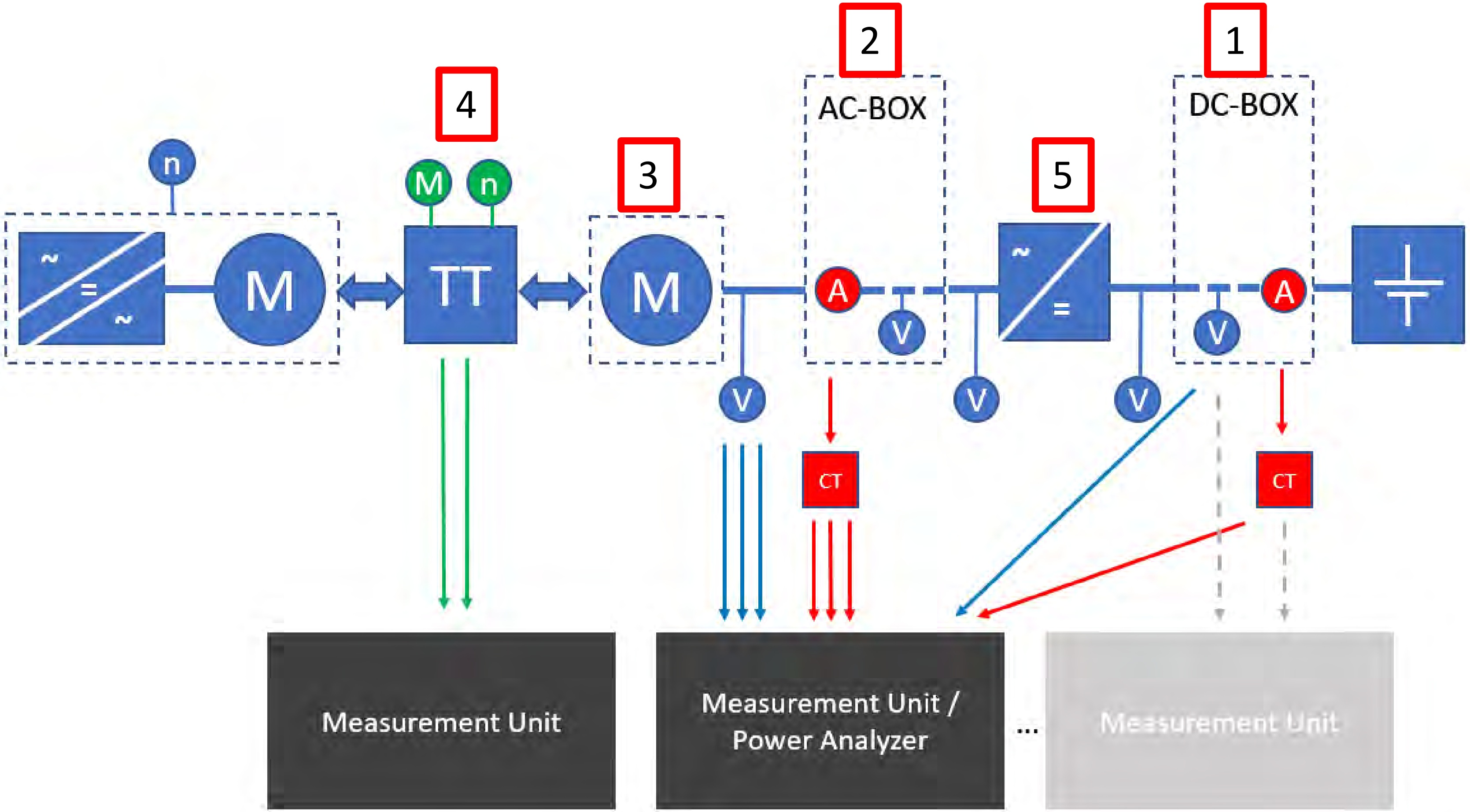
Testing configuration, [1]

1) DC-power
2) AC-power
3) E-motor
4) mechanical power
5) Inverter



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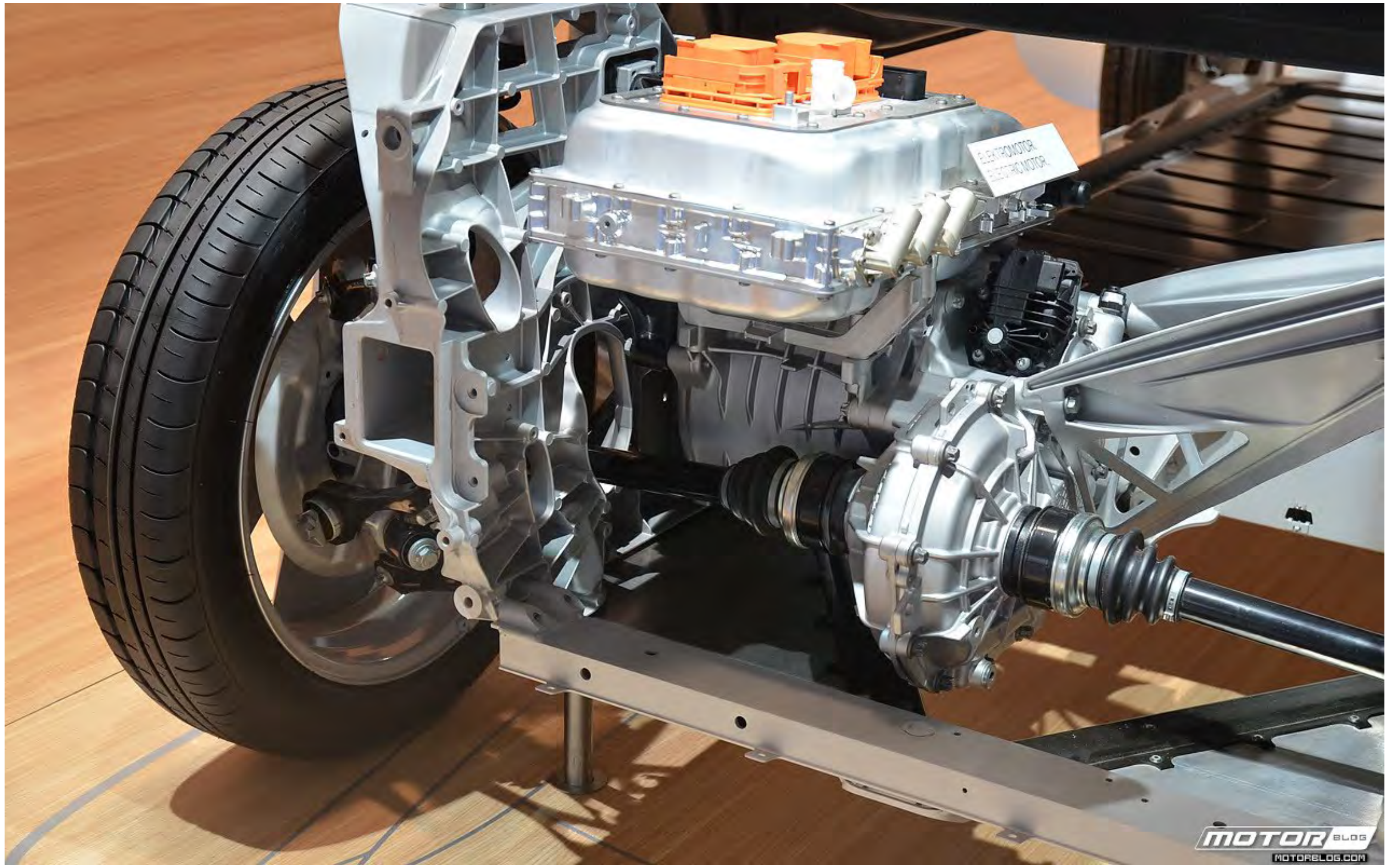
BMW i3 section model, [4]

High encapsulated construction → hard to connect the probes for voltage and current measuring.



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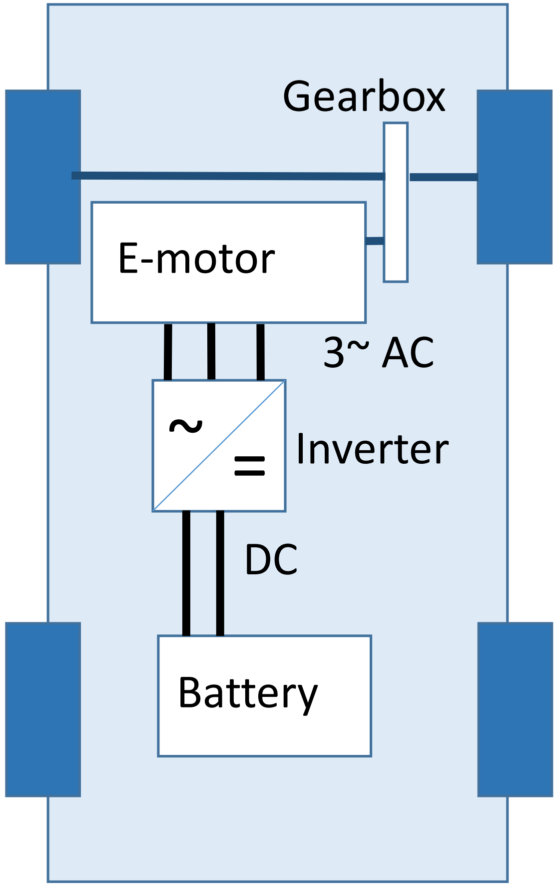
Electric power measurement

- The switching frequency of the frequency converter must be set to a value to reduce or prevent audible noise.
  - Switching frequency > 10 kHz
  - For accurate power measurement: Data acquisition devices with high sample rates are necessary.
- Inverter efficiency is very high
  - For accurate power measurement: currents an voltages must be measured very exactly.



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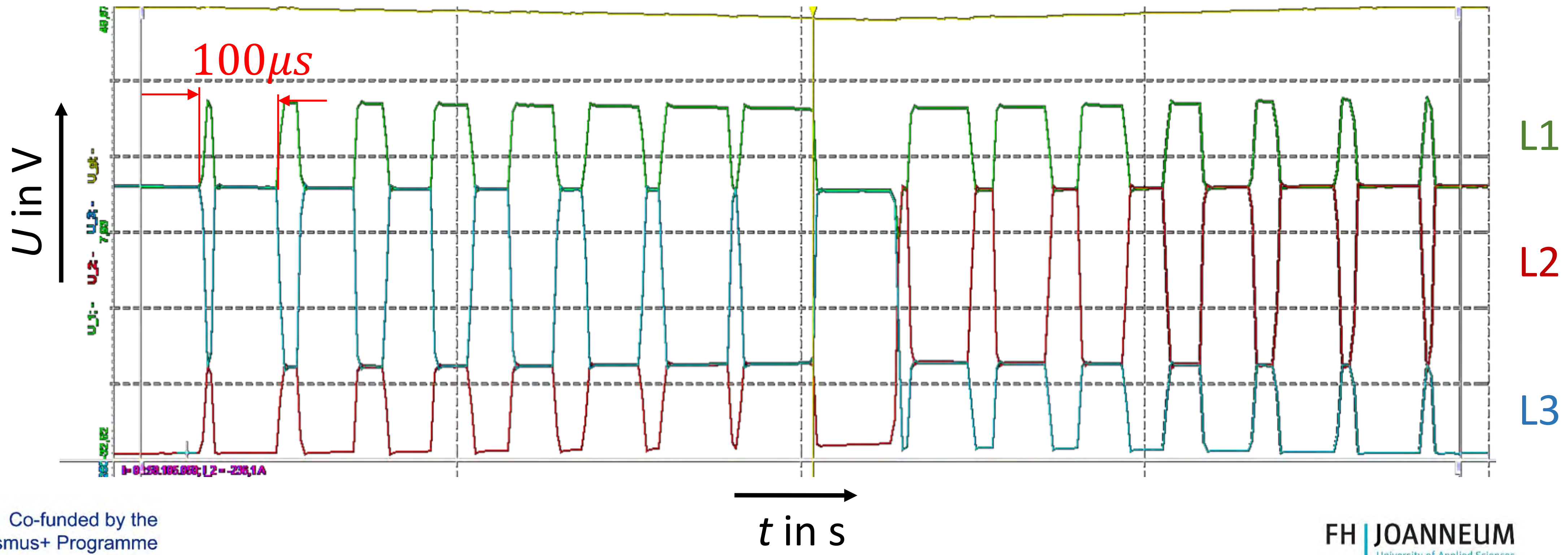
DAQ-System, sample rate

- Which sample frequency f_s is needed?
  - Inverter pulsed voltage:



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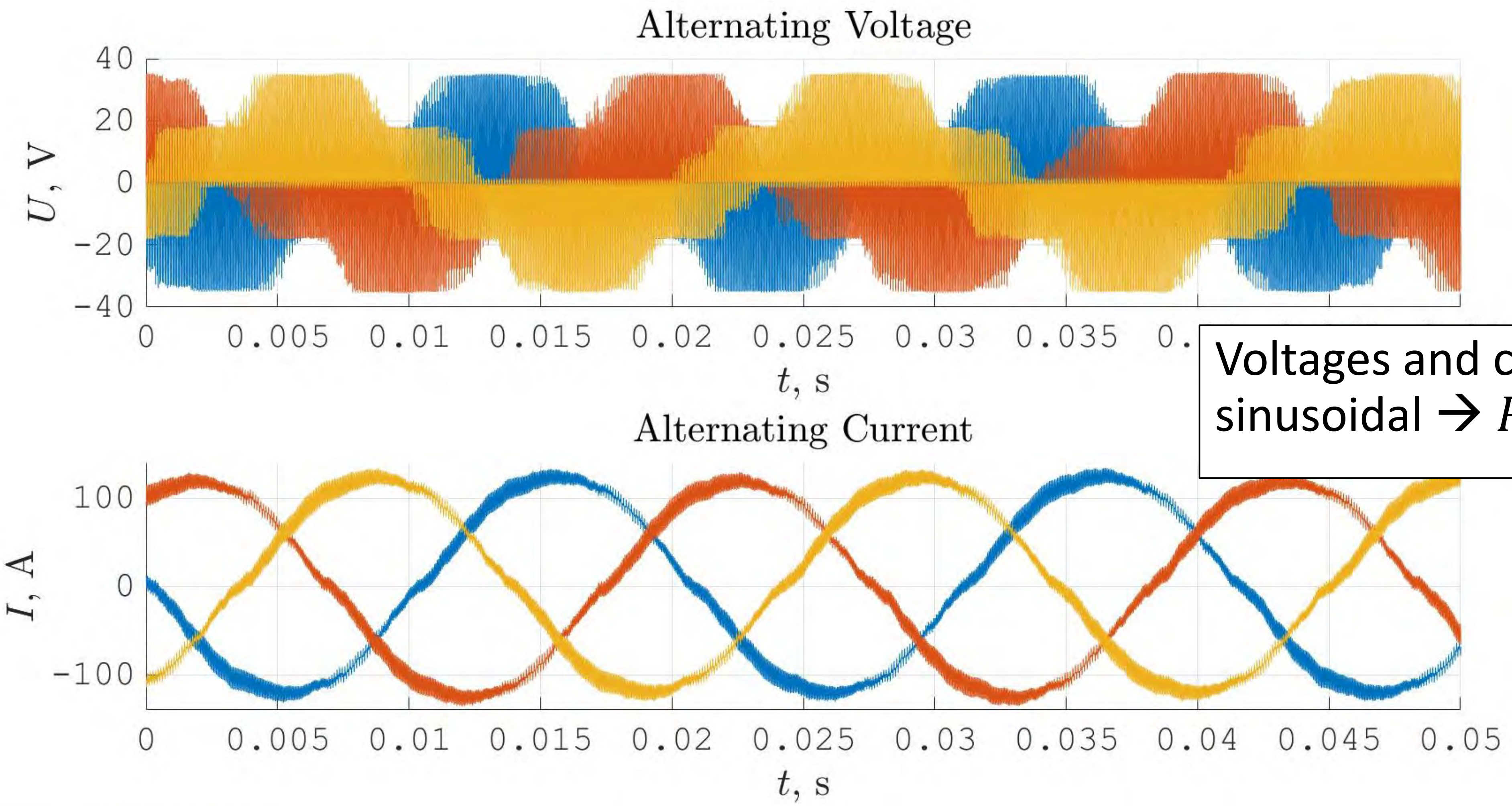
Result of current and voltage measure



Voltages and currents are not sinusoidal → $P \neq U_{\text{eff}} \cdot I_{\text{eff}}$

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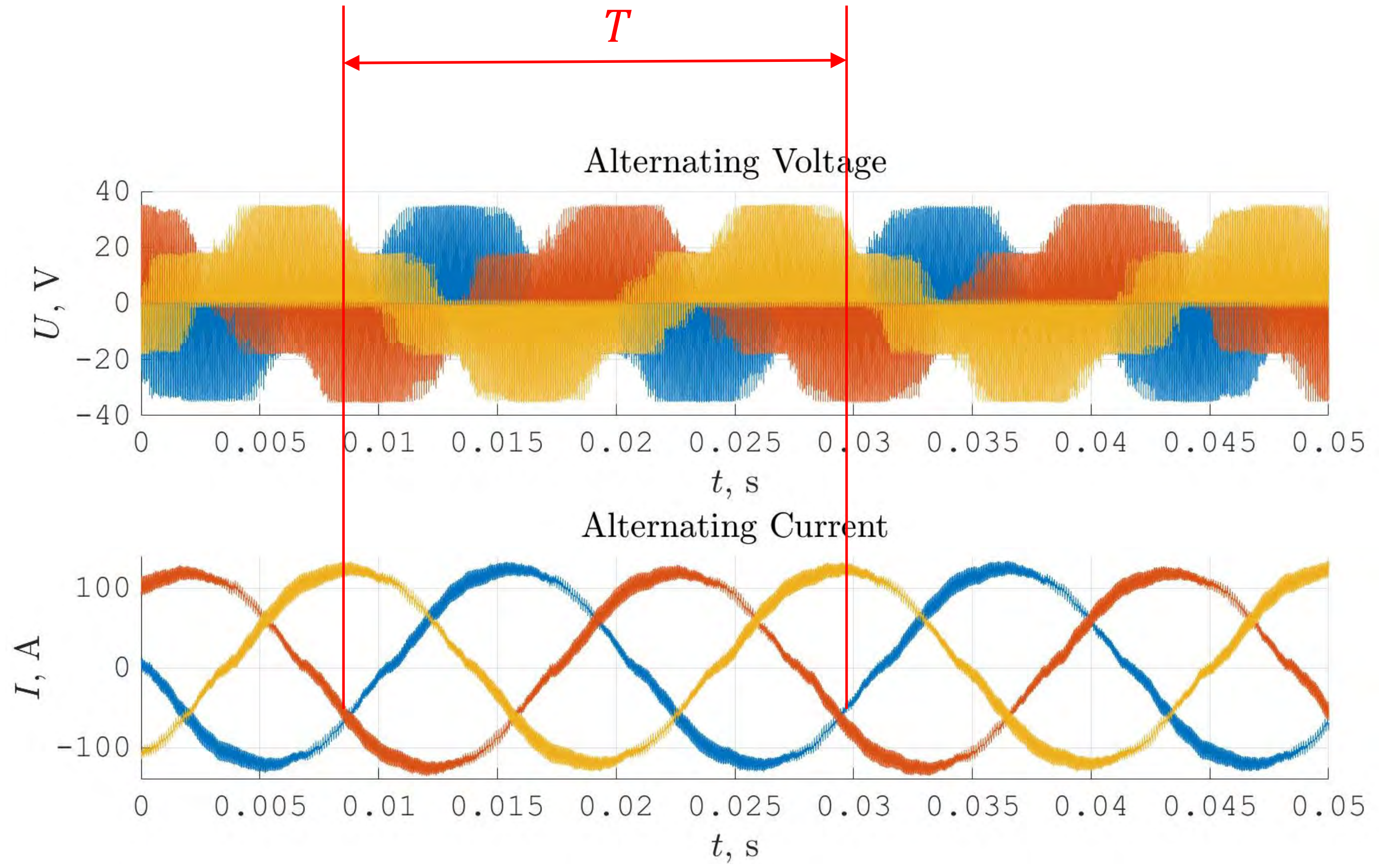
Active power calculation



L1
L2
L3

Current power value

$$p(t) = u(t) \cdot i(t)$$

Active power P per phase L_j

$$P_{L_j} = \int_{t_1}^{t_1+n\cdot T} p_j(t)\mathrm{d}t$$

Active power

$$P = P_{L1} + P_{L2} + P_{L3}$$

→ Find the periodicity!

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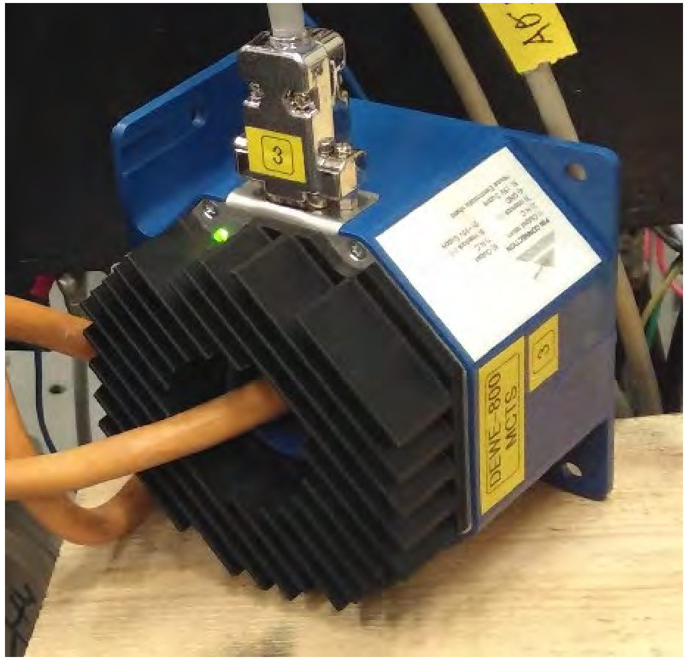
DAQ-System, accuracy

- Typical inverter losses: 3 %
  - Example: 0.1 % accuracy for voltage and current measuring → maximum 0.2 % error for input power P_{in} and output power P_{out}.
  - Power loss $P_v = P_{out} - P_{in}$

    P_v fluctuates around +/- 0.4% of P_{in}. This are +/- 13% of P_v!
- Current measurement:
  - Indirect measured via the magnetic field that covers the electric conductor
  - Sensor: Zero flux transducer, Error out of:

    linearity 0.001%, offset deviation 0.004 %



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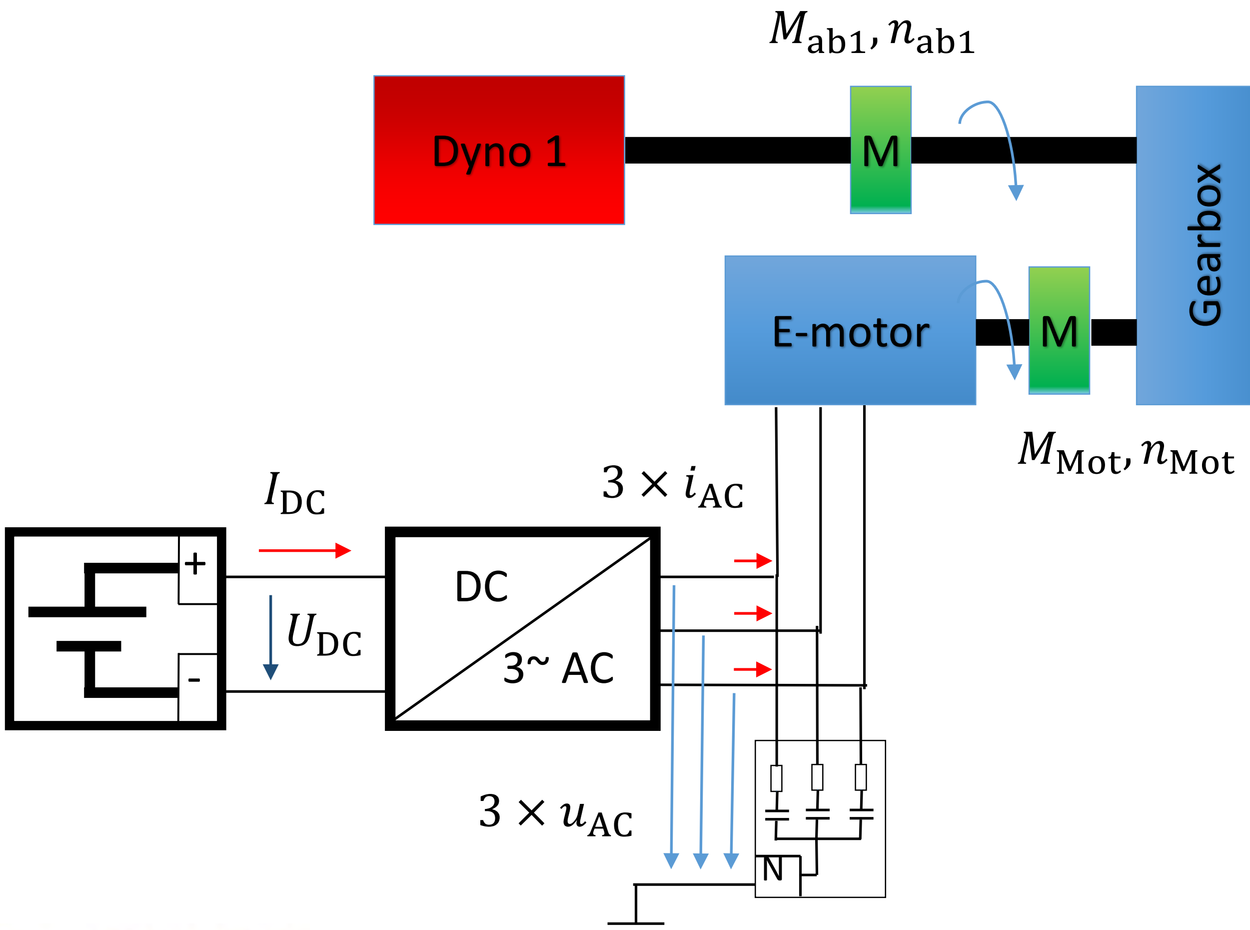
Exemplary test bed setup



- Sensors for the electric power measurement:

  1 times I_{DC}

  1 times U_{DC}

  2 or 3 times i_{AC}

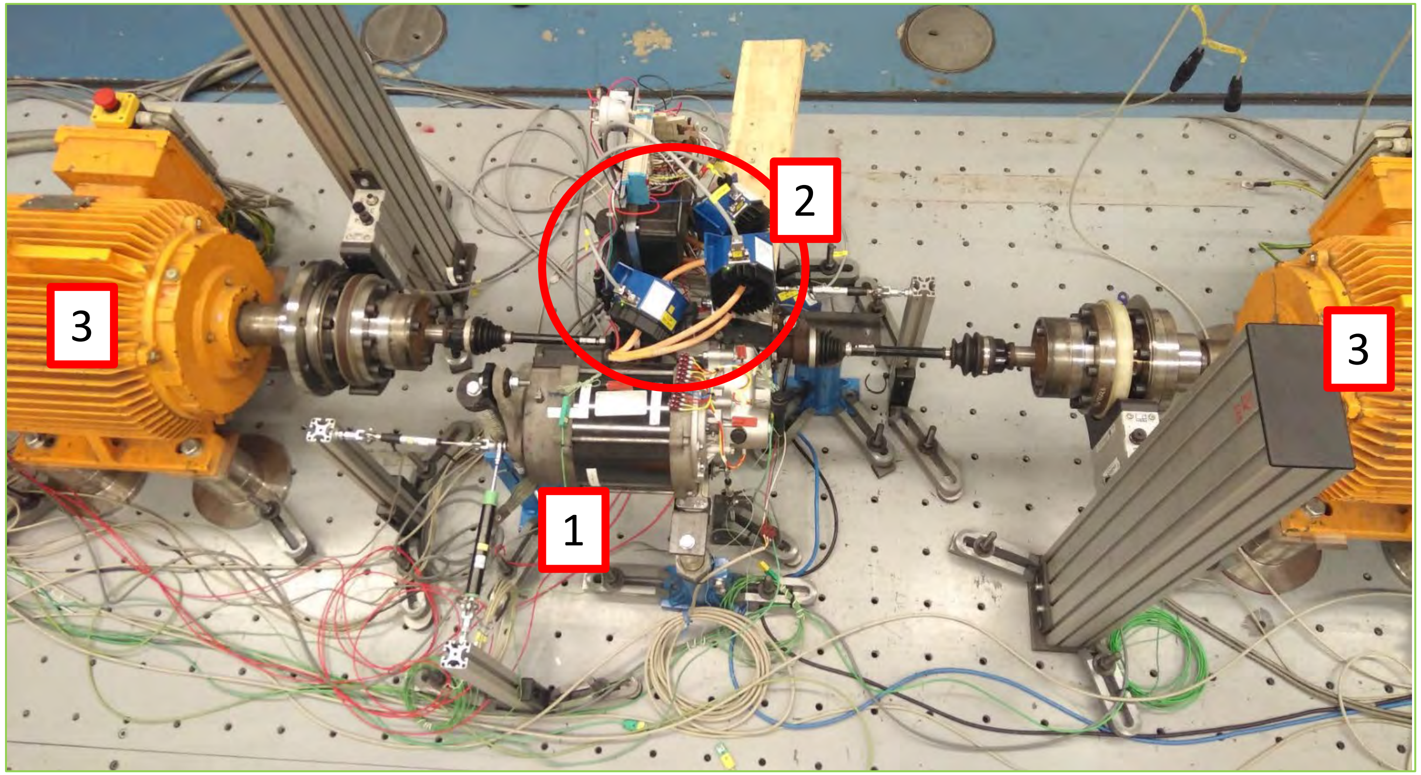
  3 times u_{AC}

Exemplary setup at a test bed

1 – Device under test (DUT)

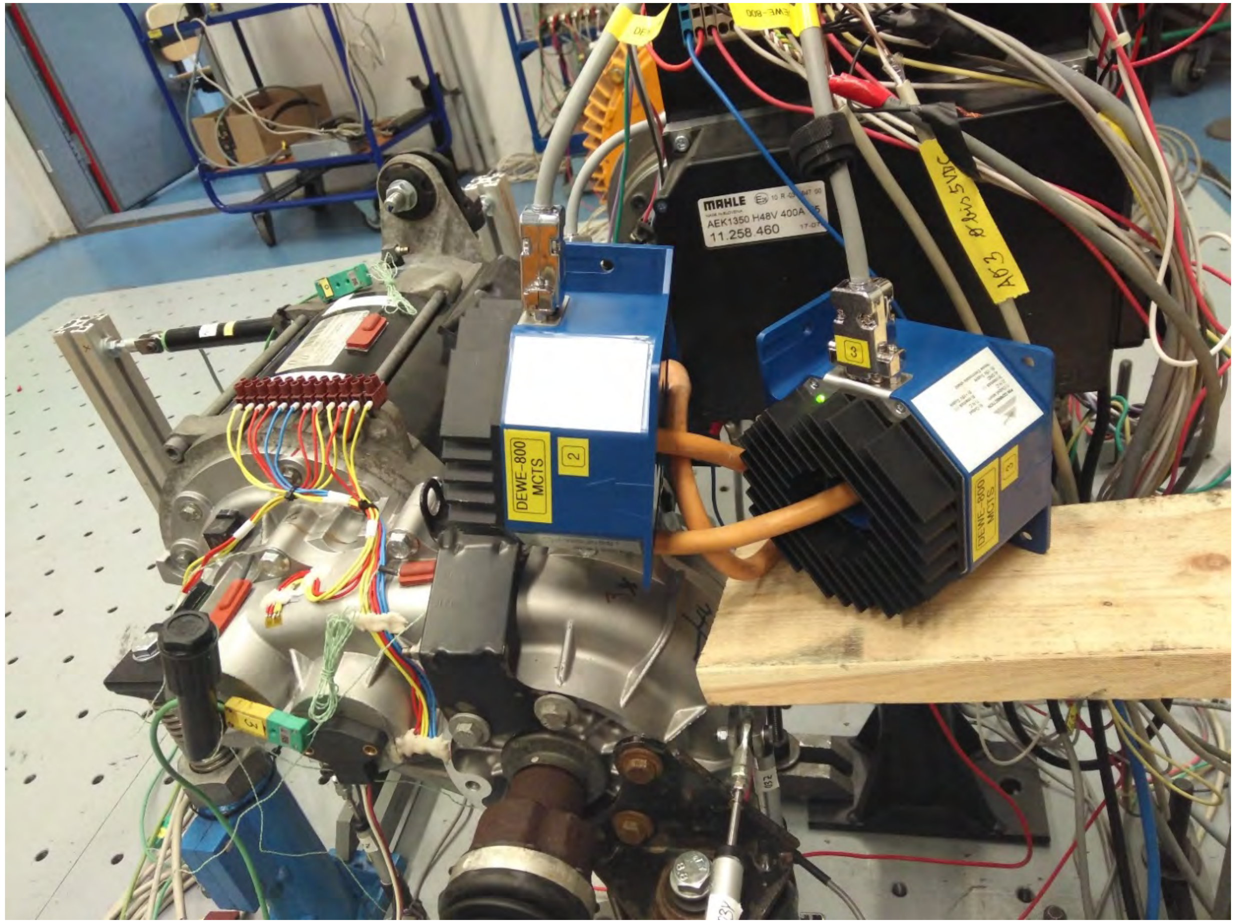
2 – Current transducer for AC

3 – Dynamometer 1 and 2



Zero flux transducer, [2]

- Zero-Flux Current Transducers
  - Model: PM-MCTS 1000
  - Input: Current
  - Output: Voltage
  - Range:
    - DC, Peak up to 1000A
    - RMS Sinus up to 700A



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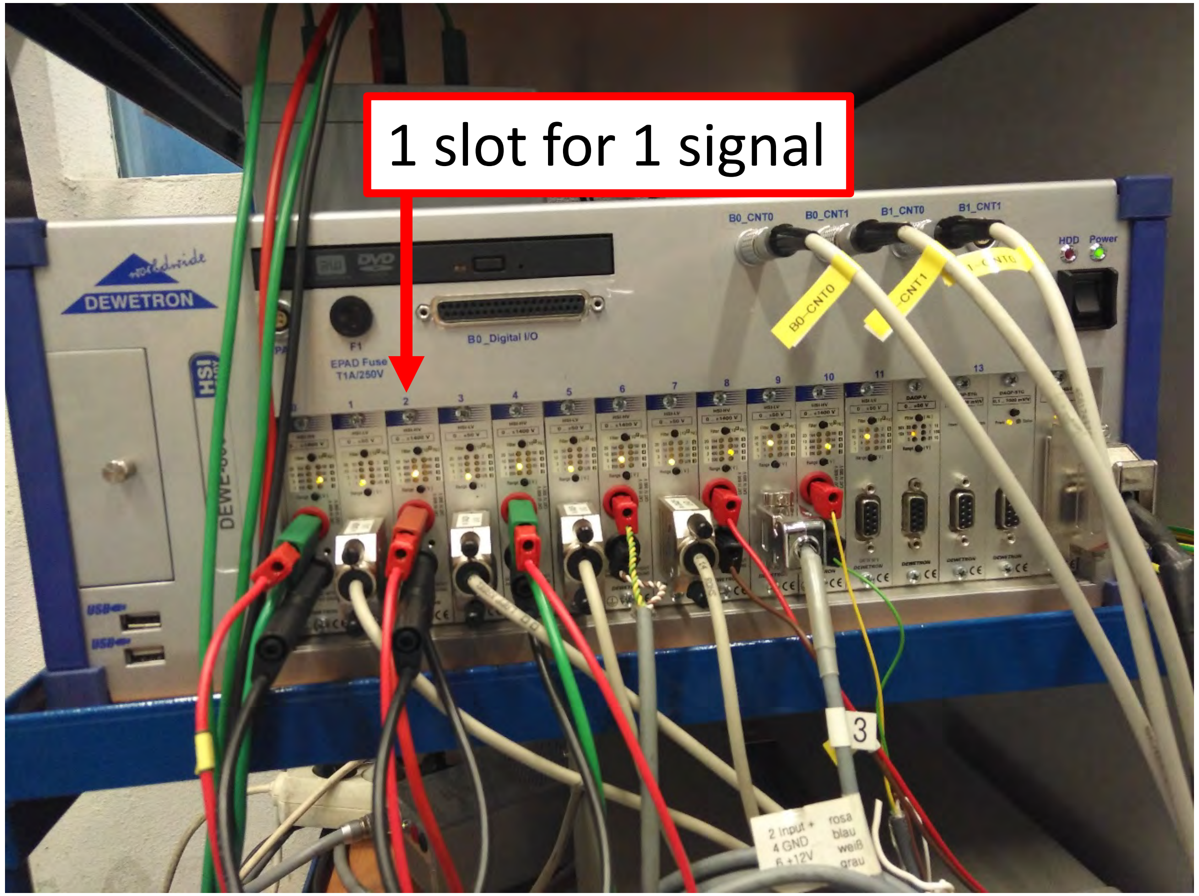
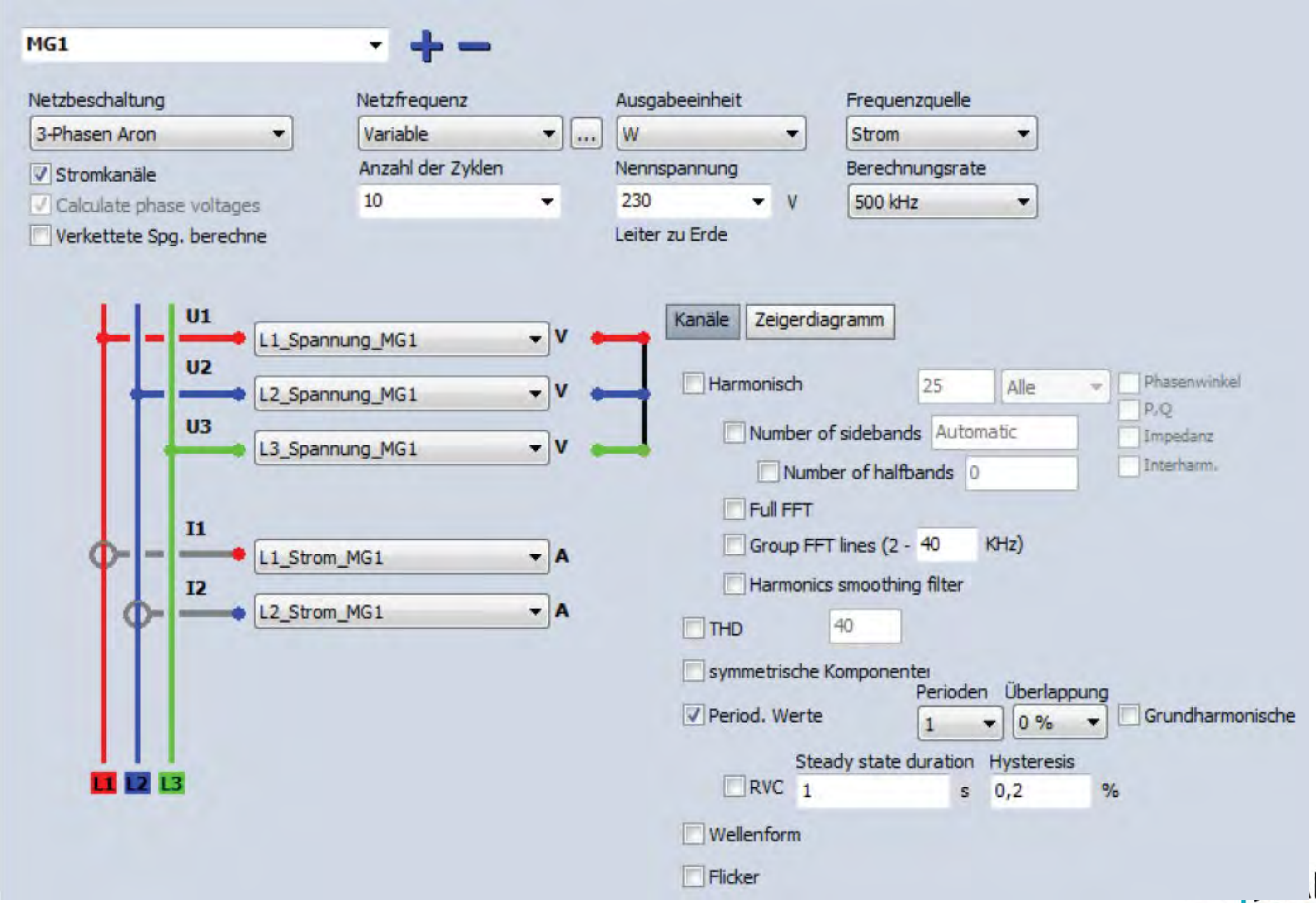
Data acquisition system

- Voltage measurement
  - direct connection possible
  - no differential probe is needed
  - to reduce errors



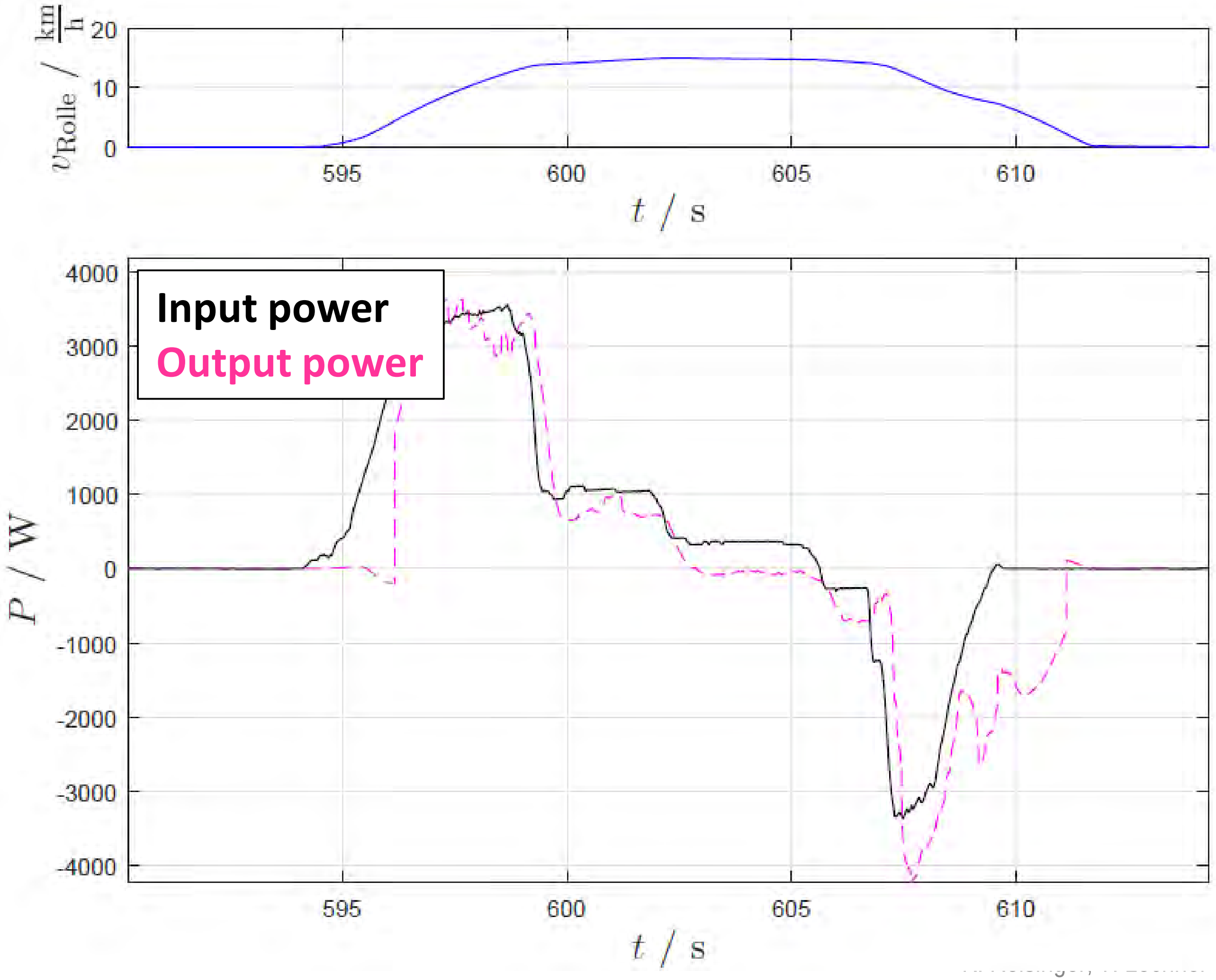
DAQ-System, Software

- Setup overview



Hybrid Car Results, [3]

- The shown results where measured at a chassis dynamometer
- The input power as well as the mechanical output power where measured depending to vehicle speed.



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[1] Wiedner, Christoph: *THE CHALLENGES OF ANALYZING THE EFFICIENCY OF ELECTRICAL POWER TRAINS*. DEWETRON GmbH, 2018

[2] 2020 01 27: https://www.dewetron.com/products/daq-components-daq-sensors/current-transducers/

[3] Patrick Moser: Leistungsflussmessung in einem Hybridfahrzeug (Bachelor Thesis), October 2016

[4] 2020 01 28: https://de.wikipedia.org/wiki/Elektroauto

Engineering Knowledge Transfer Units to Increase Student´s Employability and Regional Development

Challenges when Testing Mechatronic Systems

K.Reisinger

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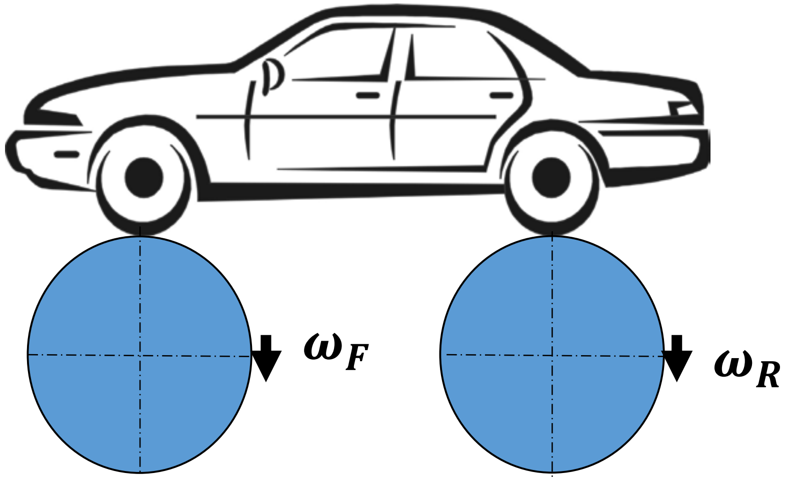
Example: Chassis Dyno



- Front and rear roller are driven separately by an speed controlled AC-Motor.
  - front roller turns $v_F = r_r \cdot \omega_F = v_{Req} \pm 5\%$
  - rear roller makes $v_R = v_{Req} \pm 5\%$
  - Speed difference $\Delta v = \pm 0.1 \cdot v_{Req}$
- What happens in an 2WD car?
  - nearly nothing → OK for testing
- What happens in an locked 4WD car?
  - nearly nothing, speed will be synchronized by car → OK
- What happens in an controlled 4WD car?
  - AWD-ECU recognizes too high slip, sometimes at front, sometimes at rear
  - AWD-Clutch opens/closes periodically
  - self exciting vibration

Controller needs to synchronize front/rear roller

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Requirements for Testing Embedded Systems

- All interfaces must be simulated as accurately as required
- Mechanic interfaces
  - speeds **often speed differences (=wheel slip)** must fit to models in Embedded System under test (DUT)
  - accuracy depends on sensitivity of DUT
- Electric interfaces
  - supply like in the car
  - electrical signals
- Bus-Interface (CAN)
  - control signals as in the car
  - residual bus simulation to be satisfied to run
- ECU internal
  - set to test mode
  - prepare for remote control
  - read signals

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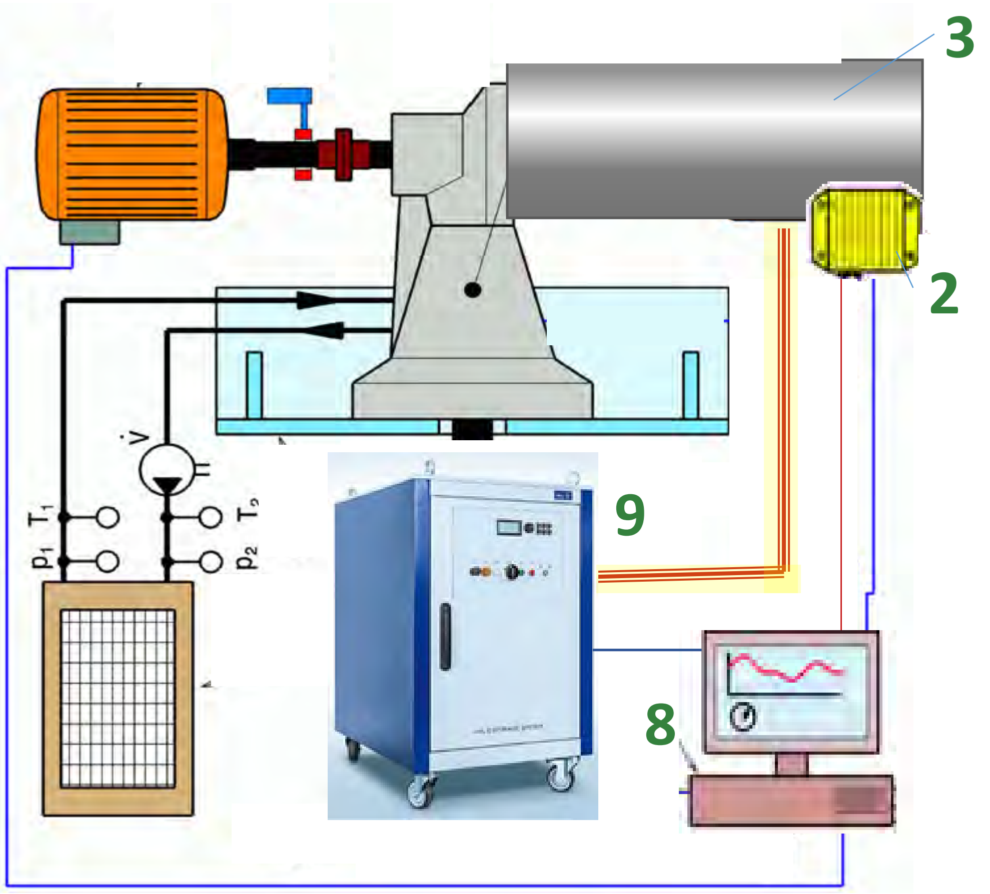
Simulate Electrical Supply at Test Bench

UNITED

- **Supply battery voltage independent of test duration**
- Tests are compacted, no time to relax like in the car
  - real battery can burn (prototypes)
  - real battery becomes empty
  - real battery becomes hot
- We have to simulate a real battery
  - test bench defines SOC
  - a battery model calculates offered voltage in real time
    - constant (nominal) voltage
    - **behaviour model: R,R+RC, …**
    - electro-chemical model
  - Battery Emulator offers voltage



3 .. DUT, 2 .. DUT's ECU
8 .. test bench control
9 .. battery emulator

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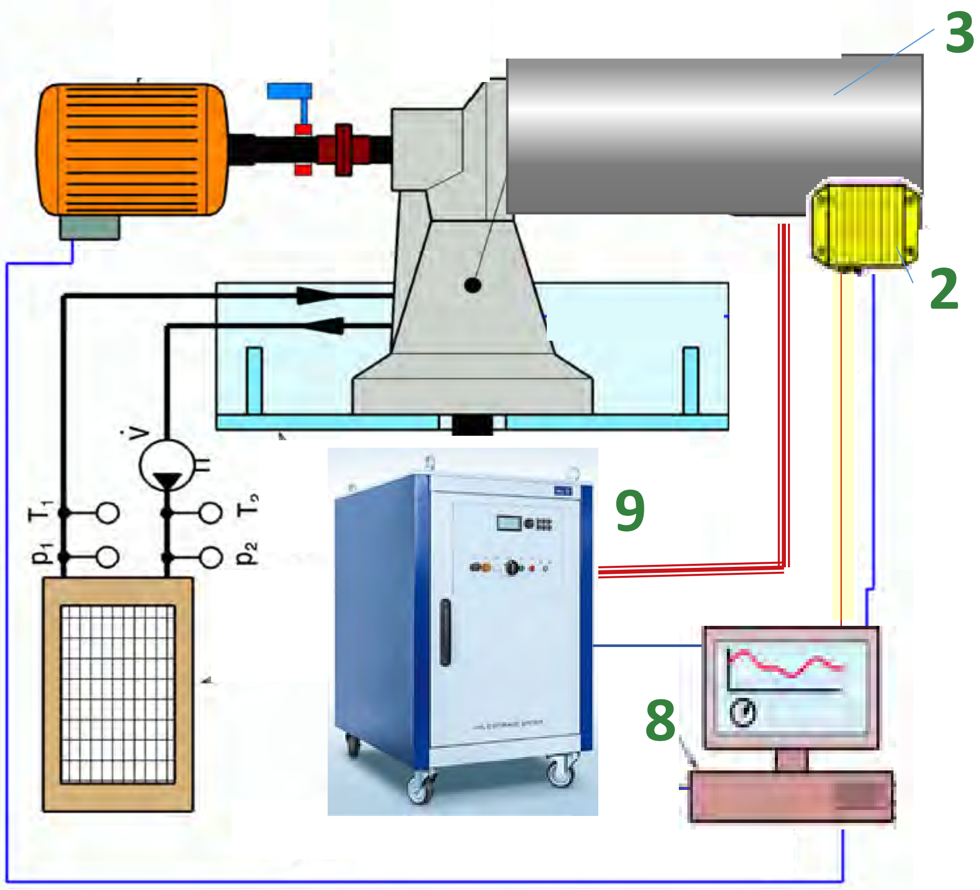
Simulate Electrical Signals at Test Bench

- **Invoke DUT's start-up;**
- **provide sensor signals**
  - e.g. Ignition On (Term15), brake light switch, sensor signals, …
- provide electrical signals
  - test bench relays
  - test bench replay (time dependent tables) + D/A interface
  - real time simulation + D/A interface



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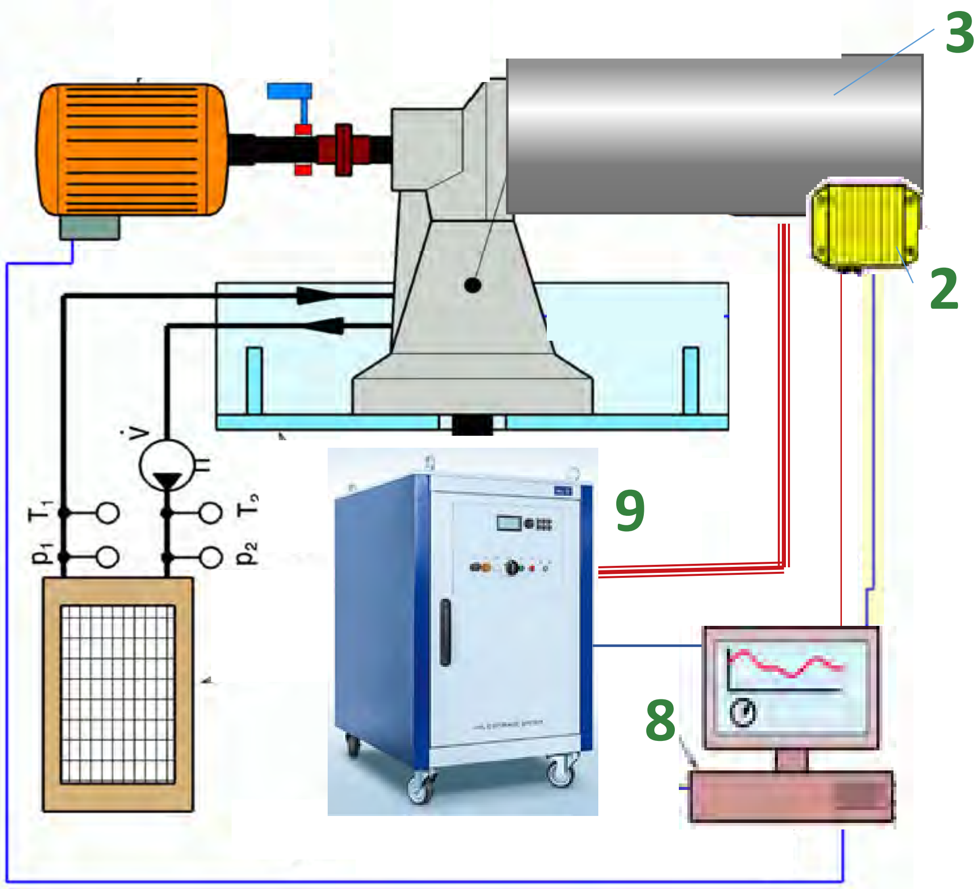
Simulate BUS Signals at the Testbench

- **interface for control**
- **provide correct sensor signals and acknowledgements to run**
  - e.g. anti-theft protection
  - external sensors
- residual bus simulation - replay
  - install neighbour ECU
  - replay recorded bus signals using CANoe
  - test bench replay (time dependent tables)
- control signals as in the car
  - depends on test concept and models running in DUT's ECU
  - test bench replay (time dependent tables)
  - Hardware In the Loop simulation



3 .. DUT, 2 .. DUT's ECU
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9 .. battery emulator

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https://en.wikipedia.org/wiki/CANoe
https://www.vector.com/

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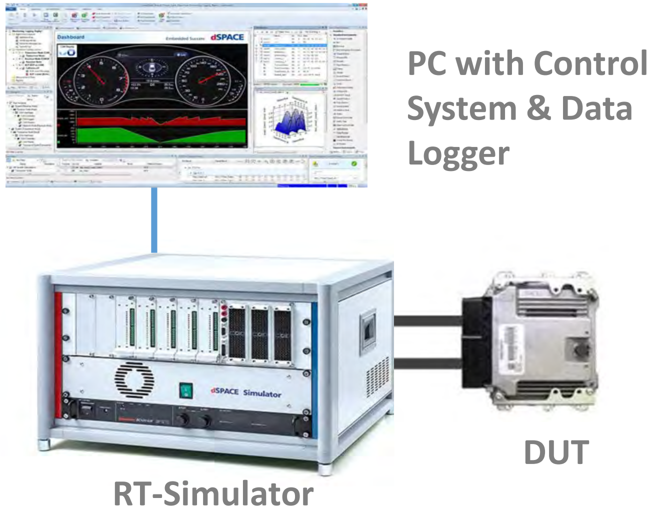
RT-Hardware for test bench

- **Simulates signals like in the car in real-time**
  - **based on requested values from testbench**
  - **based on measured signals from Testbench and DUT**
  - **uses models representing car's parts, which are not present**
  - **Shall be compatible to Matlab/Simulink**

- e.g. Hardware in The Loop
  - Test automation: PC
  - Reality: ECU + Software
  - Measuring: ECU output signals
  - Simulation: All except ECU
  - Output to ECU: ECU input signals



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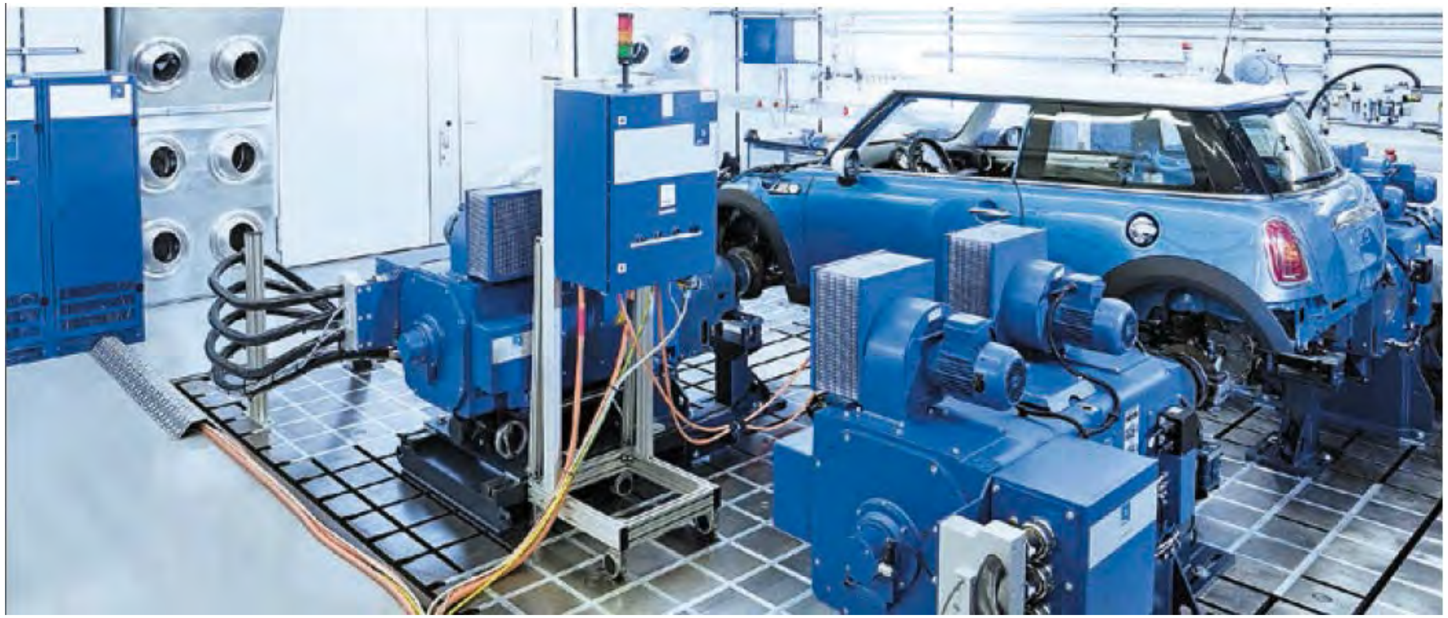
e.g. Vehicle In the Loop

- Test automation: Test bench control
- Reality
  Vehicle, except tyres,
  acceleration, yaw-rate
- Measuring
  wheel torques
- Simulation
  - tyre slip, road, resistances
  - wheels acceleration, speeds
  - body motion
- Output to test bench
  wheel speeds, brake/throttle robot,
  steering robot
- Bypass signals in Vehicle-CAN
  acceleration, yaw rate (if necessary)



[https://www.avl.com/de/-/vehicle-in-the-loop-test-system

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UNITED

Engineering Knowledge Transfer Units to Increase Student´s Employability and Regional Development

SHED Chamber

J. Brenner, T. Lechner, K. Reisinger

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Introduction

- ALL emissions of vehicles must be measured
  - For exhaust gas emissions → Chassis Dynamometer
- For evaporative emissions on vehicle
  - tank systems and components
  - as well as elastic plastics and rubber parts

  → SHED Chamber
- The goal is it, to measure emitted <u>**h**</u>ydro<u>**c**</u>arbon (HC) emissions.
  - Whole vehicle
  - Parts of vehicles like fuel systems and components for fuel transport.
- Used sensor: gas analyser → FID … flame ionization detector

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SHED Schematic

Sealed Housing for Evaporative emission Determination

1 Computer
controls temperature profile, data acquisition

2 Air bag (4 m^3)
membrane to equalize air pressure

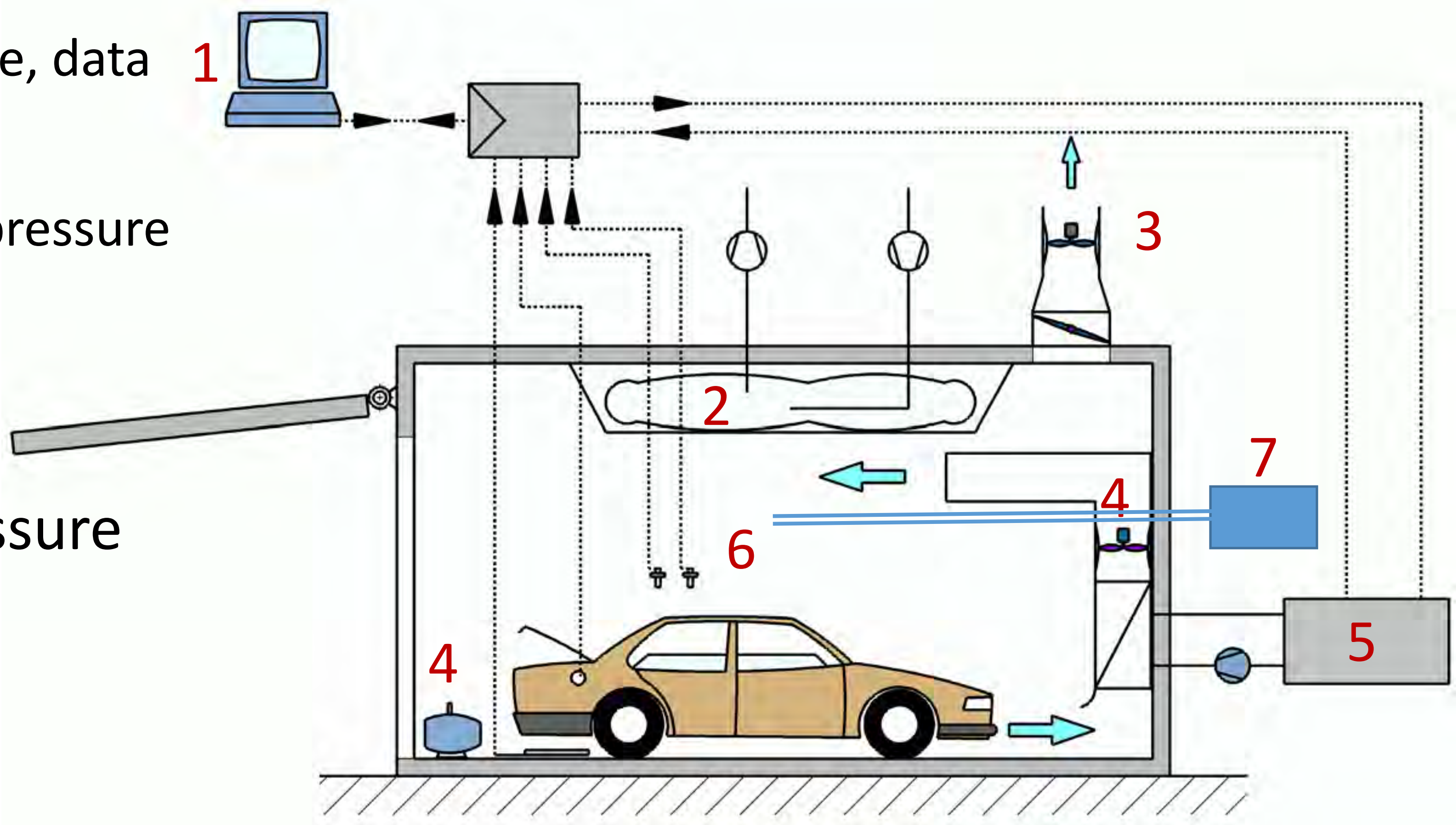
3 Purging fan

4 Mixing fan + Blower
defined air convection

5 Heating system

6 Temperature and pressure sensors

7 FID flame ionisations detector



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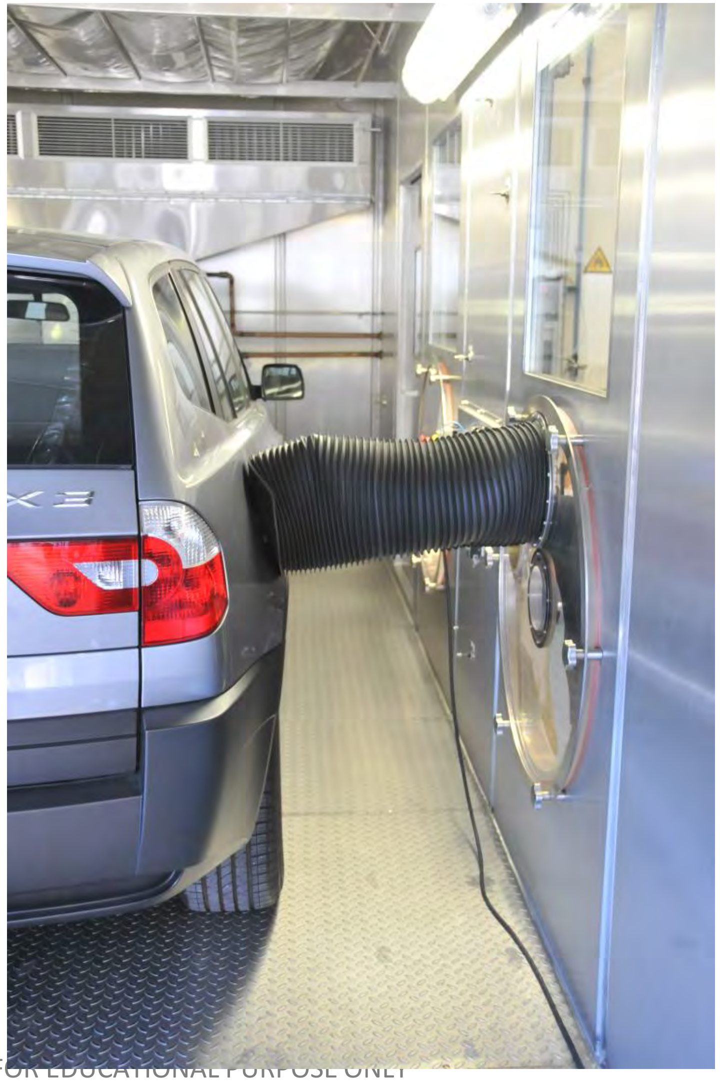
SHED

[Trzesniowski]

On-board Refuelling



[Trzesniowski]

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FHJ SHED Technical Data

- Measuring Chamber
  - Temperature Range: 18°C to 45°C
  - Test chamber volume: 70 m^3
  - Volume compensation by Tedlar-bag
  - For refuelling test: variable ports
- Analysis System
  - FID
  - Measuring ranges: 10, 52, 100 and 250 ppm (C_1)
- Test bed control system
  - Tornado from the manufacturer Kristel, Seibt & Co GmbH

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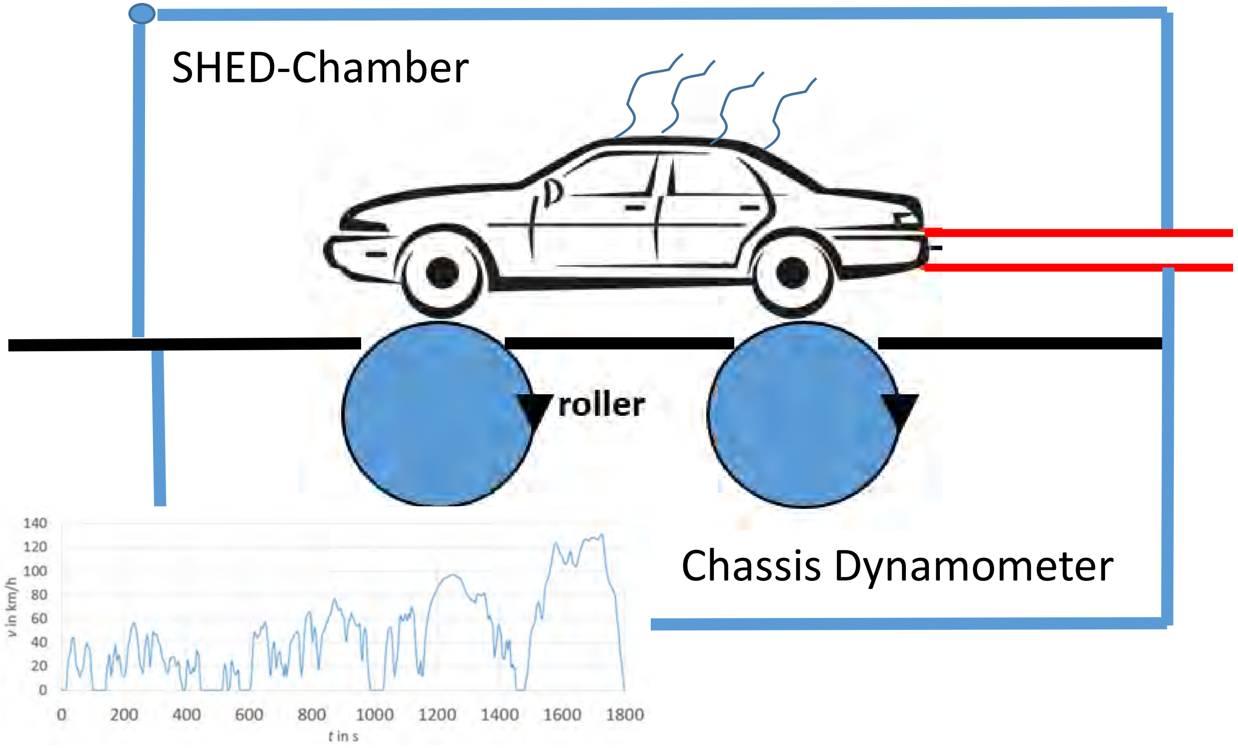
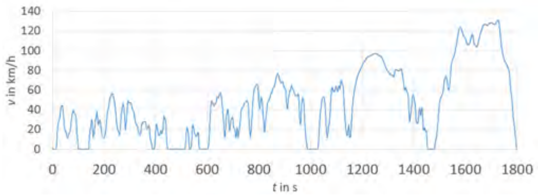
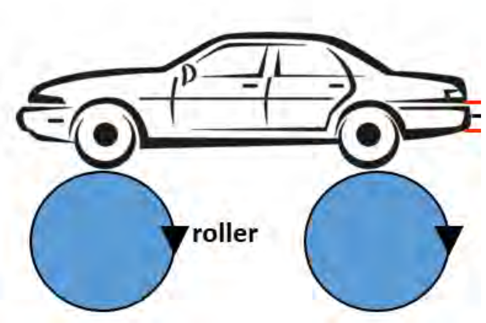
Running Losses



- To measure the evaporation emissions of a driving car
  - Needs a combination out of chassis dynamometer and SHED-chamber.
  - Not covered by the portfolio of FHJ.

Hot Soak Test





- To measure the THC evaporation emissions of a car after it has driven.
  - Needs a chassis dynamometer and an extra SHED-chamber.
  - Certified fuel is needed.
  - The carbon canister has to be prepared.
  - The SHED-chamber must be air conditioned.
  - The THC-emissions are measured after different time stamps

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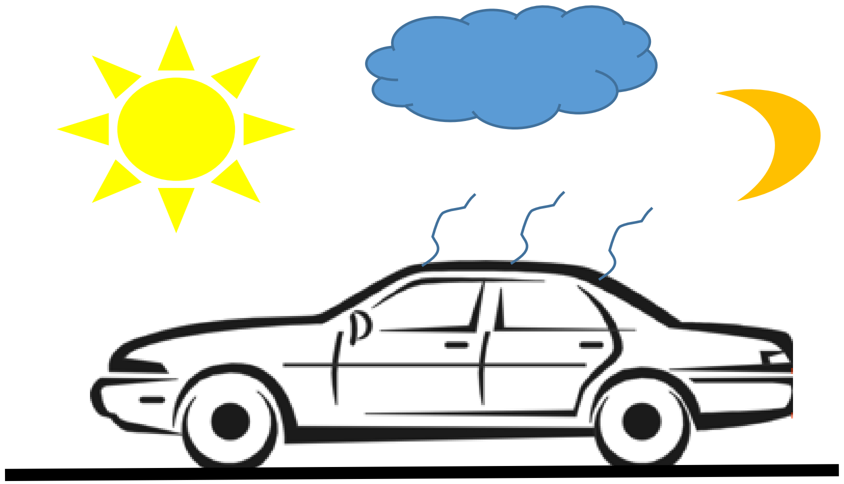
Diurnal Test



- To simulate a typical parking situation
  - To measure the evaporating THC emissions while the vehicle is parked.
  - The temperature is changing during the course of a day.
  - Measurement duration: 24, 48 or 72 hours

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ORVR Test

On-board **R**efuelling **Vapour** **R**ecovery (ORVR)-Test

- Goal is to measure the THC evaporating emissions while fuel-filling a vehicle.
- A system with a fuel-hose as well as fuel conditioning and dispensing is needed.
- Emissions from filler neck or ambient connector for carbon canister are to measure.

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Calibration of SHED System

Calibration of FID

- pure air for zero point calibration
- 4 bottles of calibrated test gas, a mixture of propane and pure air for different measurement ranges.

Propane injection for Shed chamber calibration

Calibration of SHED chamber

- To proof the measurement quality, the measurement system must be calibrated → propane injection test
- 0.5 g -1.0 g propane where injected in the shed-chamber (66 m^3).
- The measurement system must find 98 %.

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Questions…

feel free to contact for

- Mechatronics, Efficiency

  Dr. Karl Reisinger, karl.Reisinger@fh-Joanneum.at

- Testing, Measurement, Calibration:

  DI(FH) Thomas Lechner, thomas.lechner@fh-Joanneum.at

- SHED Chamber:

  Jürgen Brenner, juergen.brenner@fh-Joanneum.at

Engineering Knowledge Transfer Units to Increase Student´s Employability and Regional Development

Measuring fuel consumption and pollutant emissions - Chassis Dynamometer

T. Lechner

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Contents

- Introduction
- Chassis dynamometer
- Drive cycles
- Exhaust gas measurement
  - Gaseous compounds
  - Soot particle

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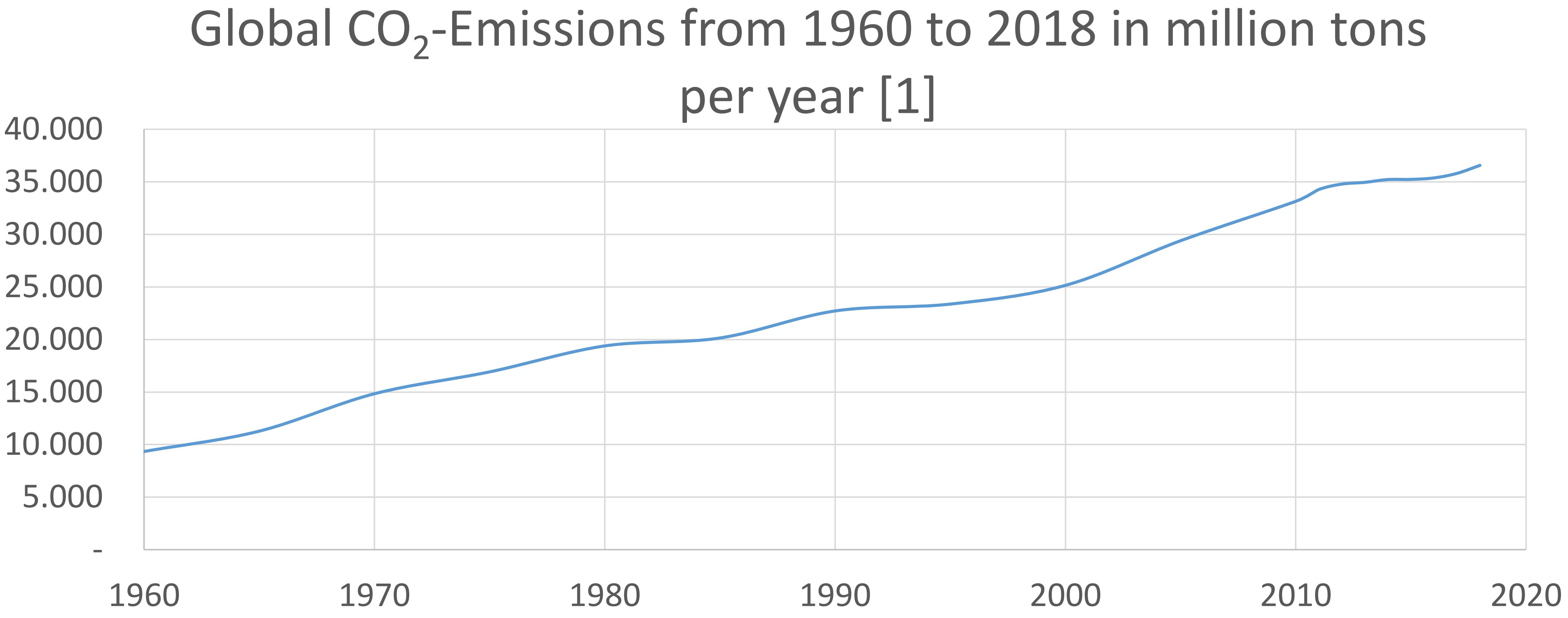
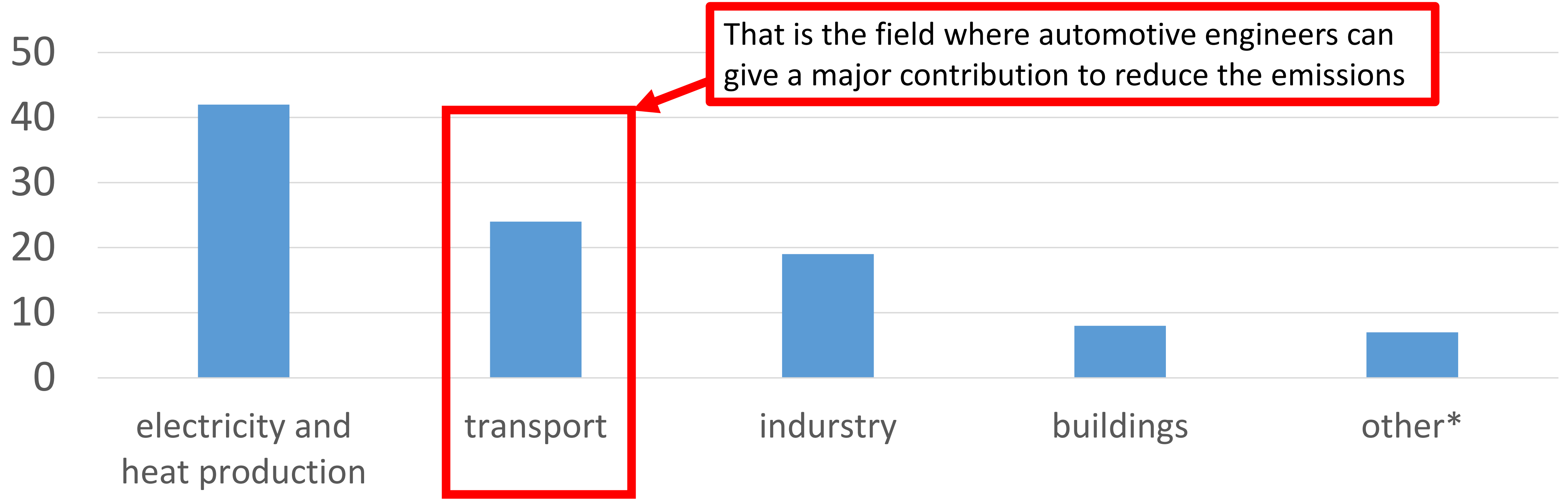
Global CO2-Emissions - Trend



Global CO2-Emissions per Sector

CO2, sector share of global emissions in 2016 in % [3]



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EU CO2 emission target

- EU contribution for climate protection
  - Since 2015, a **target of 130 grams of CO2 per kilometre** applies for the EU fleet-wide average emission of new passenger cars.
  - From 2021 the EU fleet-wide average emission target for new cars will be **95 g CO_2/km**.
    - Petrol: ~ 4.1 litre/100 km
    - Diesel: ~ 3.6 litre/100 km

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CO2-fleet emission 2018

2018th CO_2-fleet emission of selected OEM's [4]

OEM	CO2 Emission in g/100 km	delta to 95 g/100 km
Mercedes	139.6	44.5
Mazda	135.2	40.2
BMW	128.9	33.9
Kia	120.4	25.4
Peugeot	107.7	12.2
Toyota	99.9	4.9

based on NEDC

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Pollutant

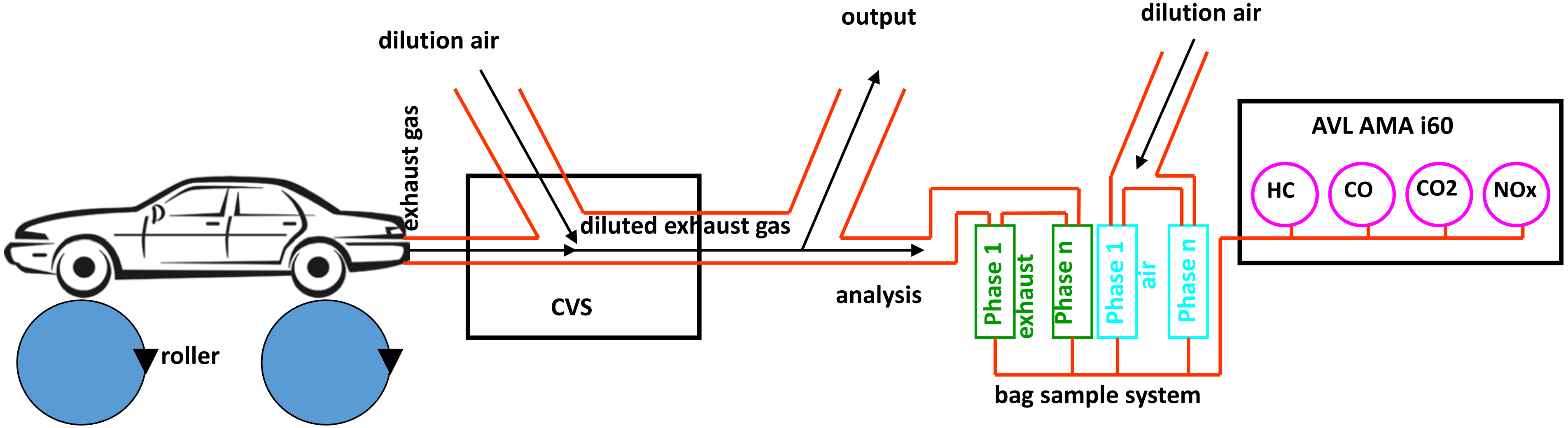
- EURO 6: List of pollutants to measure and legal limits [6]

Measured Value	Diesel	Petrol
$CO2$, g/km	-	-
CO, g/km	0.5	1
THC, g/km	-	0.1
NMHC, g/km	-	0.068
NO_X, g/km	0.08	0.06
$HC+NO_X$, g/km	0.17	-
PM, g/km	0.0045	0.0045*
PN, #/km	$6 \cdot 10^{11}$	$6 \cdot 10^{11}$

*) for direct injected engines

Measuring Device

- Equipment to measure emission values
  → chassis dynamometer



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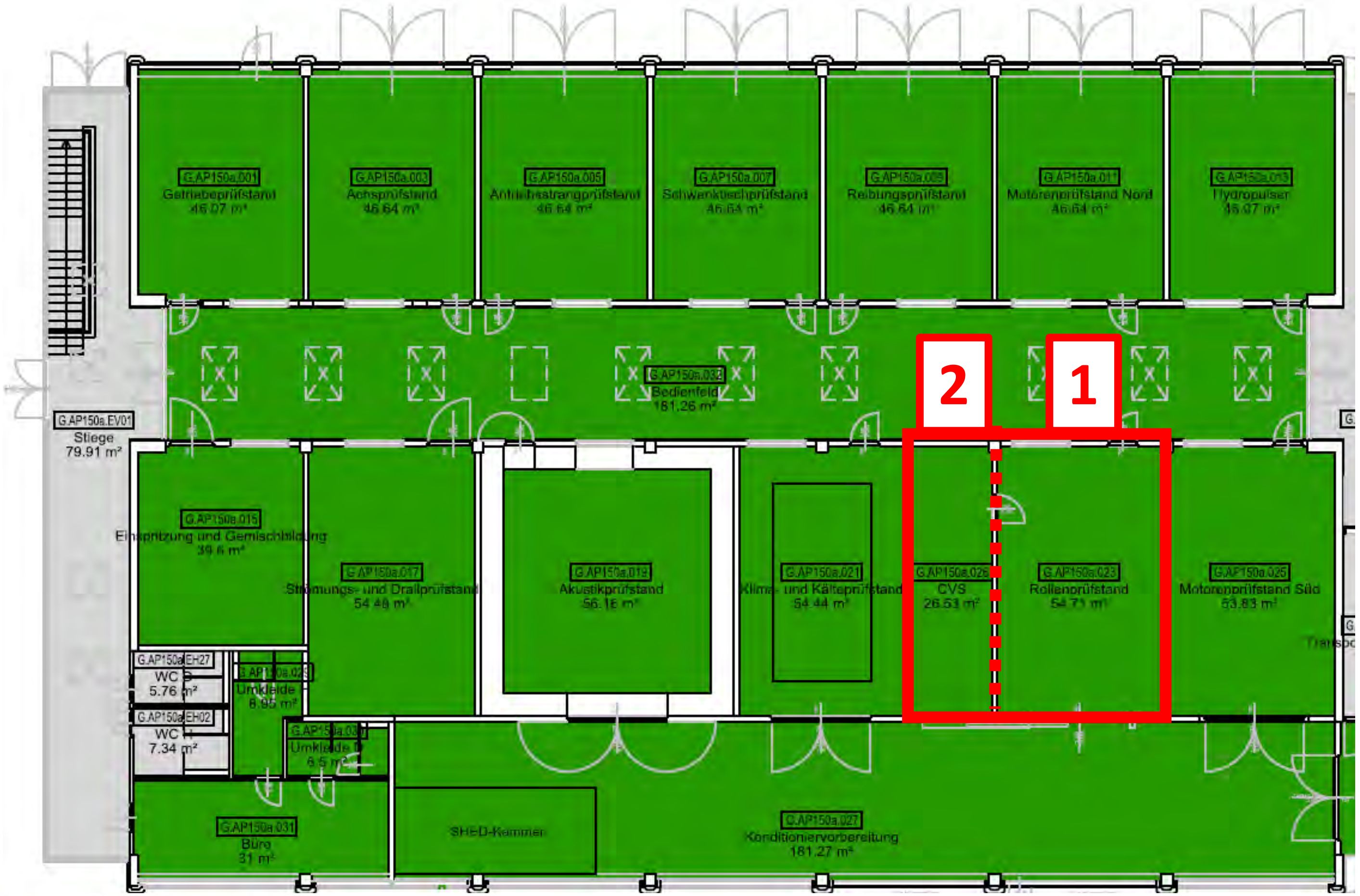
Floor plane



1 – Chassis dynamometer 54.71 m²

2 – Exhaust gas analysing device, 26.53 m²

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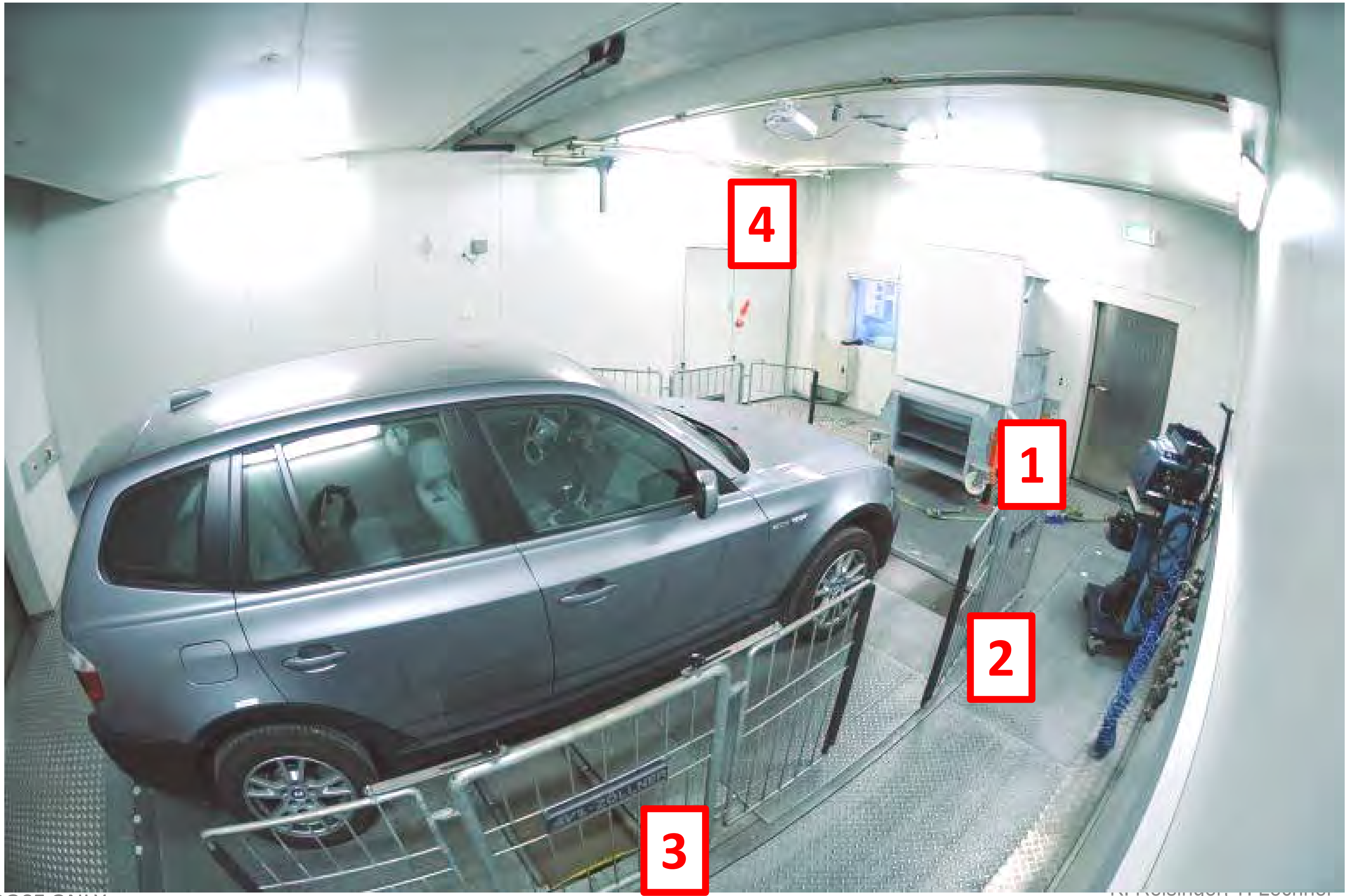
Measuring Device – Overview

1 – wind fan

2 – front axle

3 – rear axle

4 – CVS and Analysers are behind



CVS - Venturi Nozzle

- The volume of the diluted exhaust gas (V_{mix}) is an important measurement value.
- Measuring device → **C**ritical **F**low **V**enturi (CFV) → commonly used
- Flow rate depends on
  - geometric dimensions
  - absolute temperature and pressure at Venturi inlet

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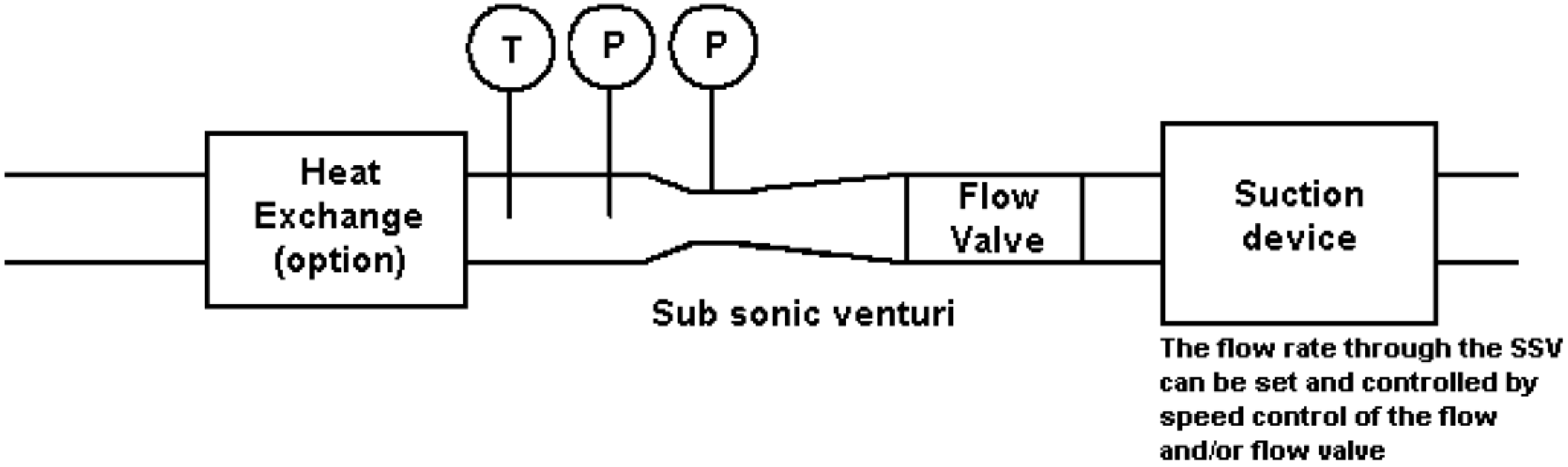
SSV, schematic drawing



[5] Sub-Annex 5, § 3.3.6.3.2

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Legal Documents

- Europe: Regulation No. 2017/1151 [5]
- USA: 40 CFR Part 1066 with references to Part 1065
- China Similar to the European law (EURO 5 and EURO6)

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Driving Cycle, basis

- The goal is to measure **realistic and comparable** exhaust gas emissions as well as the fuel consumption.
  - The chassis dynamometer must simulate real driving conditions.
    - Task of the control system
    - Simulate a flat road, not wind influenced
    - Vehicle specific driving resistance values (road load)
  - The driving route must be representative for real life.
    - Regulated drive cycle → vehicle velocity over time
    - Shall be represent the average of all vehicle drives

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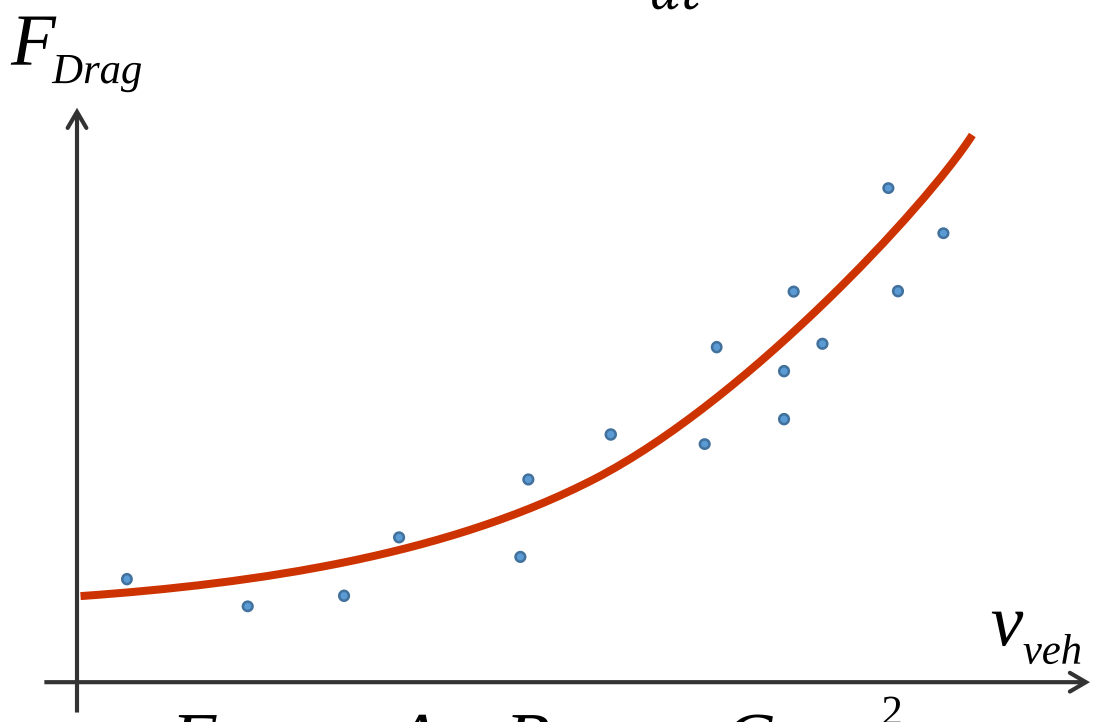
Drag Measurement

- Coast Down Test at horizontal road in neutral gear measures
  - rolling resistance
  - + aerodynamic drag
  - + losses in drive train
- Measure speed over time
- Differentiate in respect to time, calculate drag
- Fit quadratic parabolic equation

$$(m_{veh} + m'_{rot}) \cdot \frac{d\,v}{dt} = F_R + F_{AD}$$



$$F_{Drag} = A + B v_{veh} + C v_{veh}{}^2$$

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Road load equation, [5] Sub-Annex 4

- To simulate realistic driving conditions, the road load must be detected for each vehicle.
- The road load equation:

$$F = f_0 + f_1 \cdot v + f_2 \cdot v^2$$

F	longitudinal force in N
v	velocity in km/h
f_0	constant **r**oad **l**oad **c**oefficient (rlc) → friction, rolling resistance
f_1	first order rlc → linearly depending on the velocity
f_2	second order rlc → mainly influenced by the air drag

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Road Load Coefficient

- The road load coefficient must be measured.
- For that, legally conferment methods are:
  - coast down method (standard method)
    - Accelerate the vehicle to a maximum speed at a test track
    - (WLTP: 130 km/h)
    - Coast down the vehicle
    - Measure the vehicle velocity in accurate time stamps
  - wind tunnel method
    - Combination of a wind tunnel and a (flat belt) chassis dynamometer

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Measuring Procedure Overview

- Vehicle preconditioning
  - To guarantee comparable results, vehicles must be set to a defined initial state.
  - For this, a part of the relevant drive cycle should have driven.
  - After the preconditioning phase, the vehicle shall be kept in a room with stabilized temperature.
- Emission measurement
  - Due to a legally conformant drive cycle.
  - Pollutants and fuel consumption are calculated out of measured values.
  - Documentation of results → test report for customers

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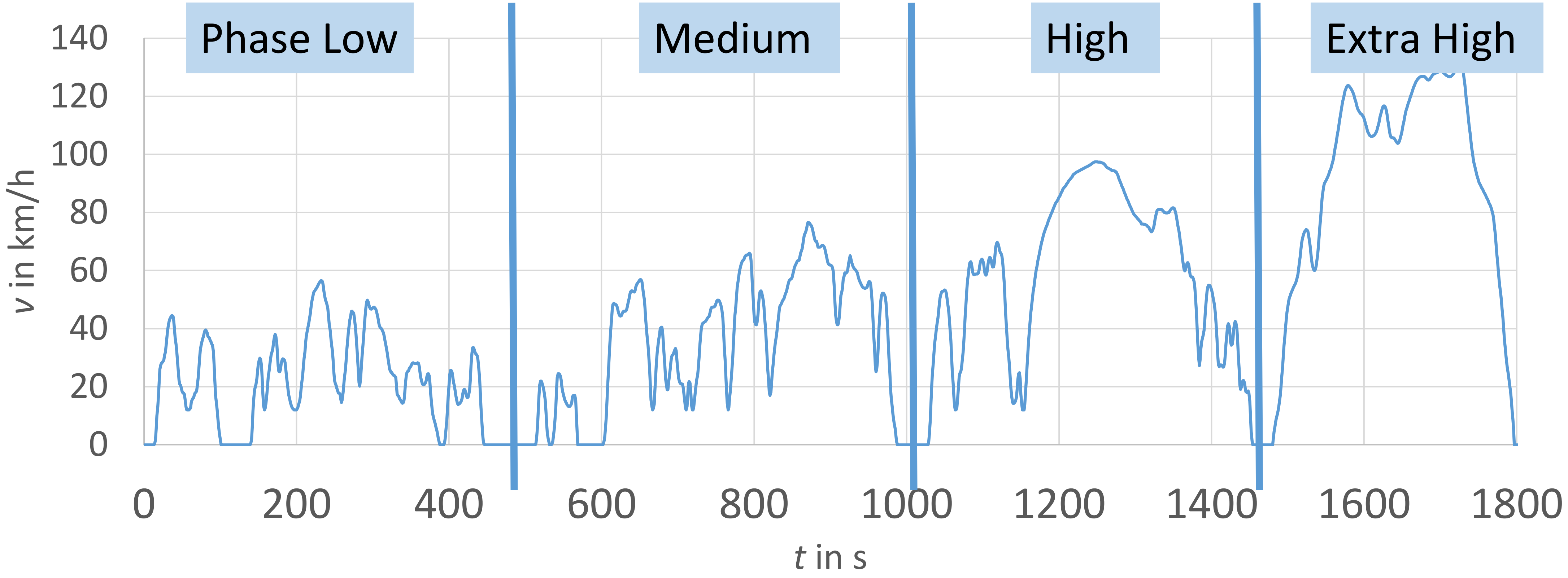
Driving Cycle Europe

WLTC Class 3 – **W**orldwide harmonized **L**ight vehicle **T**est **C**ycle



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Driving Cycle Europe

- WLTC Class 3
  - Class 3: power to weight ration >34 W/kg
  - 4 Phases → 2x4 bags per phase to sample diluted exhaust gas and dilution air
  - Maximum velocity is 131 km/h
  - Phase 1 and 2: urban
  - Phase 3 (rural) and Phase 4 (motorway): suburban
  - Testing duration is 1800 seconds

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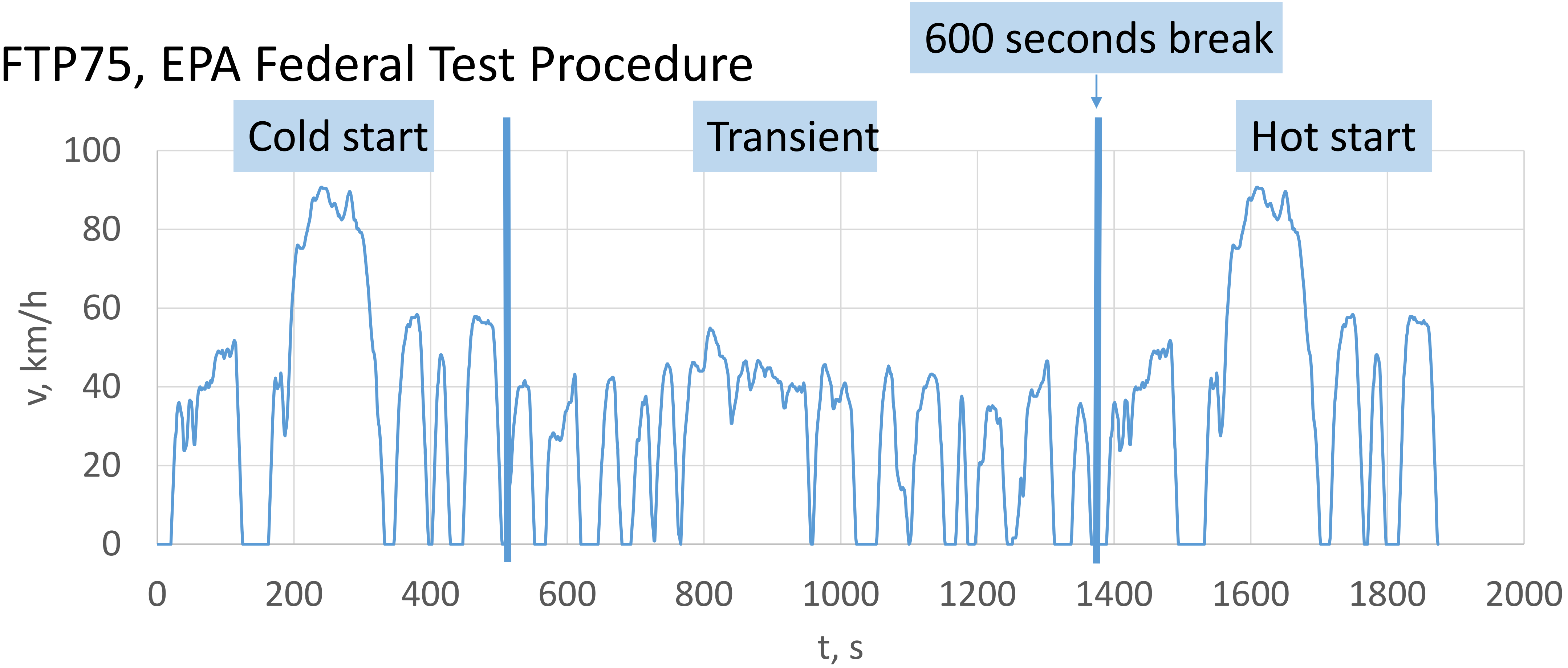
Driving Cycle USA

FTP75, EPA Federal Test Procedure



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Measuring Procedure

- A complete exhaust measurement can be segmented in 4 steps.
  1) Preliminary works
  2) Vehicle fixing at the test bed
  3) Vehicle pre-conditioning
  4) Carrying out of the measurement
- The exact procedure is described in detail at the respective laws.
- For a valid measurement, all involved participants must strictly comply with that!
- The next slides shows the measuring procedure in generally.

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Measuring Procedure, Step 1

- Preliminary works
  - Vehicle delivery and takeover
  - Control the vehicle regarding to the measurement capability
  - Refuelling the vehicle with certified fuel
    - Exact chemical compositions a needed for the calculation.
  - Mount adapters to the exhaust pipe
    - To connect the vehicle with the exhaust fan.

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Measuring Procedure, Step 2

- Fix the vehicle at the test bed
  - The vehicle must be adjusted very accurate to prevent influences by cross forces.
  - Control the tyre pressure.
  - Connect the exhaust adapter to the CVS-system.
  - Load batteries.

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Measuring Procedure, Step 2

Rear and front axes are of the vehicle are exactly loaded at the roller apex.

Measuring Procedure, Step 2

The car is fixed with belts or alternative with bars.

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Measuring Procedure, Step 3

- Pre conditioning phase
  - System warm up
    - Example: 1 WLTC without emission measurement
  - Road Load adaption to guarantee, that the control systems simulates a “true environment”
    - To check the road load coefficient:

      1) coast down at the test bed

      2) compare test bed results with measured driving resistance
  - Pre run to set the system to defined output state.
    - Example: 1 WLTC without emission measurement
  - Vehicle conditioning
    - Example WLTC: from 6 to 36 hours, ambient temperature → 23 °C +/- 3 °C

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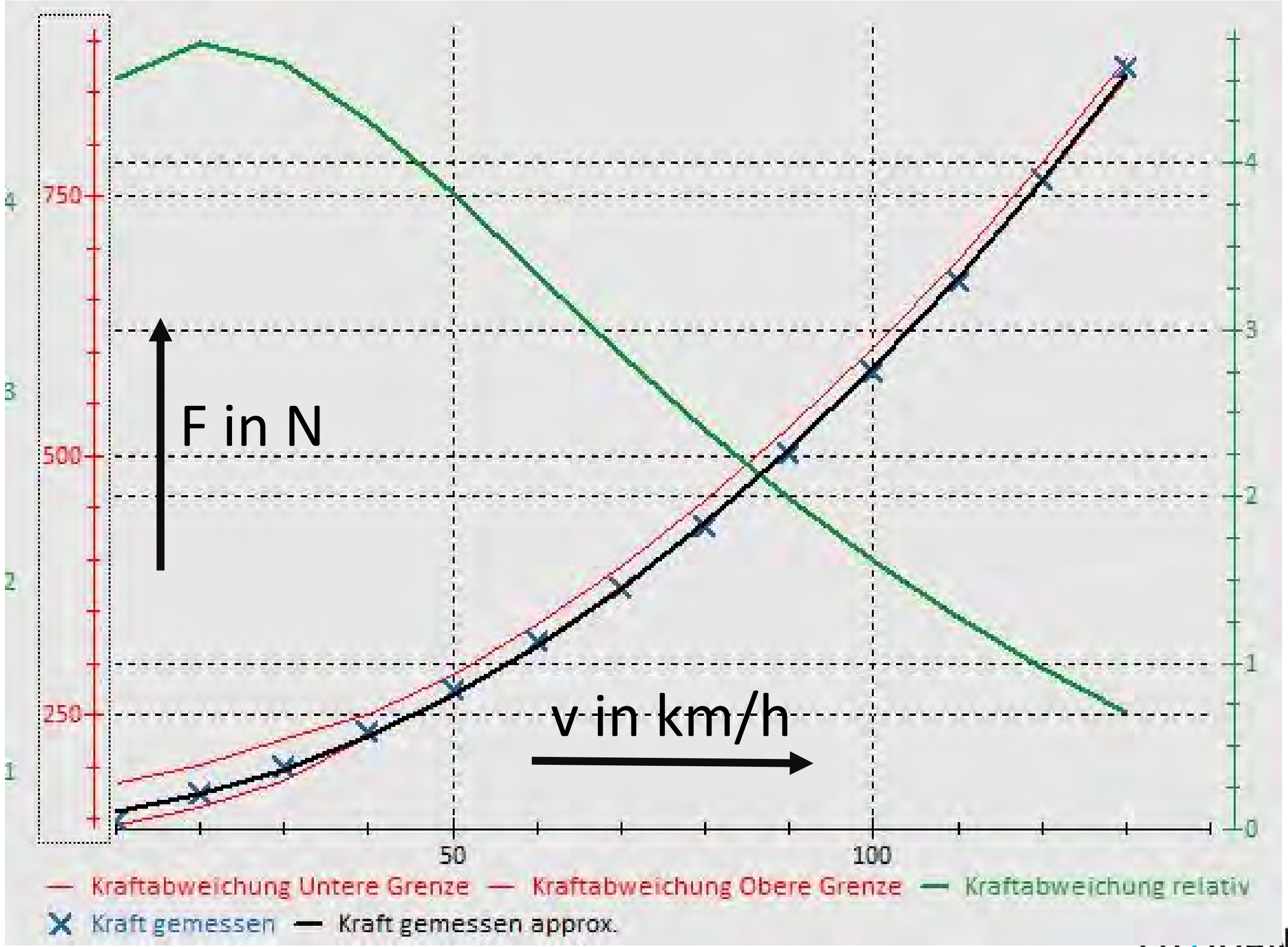
Step 3, Coast down comparison

- black: velocity depending force, measured at the test bed.
- red: desired value tolerance lines
- green: deviation between desired and measured value in %



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Step 4, ready to measure

- Calibration and, if necessary, adjustment of the measurement system
  - Gas analyser → with calibration gases
- **Measuring the vehicle**
  - Cycle for WLTP is WLTC
  - During the test, some gaseous pollutants are measured with an sampling frequency of 1 Hz.
  - A sample taken out of the diluted exhaust gas will be stored in special bags.
  - After the test (WLTC finished), the measurement system has to be calibrated once again.
  - The sample taken will be analysed, after the test has finished.

Step 4, measurement

drivers view

bag sampling system

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Measure gas concentration

- For gaseous compounds (C_{i} in ppm) → gas analyser

$$M_{\mathrm{i}} = \frac{V_{\mathrm{mix}} \cdot Q_{\mathrm{i}} \cdot k_{\mathrm{H}} \cdot \boldsymbol{C_i} \cdot 10^{-6}}{d}$$

- THC, CH_4 — Heated Flame Ionisation Detection (FID)
- CO and CO_2 — Infrared Detector (IRD)
- NO and NO_x — Chemiluminescence Detector (CLD)

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Measure soot particles

- Particle mass in g/km
  - A sample taken out of the diluted exhaust emission is passed through a special filter plate.
  - The weight of the filter plate must be measured before and after the test.
  - The weight difference between the loaded and the unloaded filter allows a conclusion to the emitted particle mass.
  - **Problem:** The weight difference is only in the range of few micrograms.
  - A accurate scale is needed. The ambient climate in the sample chamber must be constant.

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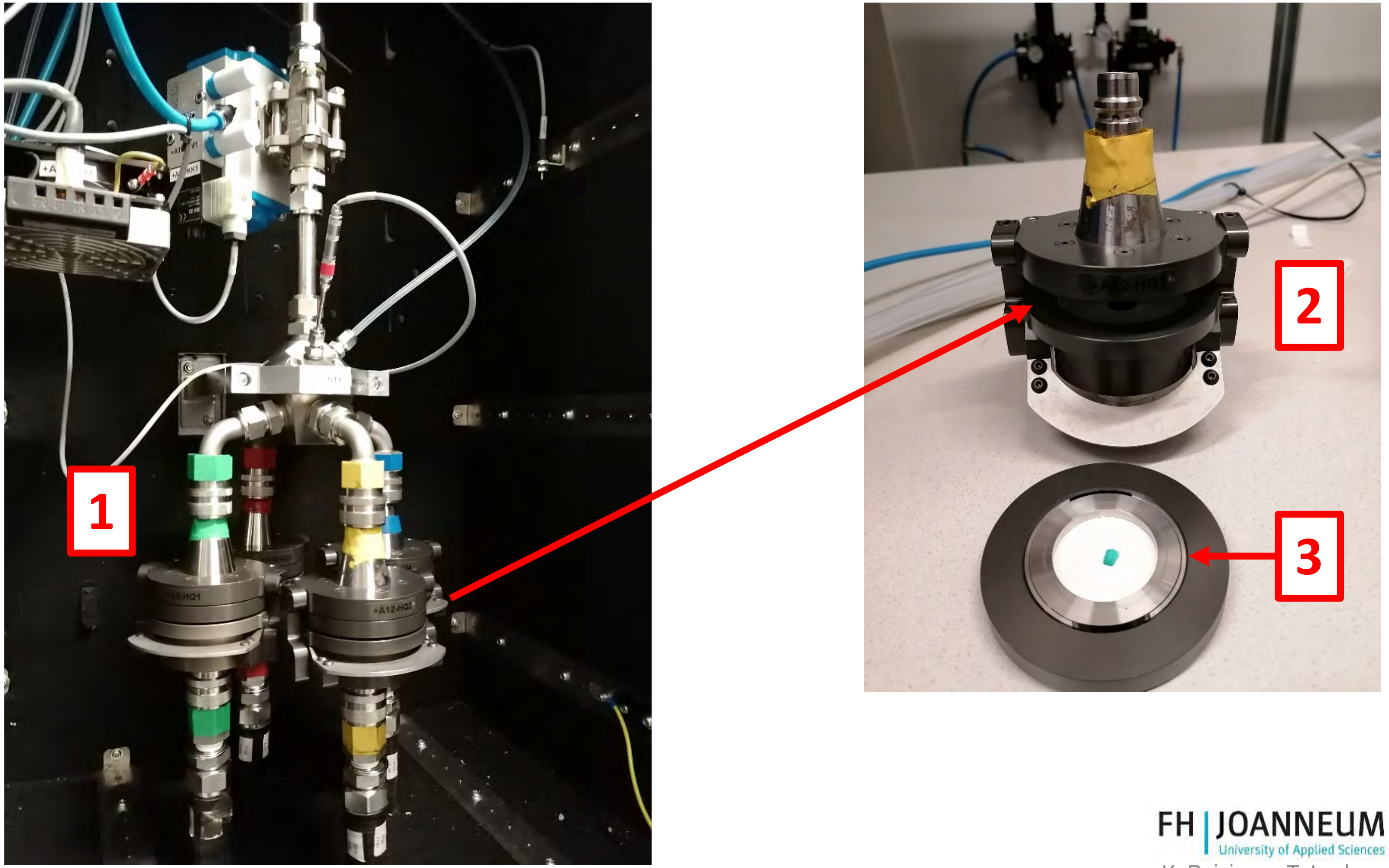
Measuring Device, PSS

1) In PSS installed filter holder
2) Dismounted and opened filter holder
3) Filter plate



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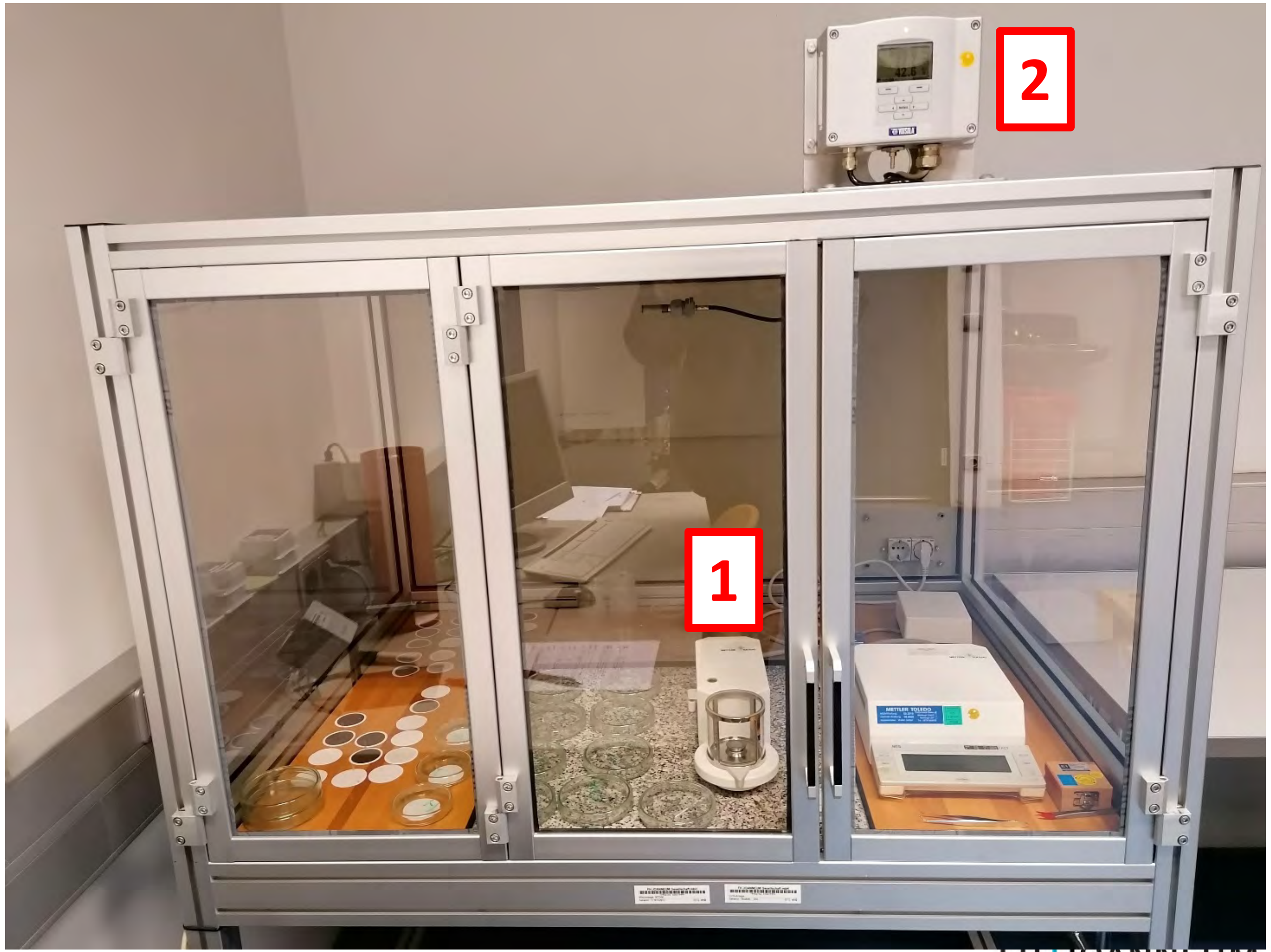
Sample Chamber

1) Micro scale
2) Ambient temperature, humidity and pressure



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Loaded Filter Plates

Different loaded
filter plates

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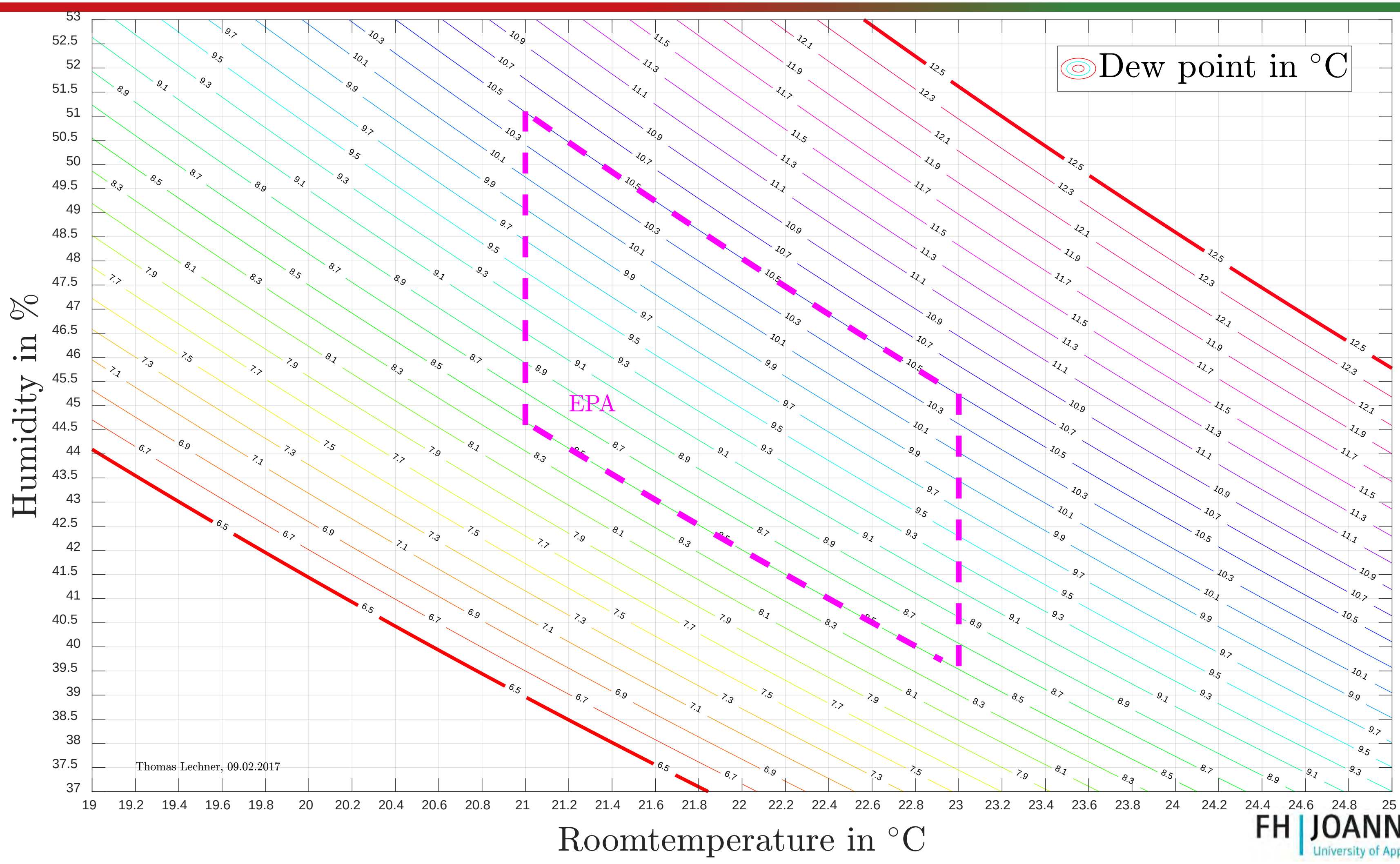
Sample Chamber, Tolerance range



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Measure soot particles

- Particle number in #/km
  - Measuring device: Particle counter

Fuel consumption

- The calculation is based on the carbon balance.
- The fuel consumption is influenced by
  - Mass emissions of HC, CO and CO_2
    - The highest measured concentration in the exhaust gas comes from CO_2
  - Fuel density and consistence
    - Certified fuel is necessary.

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Hands-On Training Test Facility

UNITED

Plan a concept for your University

Group Work for each University, prepare flip charts

- Which tests could be needed from industry?
  - Functional Testing?
  - Durability Testing?
  - Complexity?
- How can students be involved in these industry projects?
- How do the tests fit to curricula?
- Can results be introduced to lectures?
- Necessary Hardware

Presentation by a speaker and discussion after coffee brake.

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Hands-On Training

Present the tools you planned to buy and the trainings done with it

Group Work for each University, prepare flip charts

- Concept of training?
    - Technical content
    - Who shall be trained? – expected knowledge of trainees.
    - Topics to be trained
- Necessary Hardware

Presentation by a speaker and discussion

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