OTTO VON GUERICKE UNIVERSITÄT MAGDEBURG
IMS INSTITUT FÜR MOBILE SYSTEME
ENERGIEWANDLUNGSSYSTEME FÜR MOBILE ANWENDUNGEN

New acoustic challenges of current and future drive technologies

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Outline

- Motivation
- Acoustic motor test bench at the IMS-EMA
- Center for Method Development
- Acoustic Expertise
- Development examples for noise analysis and optimization of existing and future drives
- Conclusion

Motivation

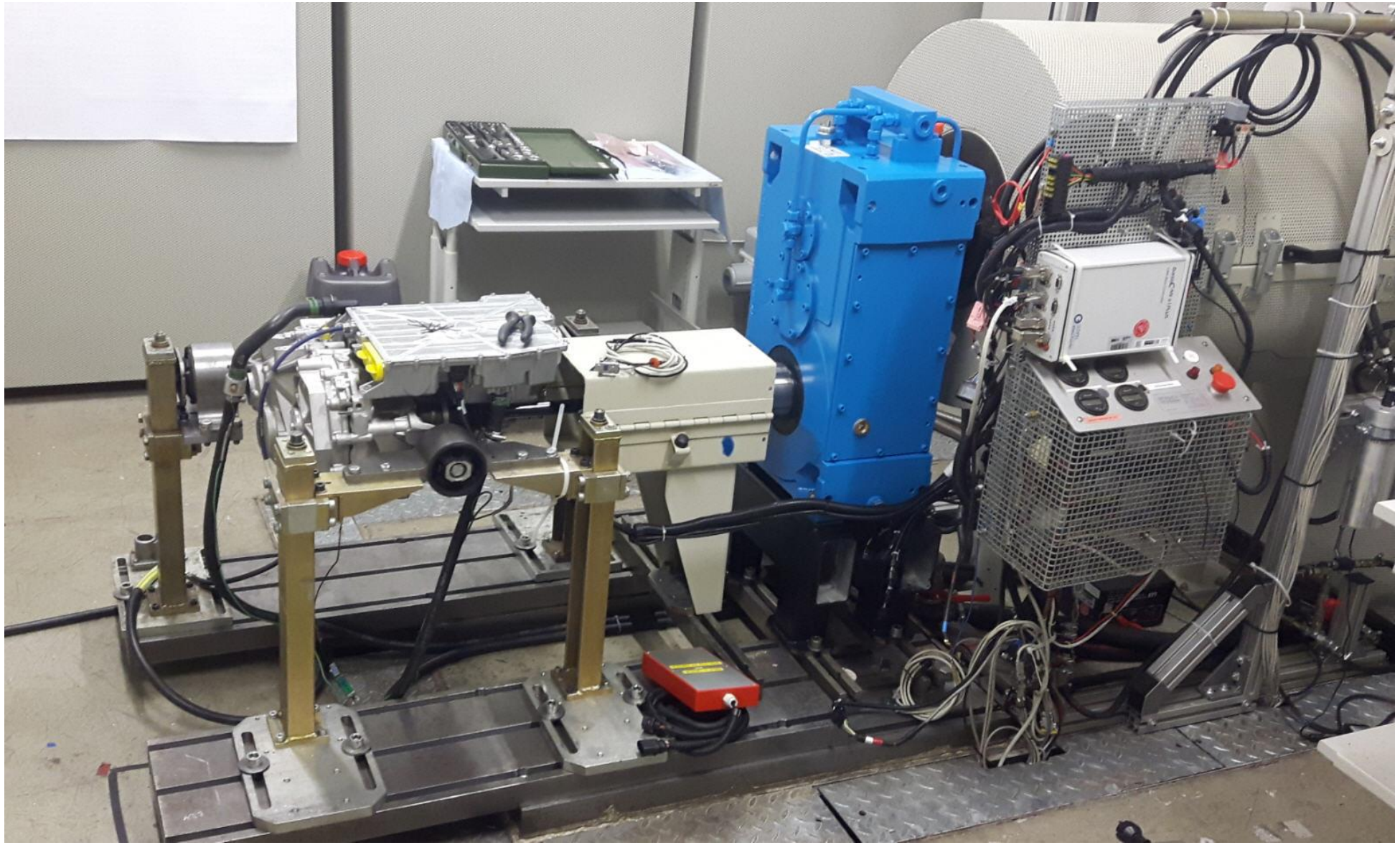
Possible future drive mix

Drive type	Vehicle type	Weight	Range
Electric motor with battery (BEV)	Car, Truck	light	short distance (urban)
Electric motor with fuel cell	Car, Truck	heavy	long distance
Internal combustion engine with green hydrogen	Truck	heavy	long distance
Hybrid vehicles (internal combustion engine and electric motor)	Car, Truck	heavy	long distance
Internal combustion engine with liquid synthetic fuels of regenerative origin (with the exception of is green hydrogen)	Car, Truck	light	long distance

* Duvigneau, F.; Schneider, S.; Doleschal, F.; Luft, T.; Rottengruber, H.; Verhey, J. L.: *Die Akustik neuer Antriebskonzepte im Rahmen der Mobilitätswende*. DEGA-Journal, Ausgabe: Januar 2022, pp. 7-20.

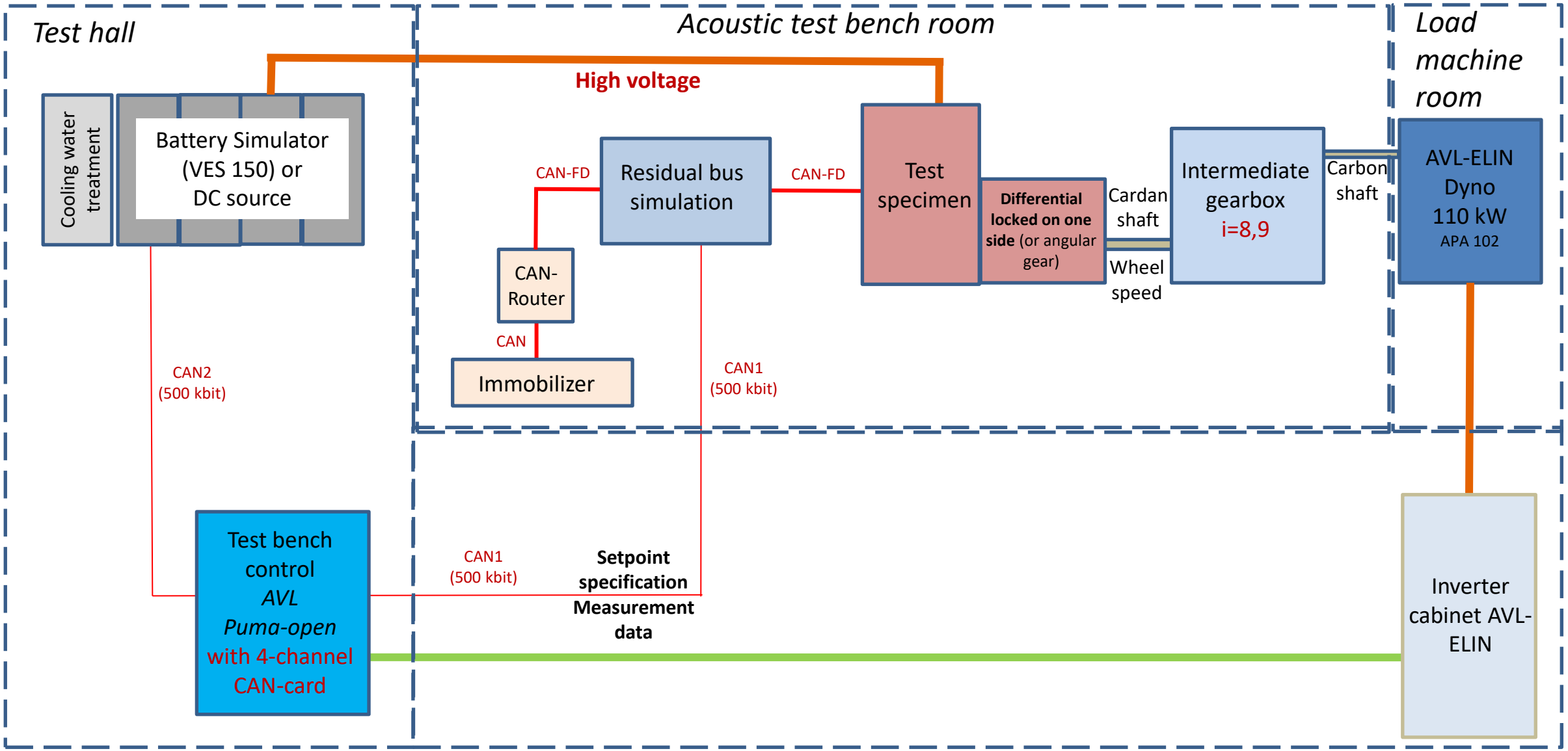
Acoustic motor test bench at the IMS-EMA

Technical structure with automotive electric motor



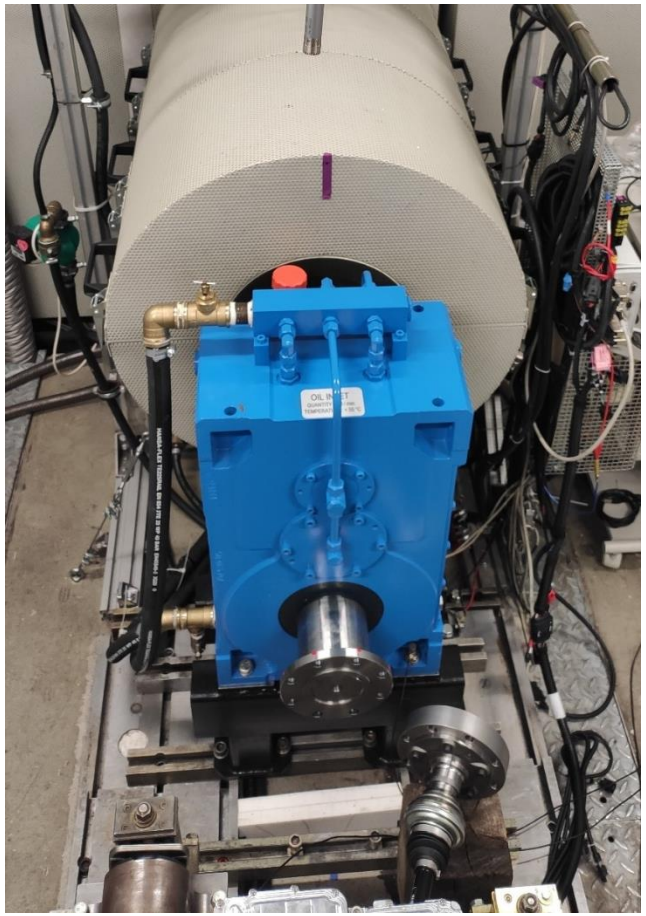
Making old test fields usable

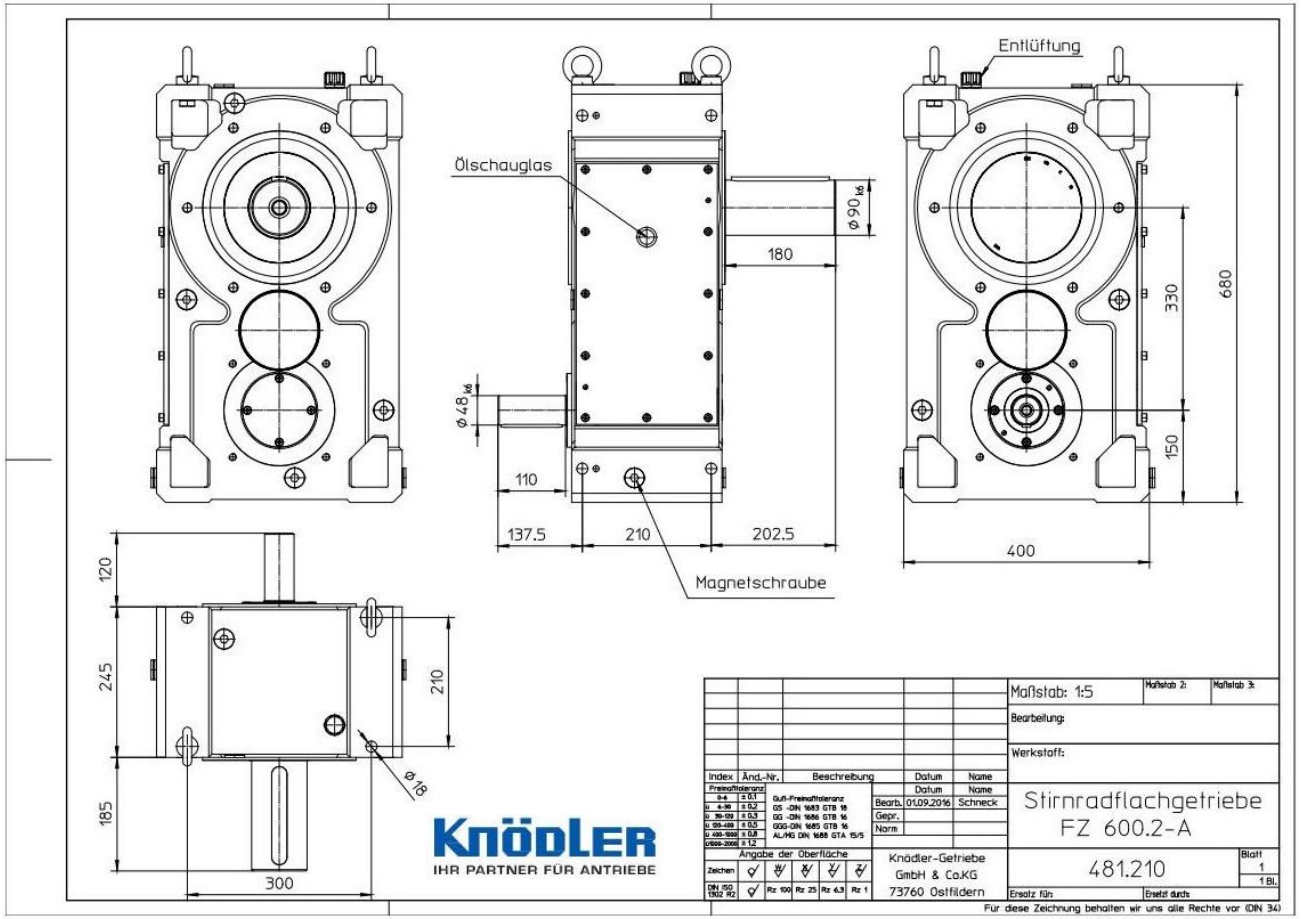
Acoustic motor test bench at the IMS-EMA – schematic structure



Acoustic motor test bench at the IMS-EMA

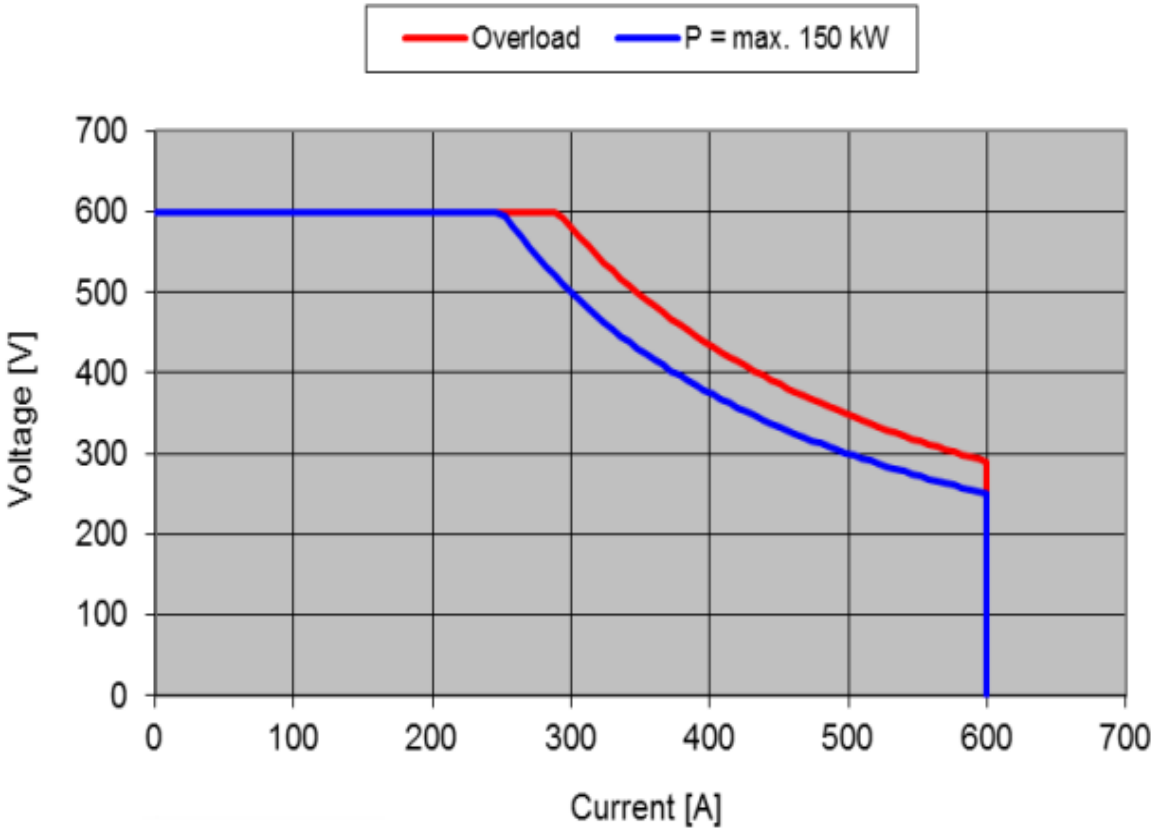
Intermediate gearbox for torque adjustment for automotive electric motors





Acoustic motor test bench at the IMS-EMA

Battery simulator (on the left) and DC voltage source (on the right)

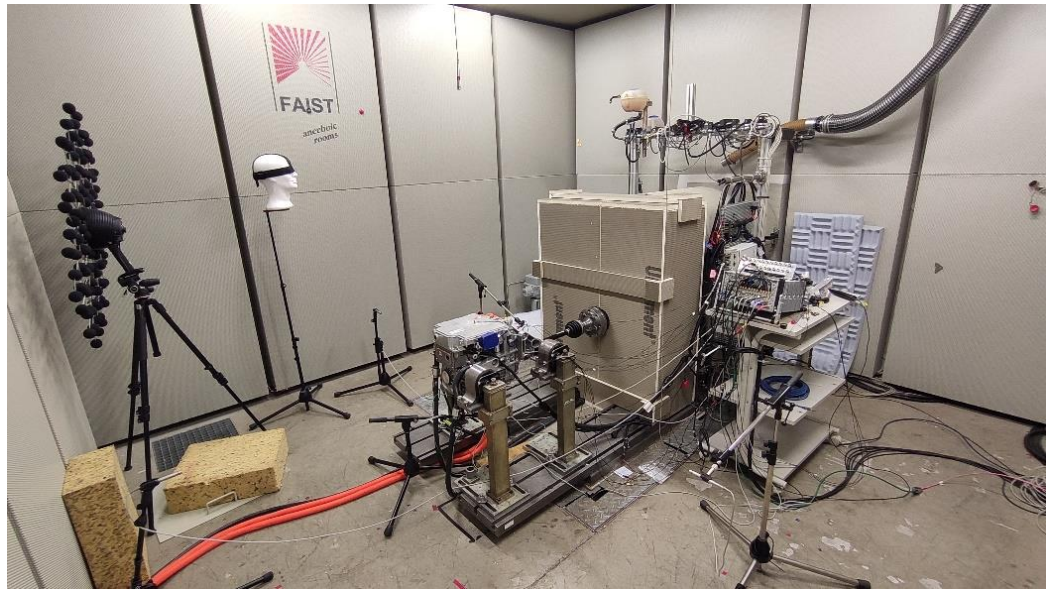


max. Power:	150 kW
max. Voltage:	600 V
max. Current:	600 A
Overload	16 %

© EA Elektro-Automatik in 2020

max. Power:	150 kW
max. Voltage:	1000 V
max. Current:	400 A
Overload	10 %

Acoustic measurement technology

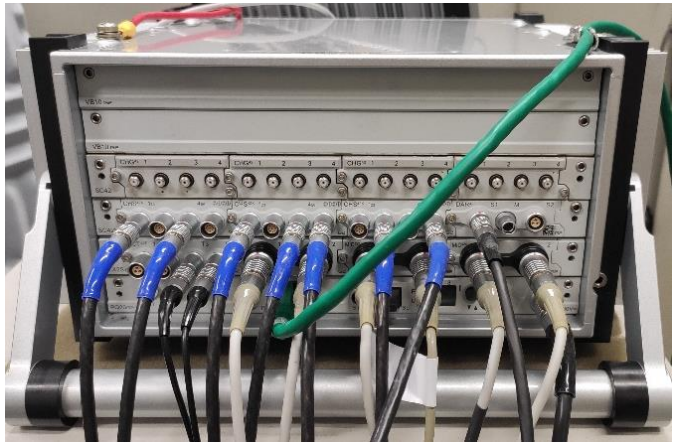


Acoustic motor test bench

- FAIST broadband absorber:
  Accuracy class 1 at f > 50 Hz
- Measurement of passenger car electric motors (max. 1000 V) and passenger car internal combustion engines
- Highdynamic Test-Rig
  High-Speed-Mode: 110 KW, max. 10.000 rpm
  High-Torque-Mode: 110 KW, max. 2700 Nm (**with encapsulated gearbox**)
- Intake and room air conditioning

Measurement Technology (Selection)

Test bench acoustic measuring system MKII (software PAK, *Müller-BBM*)



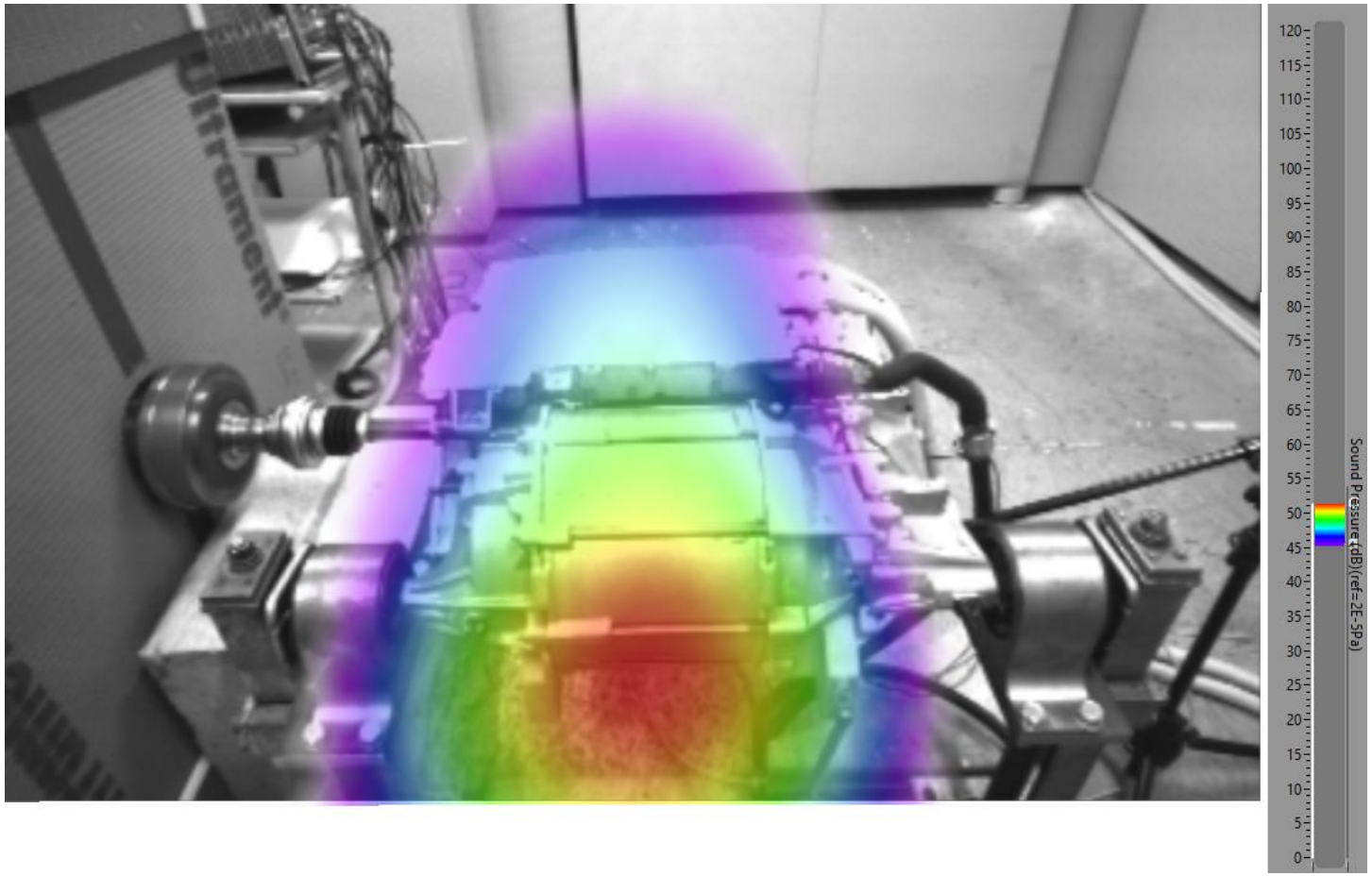
Sound Source Localization System Holography / Beamforming

Head Acoustics HSU III.2

PSV-400-3D Scanning Vibrometer

Acoustic Camera Systems

- Localization of sound sources depending on the frequency range as well as the motor orders
- Representation of sound pressure as well as sound intensity distributions

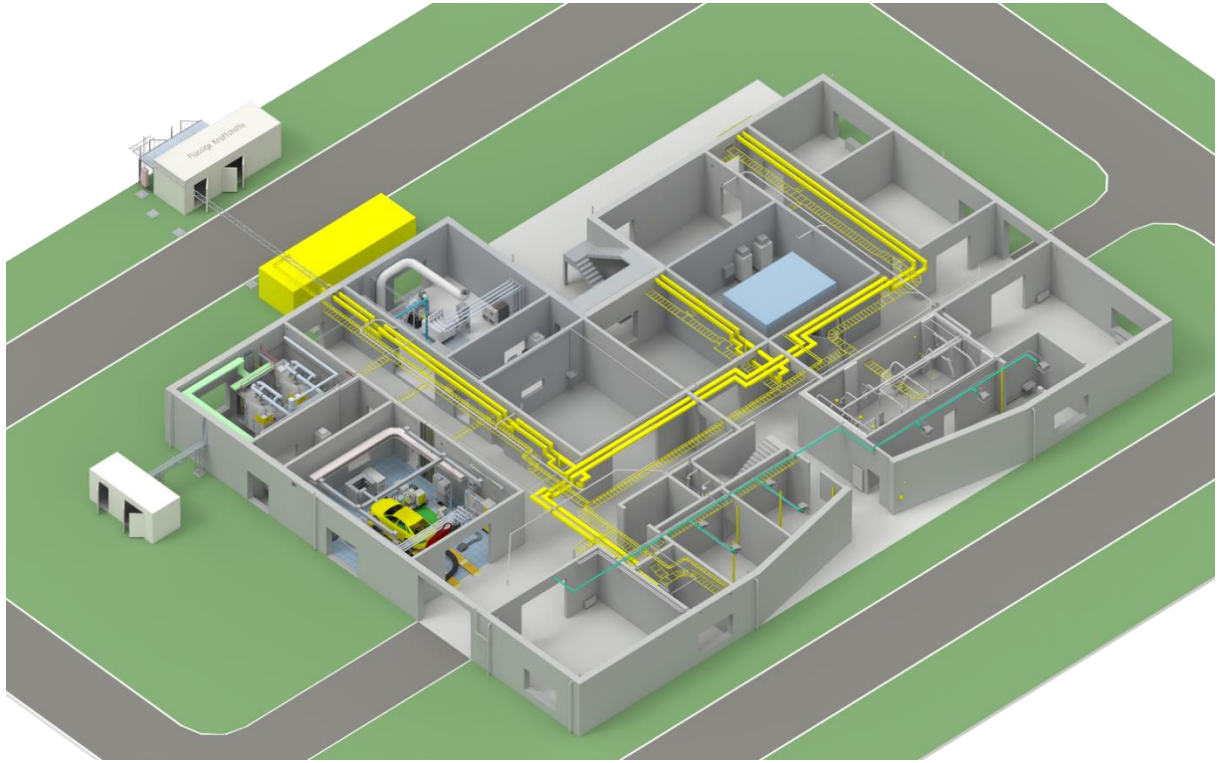


ΔL_p = 8 dB(A)

Center for Method Development

Concept

- Cross-faculty research and development facility
- State-of-the-art equipment for analysis of combustion engines (alternative and conventional fuels), electric motors, fuel cells and hybrid systems
- Variety of test benches for powertrains to develop and test new methods for powertrain analysis



Center for Method Development

Test benches

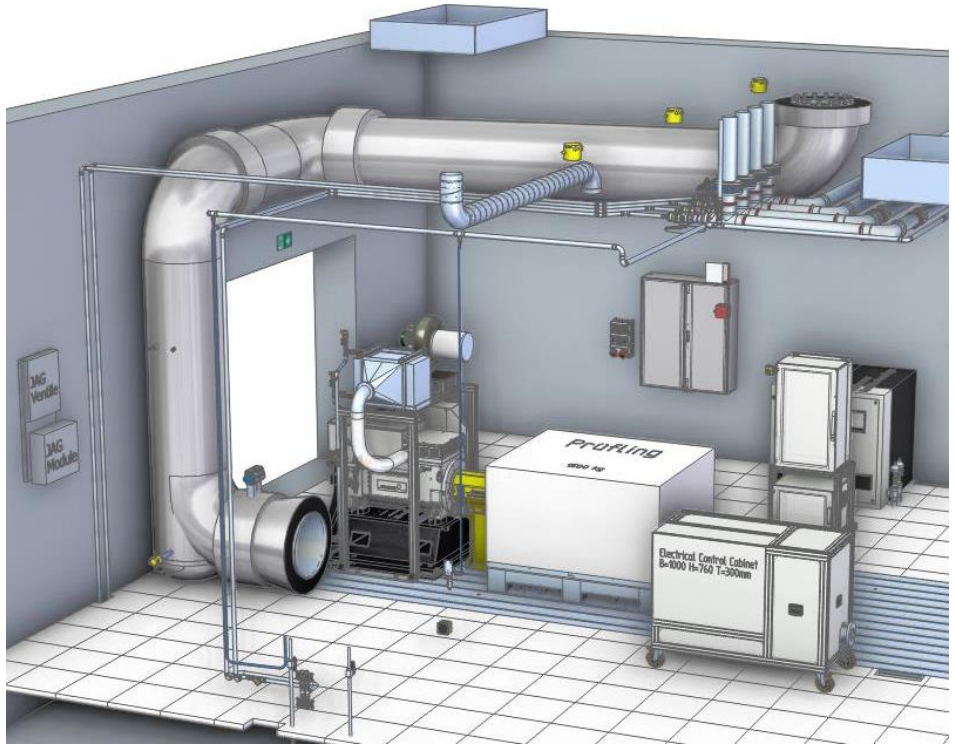
No.	Name	Description
P1	Road-to-Rig	Complete Vehicle and Drivetrain Test Bench
P3	**Power Pack**	Power-Pack Testbed for commercial vehicle und passenger car applications, which is capable for H_2-operation and. Nominal power: 650 kW
P4	**Fuel Cell**	Fuel Cell Test Rigs for PEM Short-Stacks and Single Cells
P5	**Electric Motor**	Electric Motor Test Bench with a high-torque and high-speed machine, which is capable for acoustic investigations
P7	Battery Pack	Temperature controlled battery pack test bench
P8	Networking	Networking test bench with the aim of building a digital twin
P9	Power electronics	Power electronic test bench with an electric machine emulator
P10	**Battery simulator**	**Highly dynamic current source / sink (max. 1200 V, 1800 A, 350 kW)**
P11	Corrosion	Test bench for examining corrosion (e.g. salt spray chamber)
P12	Exhaust analysis system	Exhaust analysis system for P1 and P3
P13	Gas chromatograph	Test bench for gas chromatographic investigations

Center for Method Development

P3 – „Power-Pack“ Testbed – capable for H_2-Operation

The Power-Pack engine test bench (suitable for hydrogen and gas operation) opens up the possibility of CO_2-neutral car & commercial vehicle drives at OvGU. Hydrogen combustion engines are, besides fuel cell and battery electric drives, a realistic possibility to represent heavy duty traffic CO_2-neutral.

Due to its flexible design, the Power-Pack test bench is intended primarily for method development on the H_2 combustion engine system and an optional hybrid powertrain for commercial vehicle and passenger car applications. Endurance tests are also feasible.

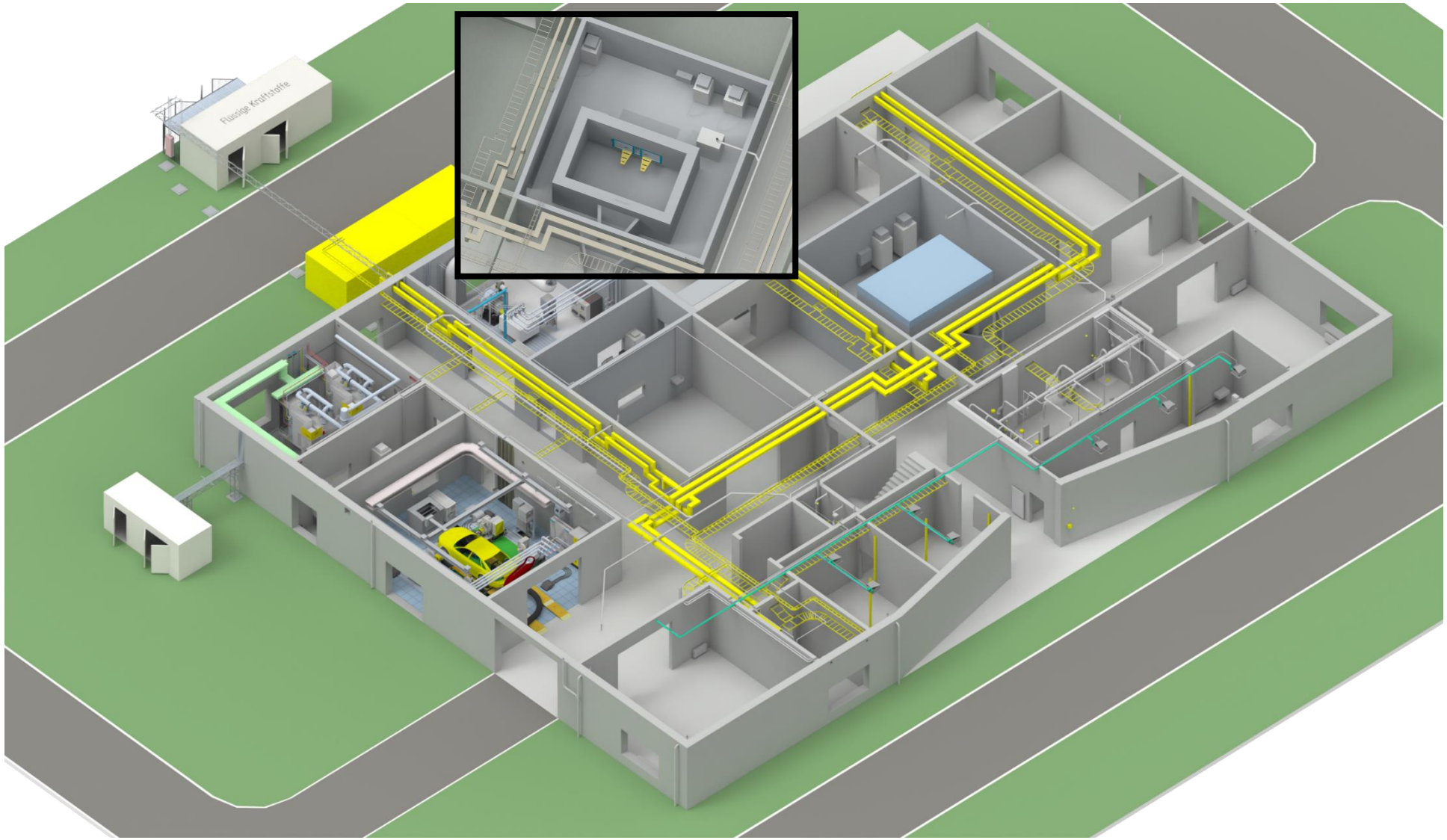


- Load machine :
  - Three-phase asynchronous machine
  - Nominal power : 650 kW (short time up to 980 kW)
  - Max. Speed: 9000 rpm
  - Max. Torque: 4500 Nm
  - Cooling type : Rotor (air-cooled), Stator (water-jacket cooled)

- Frequency inverter with *R2R*-Technology
  - Clock-synchronous connection to the automation system (set point specification with 10 kHz)
  - Clock-synchronous speed and torque measurement directly at the inverter

Center for Method Development

P5 – Electric Motor - Test Bench (capable for Acoustic Investigations)



Center for Method Development

P5 – Electric Motor - Test Bench (capable for Acoustic Investigations)

Hightorque machine

Technical data

Type:	**Asynchronous machine**
Rated Power:	440 kW
Max. Power:	650 kW (short time)
Max. Speed:	3.500 rpm
Rated Torque:	3.500 Nm
Max. Torque :	5.991 Nm (from a speed of 10 Hz)
Type of cooling:	Rotor: Air-cooled
Stator:	Water jacket cooled

Highspeed machine (encapsulated)

Technical data

Type:	**Synchronous machine**
Rated Power:	300 kW
Max. Power:	450 kW
Max. Speed:	23.000 rpm
Rated Torque:	300 Nm
Max. Torque :	450 Nm
Type of cooling:	Rotor: Air-cooled
Stator:	Water jacket cooled

P5 – Electric Motor - Test Bench (capable for Acoustic Investigations)

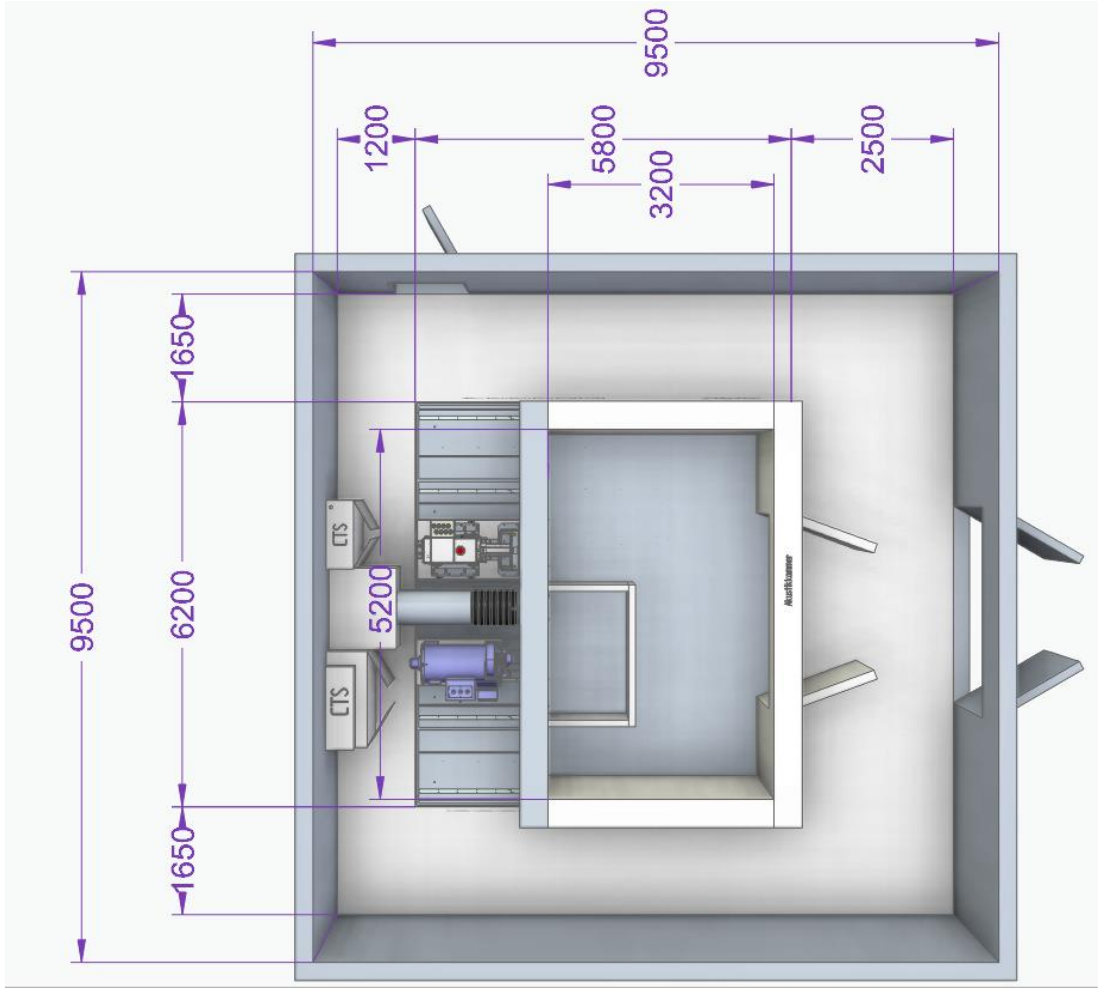
Climatic - & Acoustic Insulation Chamber

The electric motor test bench generally enables efficient testing to be carried out under conditions to which electric motors in electric and hybrid electric vehicles are subjected.

These include standard operation, extreme loads, and continuous operation in combination with thermal conditions.

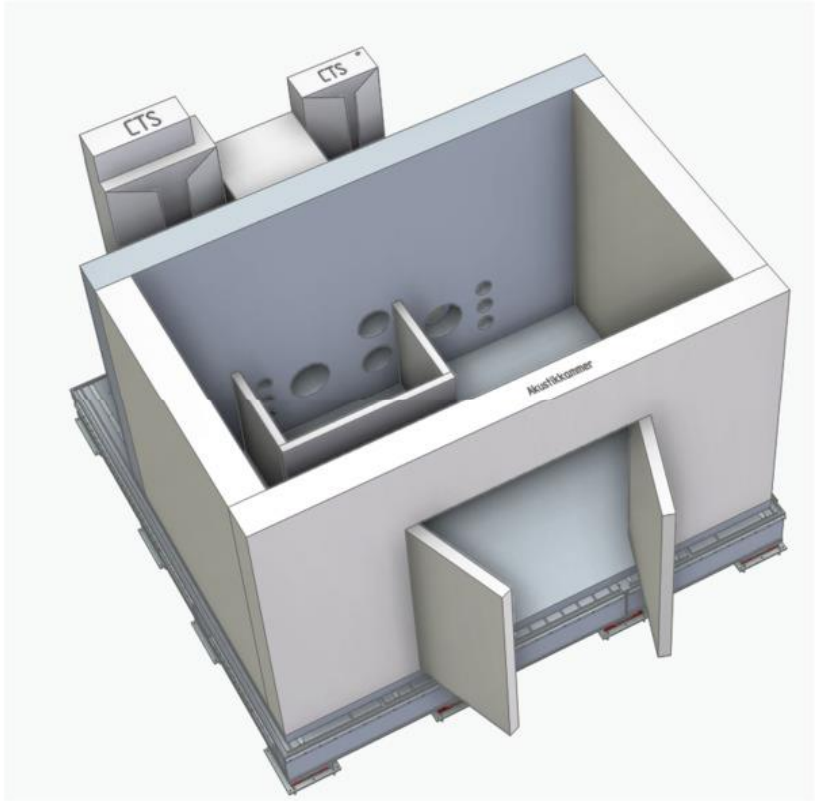
The test bench will be equipped with two load machines (either high speed or high torque), which will be located on the same test bench foundation.

The acoustic chamber will be fixed on the test stand foundation and will allow grade 2 acoustic measurements in a quarter space. The floor and the back wall to the two machines are soundproofed.
The climatic chamber is mobile and can be changed between the two loading machines.
The refrigeration system is stationary and is connected to the climatic chamber by hoses.



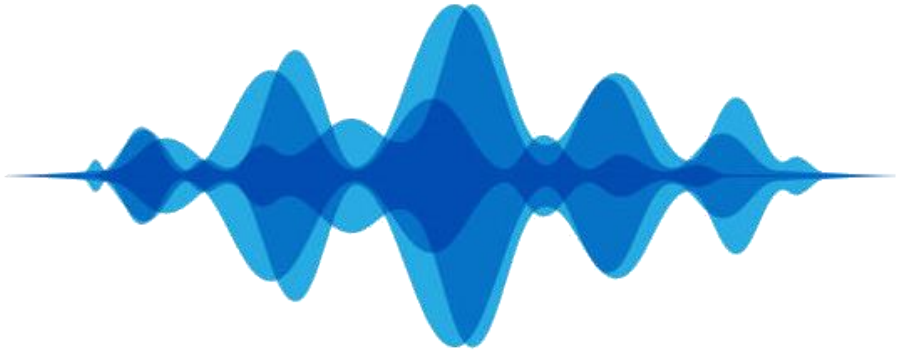
P5 – Electric Motor - Test Bench (capable for Acoustic Investigations)

Climatic - & Acoustic Insulation Chamber



Temperature range of Climatic Insulation Chamber -40˚C to 140˚C

Acoustic Expertise at the IMS-EMA



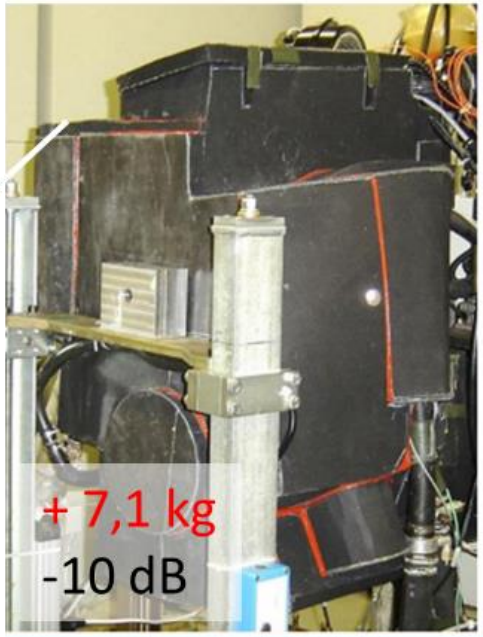
- Mapping of the structure/radiation behavior
- *Vibroacoustic Benchmarking*
- **Operational vibration analyses** - *Acoustic Engine Test Bench*
- Analysis and simulation of sound transfer paths
- **Sound source localization and analysis using *Microphone Arrays*** and *Intensity Probes*
- Sound source localization with *Laser Scanning Vibrometer*
- *Binaural sound pressure measurements*
- Measurements of rotational irregularities
- Active vibration damping with *Piezo-Actuators*
- **Psychoacoustic assessments** of overall engine and component noise

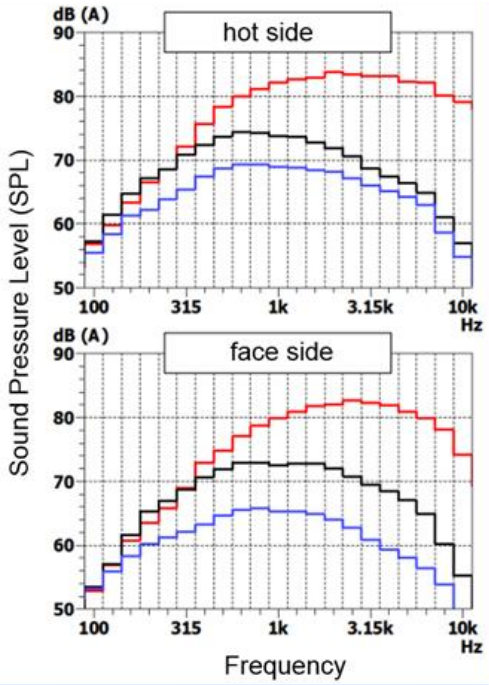
Passive Sound Reduction / Material Development

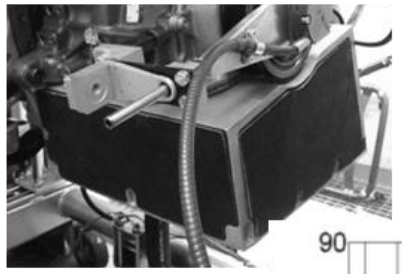
Conflict of targets:

- Noise reduction vs. mass savings and compactness:

Full encapsulation

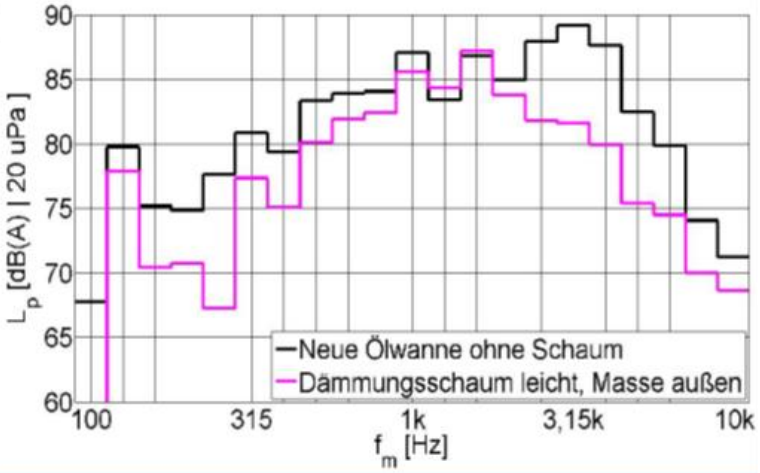






Partial encapsulation
Surface insulation

+ 0,2 kg
-1...3 dB



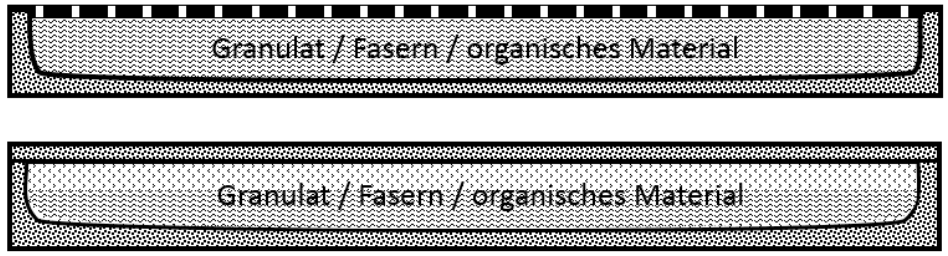
Targets:

- Partial encapsulations with significant SPL reduction and the lowest possible additional weight and volume
- Compatibility with difficult requirements (e.g. temperature of exhaust tract)

Passive Sound Reduction / Material Development

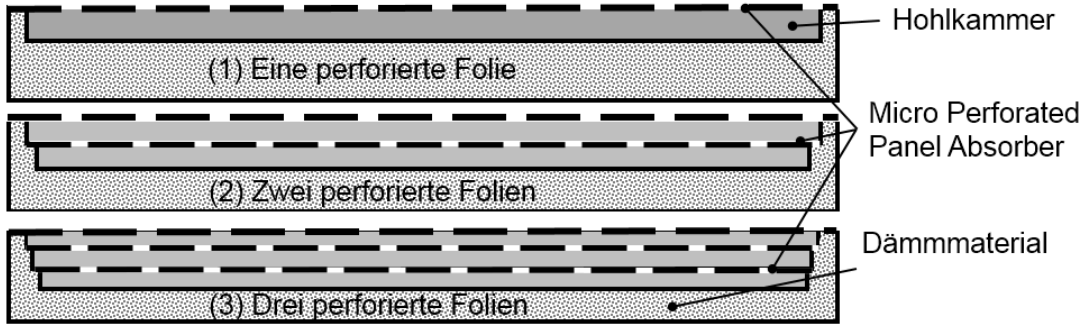
Material damping

- Light, damping materials (granulates, plastic foams and microfibers)
- Advantageous combination with other effects



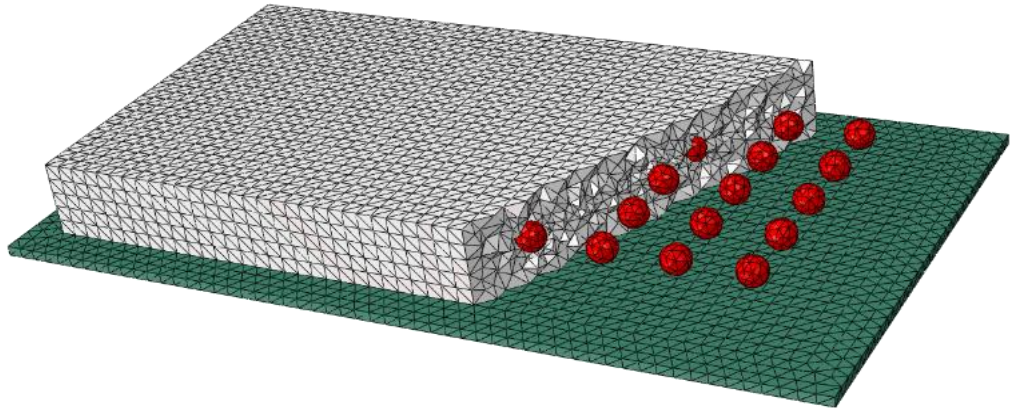
Layer / hollow chamber concepts

- Impedance jumps in the materials Absorption effects of micro-perforations.



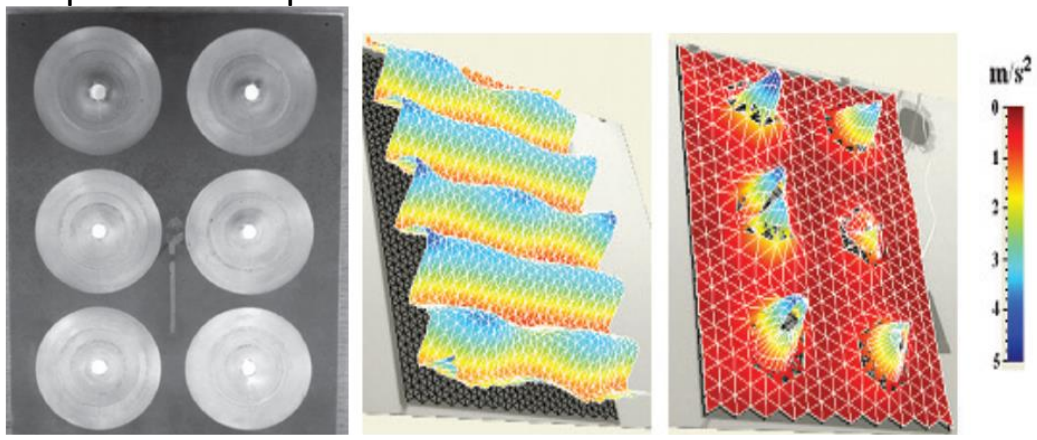
Acoustic Metamaterials

- Insulating materials with mass inclusions and local resonance effects



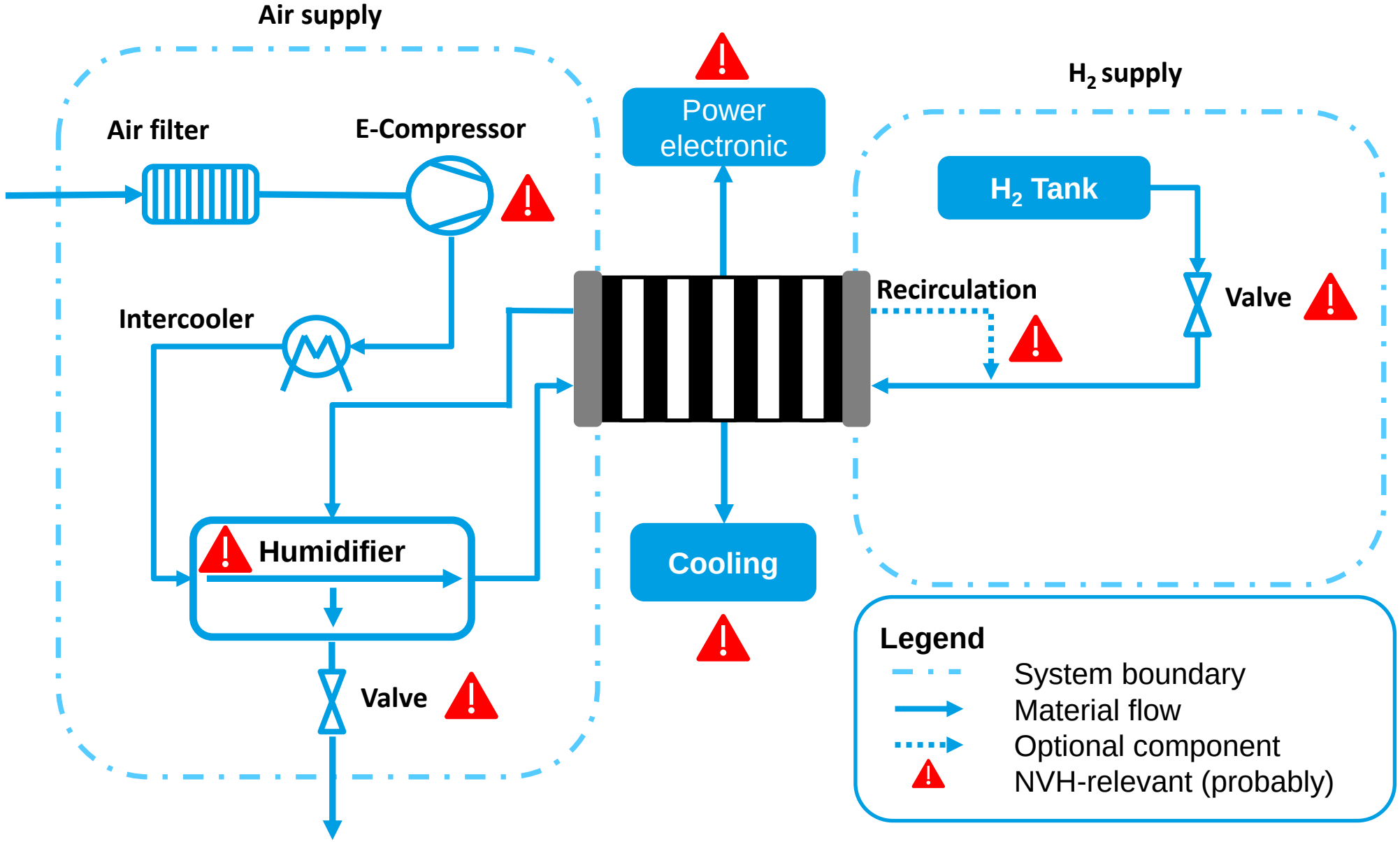
Acoustic Black Holes (ABH)

- Further development of the known geometries under lightweight aspects and improvement of the acoustic effect



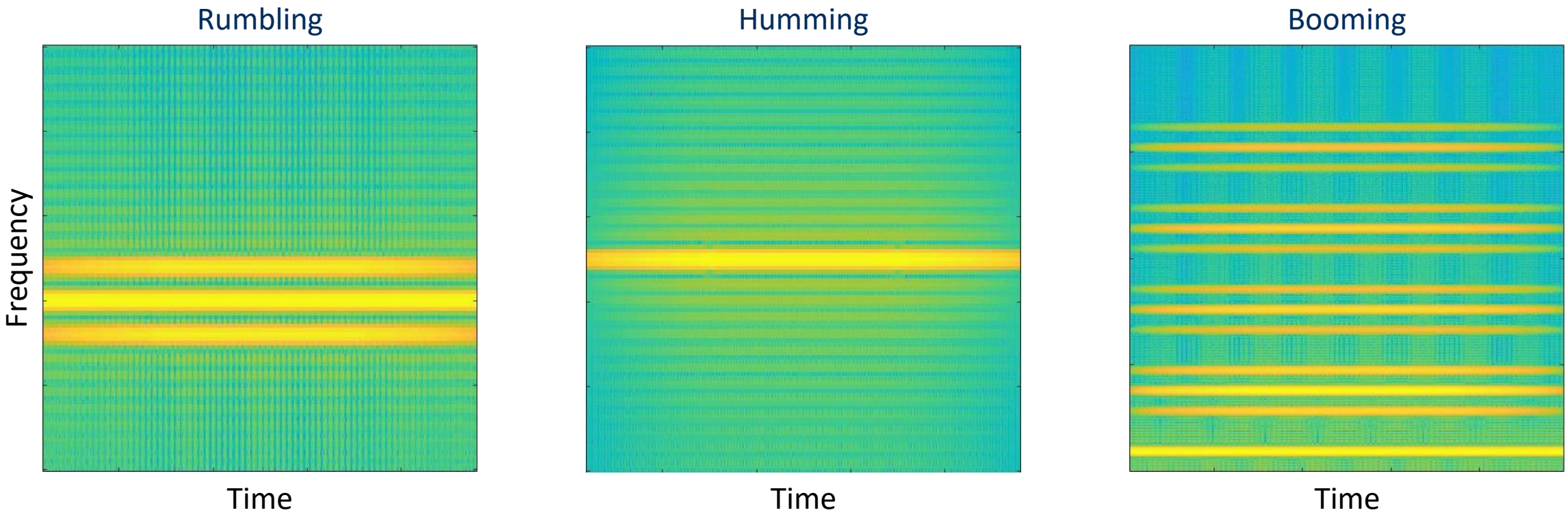
Acoustic Behaviour FCEV

Scheme of a PEM-FC-System



Definition of Measurable Sensations

- Definition of sensations (e.g. tonality, hissing, booming…)
- Additional evaluation of pleasantness
- Composition of introduction sounds



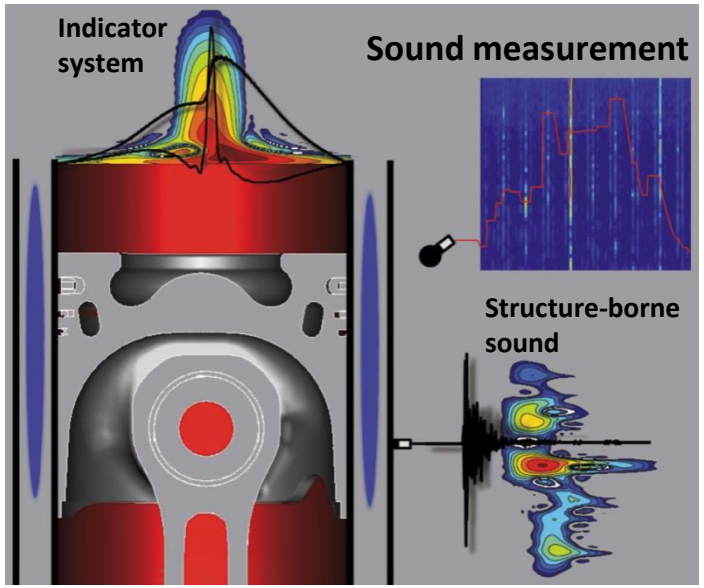
Noise evaluation methods

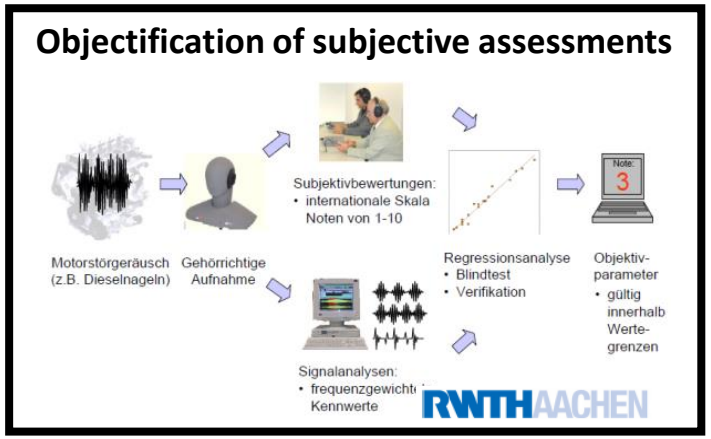
Development steps

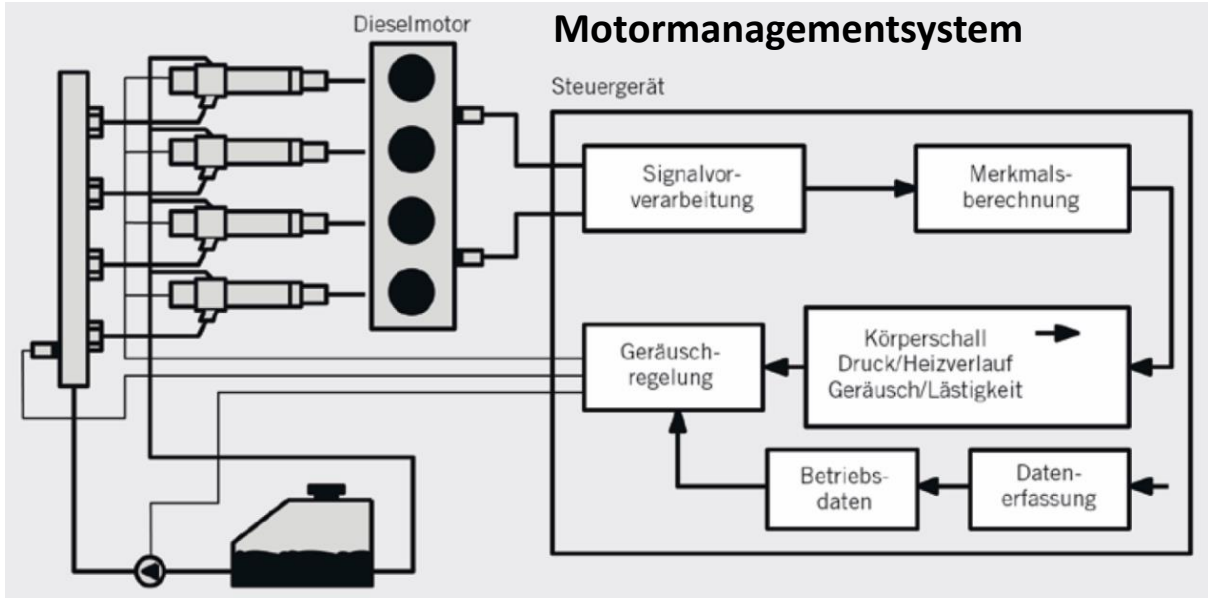
- **Subjective methods**
  - Collective listening tests of expert and lay juries
  - Mood of the listeners and their environment can shape the result
- **Objective methods**
  - Methods based on acoustic calculations and sound recordings
  - Separation of the individual noises possible
- **Empirical formula approach**
  - Diesel note (DN): impulsiveness according to Hots/Verhey, loudness, roughness
  - Ticker note (TN): impulsiveness according to Hots/Verhey, loudness, sharpness

  [Grading scale: 1 (strong nailing/ ticking) to 10 (little to no nailing/ ticking)]
- **Further development of formulas for noise evaluations of vehicle electric motors**
  - Integration of tonality instead of impulsiveness
  - Pleasantness ratings of BEV as well as HEV/PHEV/FC motor drive noises

Noise-Controlled CI-Engine







Information about :

- **Combustion**
- **Cylinder pressure**
- **Engine noise from the structure-borne sound signal**

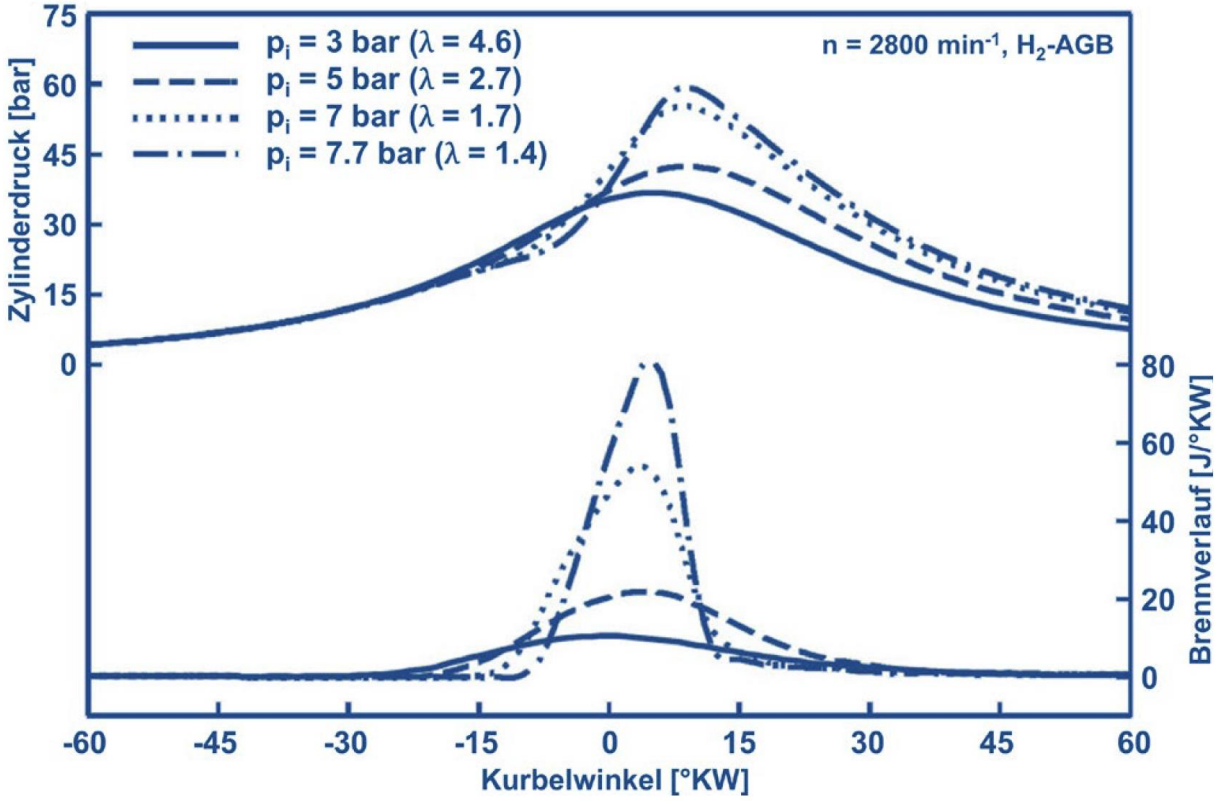
➔ **Detailed signal analysis is used to optimize engine noise, exhaust emissions and consumption.**

Project funded by:

Project in Co-operation with:

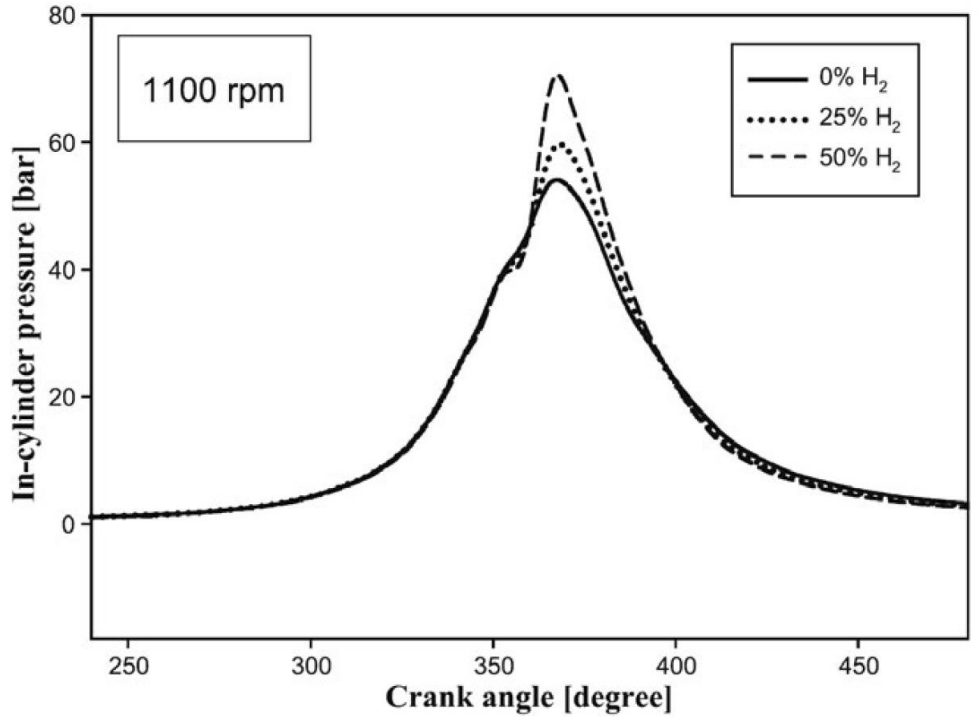
Transfer of methods from noise-controlled diesel engine to hydrogen combustion engine conceivable

- Influence of the air-fuel mixture of a hydrogen combustion engine on the cylinder pressure and combustion process



Eifler, W.: Vorlesungsunterlagen „Alternative Kfz-Antriebe (AKfzA)", Lehrstuhl für Verbrennungsmotoren, Ruhr-Universität Bochum, 2015.

- Influence of hydrogen as a fuel additive for diesel combustion on the cylinder pressure curve



Karagöz, Y; Sandalci, T; Yüksek, L; Dalkilic, A. S.; Wongwises, S.: Effect of hydrogen-diesel dual-fuel usage on performance, emissions and diesel combustion in diesel engines. Advances in Mechanical Engineering, 2016.

Project „NORA – Noise Rating and Optimization“

- Objective evaluation and optimization of the vibroacoustic behavior of mechatronic components on the vehicle powertrain -

- Extraction of the ticker noise component from the engine noise
  - Development of psychoacoustic formulas for the evaluation of ticker noise → „Tickernote“
  - Verification of the empirical formulas with the help of listening tests by acoustics experts
- Creation of engine noise syntheses by replacing the injection system noise from the overall engine noise with noise data from the system test bench at CHP Messtechnik
  - Comparison of fuel consumption and emission measurements (NOx, HC, CO, particulates) with regard to the original and NVH-optimized injection system
  - Reduction of injection system noise through drive current variation → „Softlanding“

Quelle: Neumann GmbH

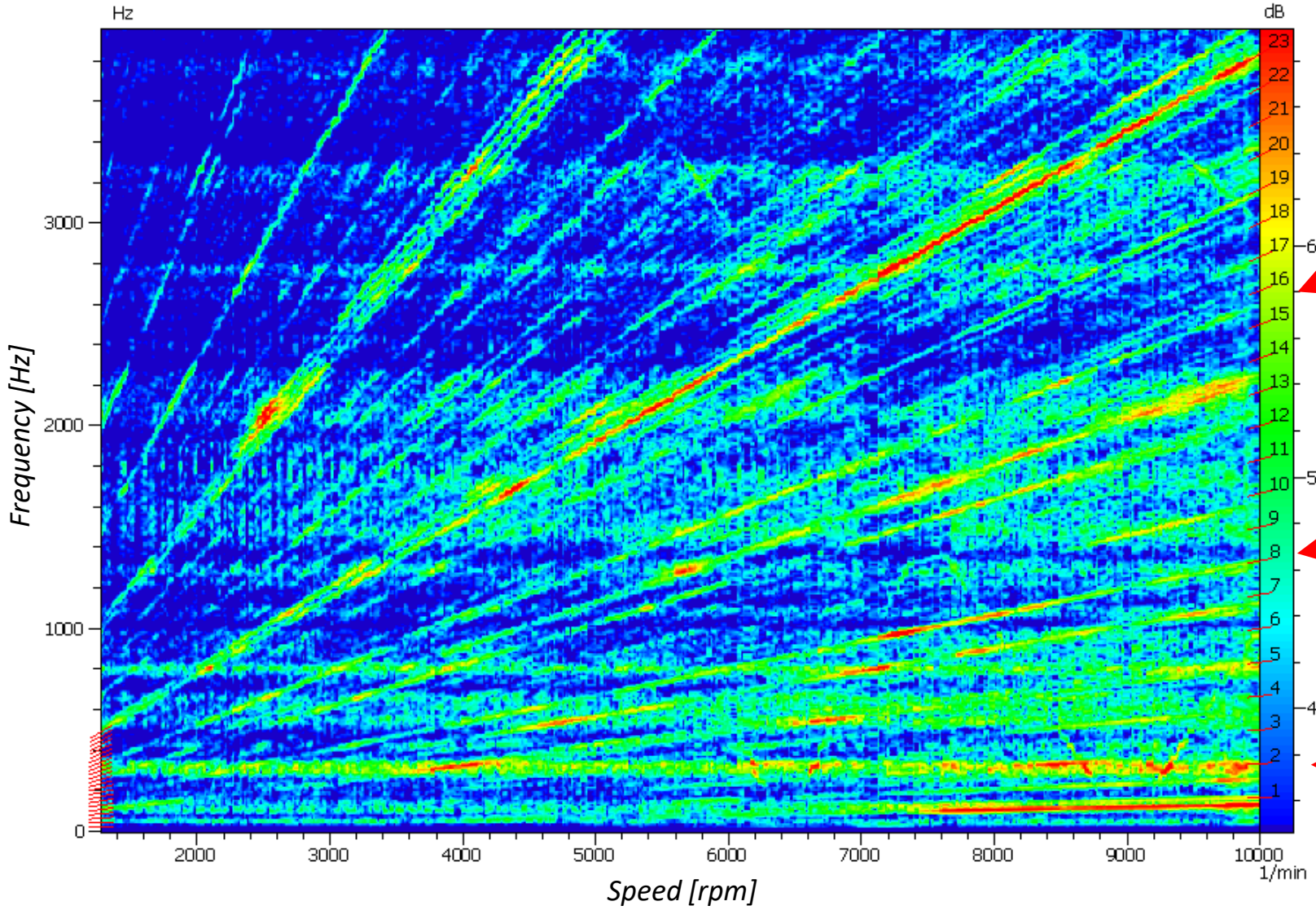
Quelle: Der neue EA211 TSI®evo von Volkswagen, Internationales Wiener Motorensymposium, 2016

Project funded by:

Project in Co-operation with:

Acoustic analysis of a vehicle electric motor

Airborne sound measurement – lower frequencies



15.6th Engine order

- Intermediate gearbox

8th Engine order

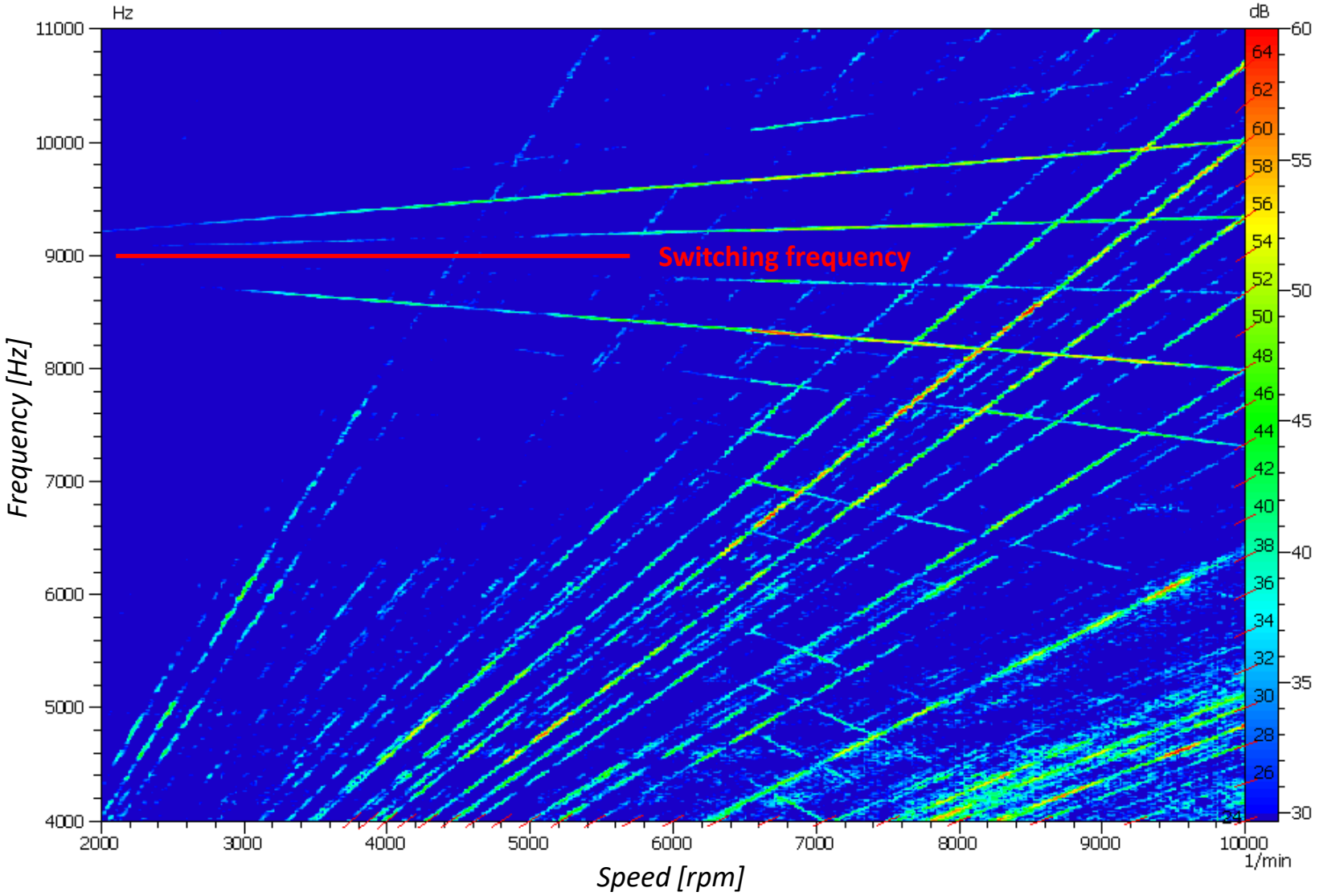
- 4 Pole pairs (harmonics)

Eigenmode

- Intermediate gearbox

Acoustic analysis of a vehicle electric motor

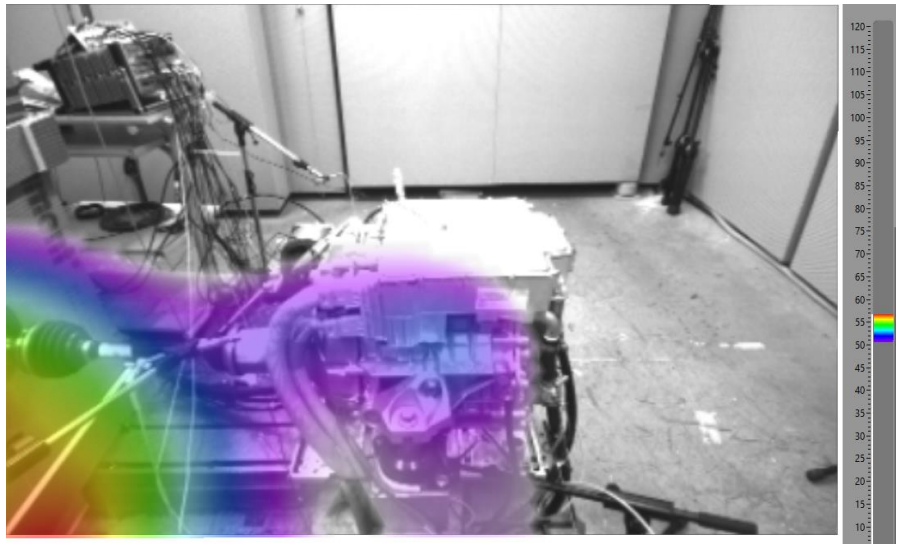
Airborne sound measurement – higher frequencies



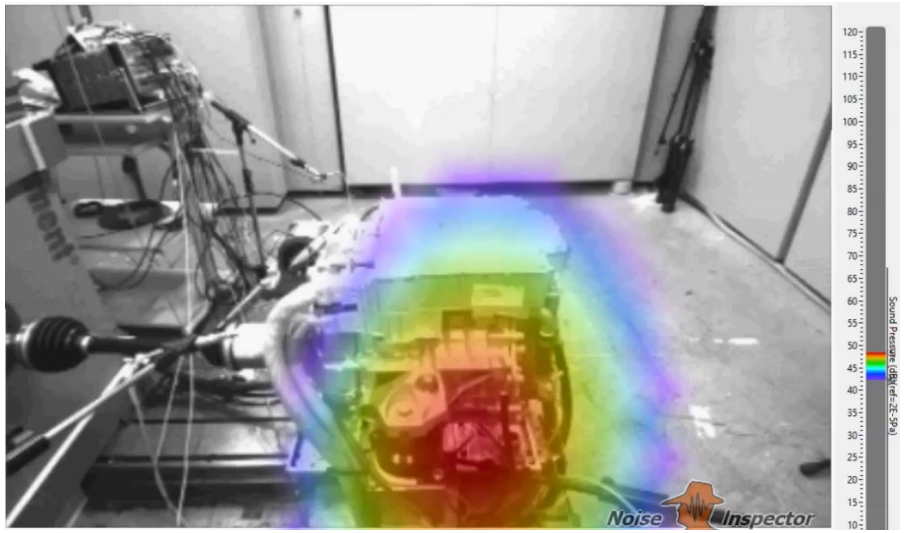
Sound source localization

Sound pressure distribution from speed run-up

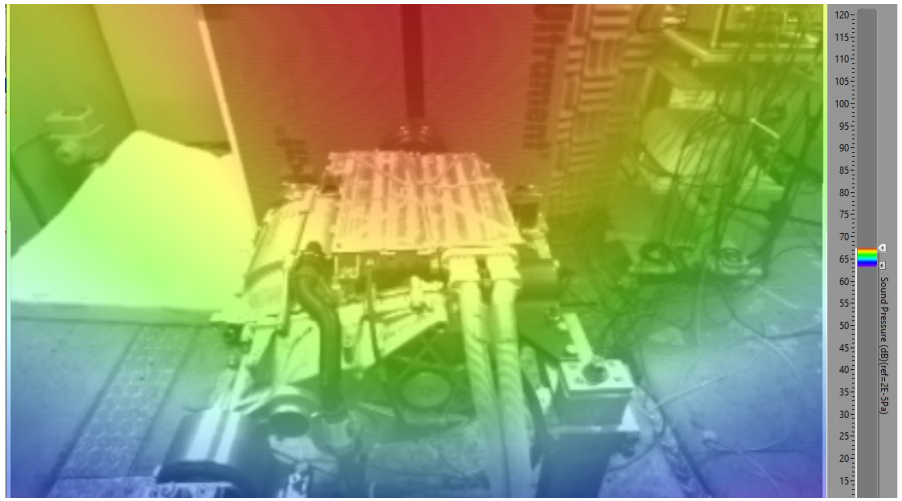
15.6th engine order (intermediate gearbox)



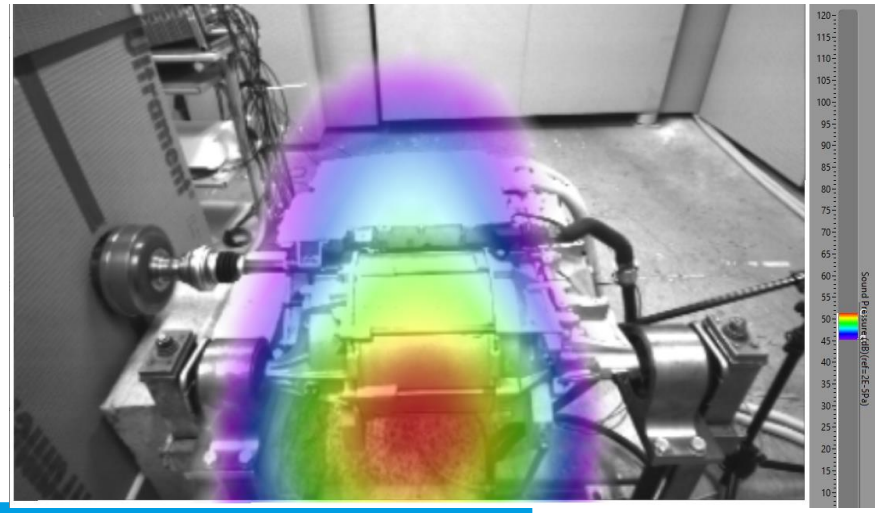
4th engine order (pole pairs)



Eigenmode (intermediate gearbox)



8th engine order (harmonics of pole pairs)



Conclusion

- The drive concepts are changing and becoming more versatile.
- **This also changes the test environments.**
- Some of the methods developed for the classical combustion engines are transferable to the new drive concepts.
- The pleasantness of a sound plays a greater role in future drives. So it is not just the loudness of the noise. There is a greater proportion of tonal components in electrified drives
- **In some cases, new drive concepts require new acoustics.**

Thank you for your kind attention.

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