Contents of Work Package 4-WP08: Advanced Design Solutions for Future Automotive ICEs

4-WP08: Advanced Design Solutions for Future Automotive ICEs

Coordinator of the WP

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Participants of the WP

Skoda Auto: Ing. V. Uzlík, TU Liberec: Ing. R. Voženílek, Ph.D, Vysoké učení technické v Brně: Ing. L. Drápal, Ph.D.

Main Goal of the WP

The WP is focused on design solutions of future hybridized powertrain (based on ICE) with the main goal to improve efficiency while also considering effects of NVH, port fuel injection, lubrication, etc. Selected parts and subassemblies will be analyzed, optimized and tested/verified.

Partial Goals for the Current Period

<u>TUL + Skoda Auto:</u> focus on port fuel injection + lubrication circuit performance.

<u>BUT + Skoda Auto:</u> analyze & design & optimize ICE parts for future applications focused on improved efficiency.

Contents of Work Package 4-WP08: Advanced Design Solutions for Future Automotive ICEs

Official 4-WP08 Deliverables:

- 4-WP08-001 | **Intake module with an innovative position for new-generation of fuel injectors**, G-funk, XII./2025, Skoda Auto 0.9; TUL 0.1
- 4-WP08-002 | **Lubrication channel of the experimental driving unit system**, G-funk, XII./2025, Skoda Auto 0.9; TUL 0.1
- 4-WP08-003 | **Key component parts and subassemblies for optimized engine of a hybrid power train**, G-funk, XII./2025, Skoda Auto 0.5; BUT 0.5
- 4-WP08-004 | **Advanced computational model of dynamics and tribology of the engine for a hybrid power train**, O-ostatní, XII./2025, Skoda Auto 0.5; TUL 0.5

Activities in 4-WP08: Advanced Design Solutions for Future Automotive ICEs

4-WP08-001: Intake module with an innovative position for new-generation of fuel injectors

- A new generation of intake manifold module (for a non-supercharged gasoline piston internal combustion engine) will be created, enabling innovative positioning of the (primarily liquid) fuel injectors, both currently used and injectors for synthetic and low-carbon fuels. The module will be prepared so that it is possible to install it on the currently used and developed power unit with the external formation of the fuel-air mixture. The indication and visualisation techniques available at the workplace at TUL will be used to identify and verify the correct position of the initial state designed by the 3D modelling method.
- <u>Methods: design modifications, experimental research and simulations.</u>

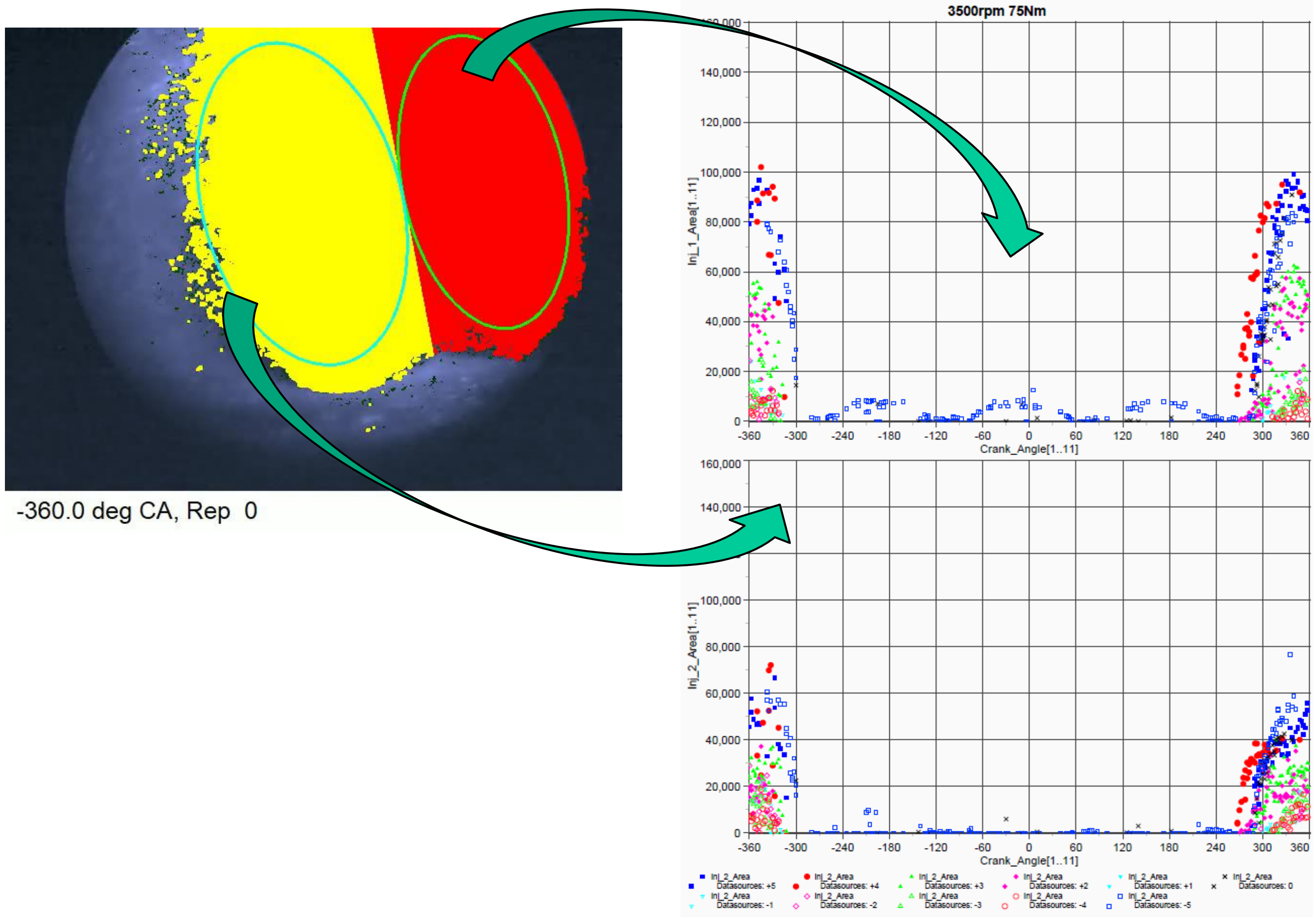
- Main topics (for the current time period):
  - Updated design of the experimental setup.
  - New/updated SW tools to process/analyze experimental data.
  - Automation of the whole procedure.
  - Connecting/relating visualization results with indication and emission measurement.

Activities in 4-WP08: Advanced Design Solutions for Future Automotive ICEs

4-WP08-001: Intake module with an innovative position for new-generation of fuel injectors

- Data analysis:

- Inj_1_Area and Inj_2_Area: These values represent the cross-sectional area of the fuel flow from each injector.
- Ellipse_Inj_1_Area and Ellipse_Inj_2_Area: Quantification of the elliptical area for each injector, enabling analysis of the shape and symmetry of the fuel stream.
- Inj_1_Major Axis Length and Inj_2_Major Axis Length: The length of the major axis of the ellipse for both injectors, providing insights into the primary dimensions of the fuel flow.
- Inj_1_Minor Axis Length and Inj_2_Minor Axis Length: The length of the minor axis of the ellipse for both injectors, important for evaluating the width of the fuel stream.



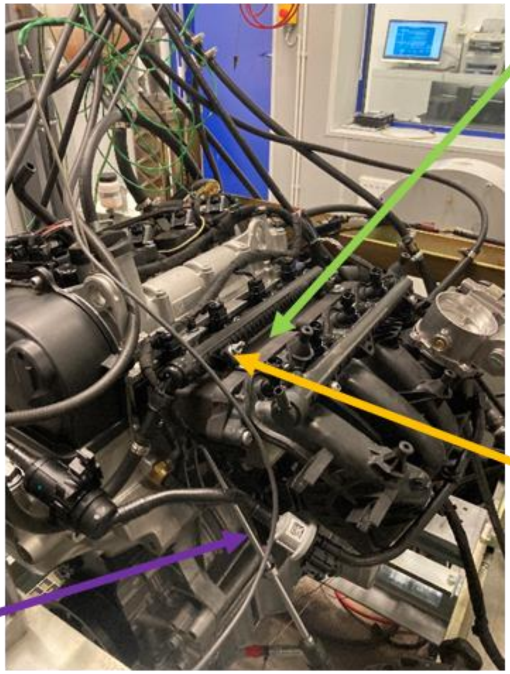
Activities in 4-WP08: Advanced Design Solutions for Future Automotive ICEs

4-WP08-001: Intake module with an innovative position for new-generation of fuel injectors

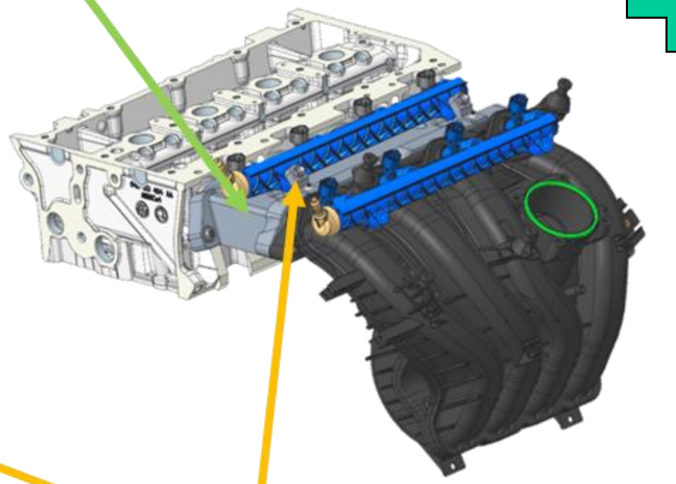
- <u>Experiments:</u>

MPI adapter

Testbed



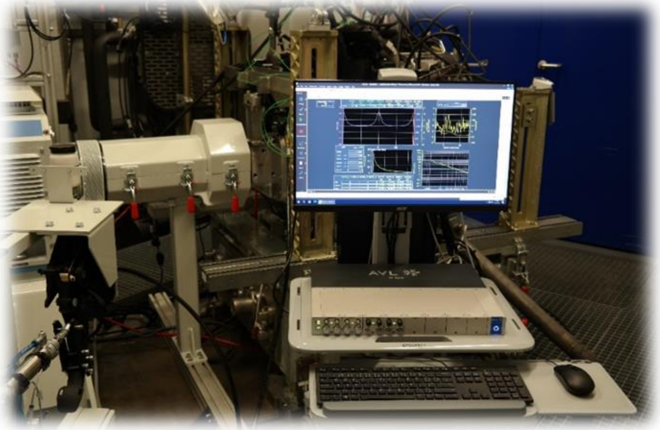
3D model



Endoscope

Positioning adapter

Indication technology
AVL X-ion



Exhaust gas analyzers
(future measurements)

Activities in 4-WP08: Advanced Design Solutions for Future Automotive ICEs

4-WP08-002: Lubrication channel of the experimental driving unit system

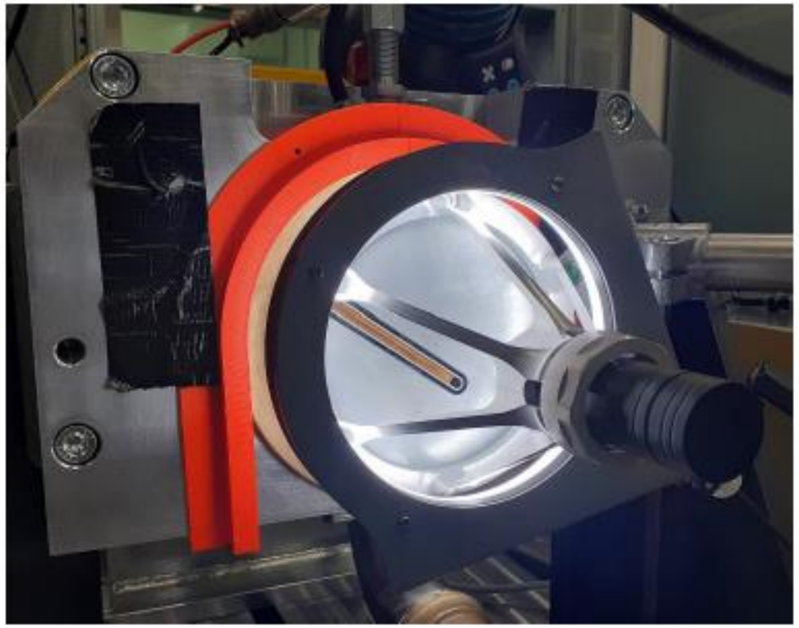
- A part for modelling and simulating oil flow through the lubrication channel of the rotating crankshaft will be created. The part will be created in several design variants, and the operating conditions of the drive unit will be simulated on it. The channel will be optimized based on computer simulations, and the results will be compared with experimental data. The goal is to create experimental support for the structural arrangement of the crankshaft lubrication system, which will ensure a reliable lubrication function with low energy requirements in the entire range of operating conditions of the drive unit.
- <u>Methods: design modifications, experimental research and simulations.</u>

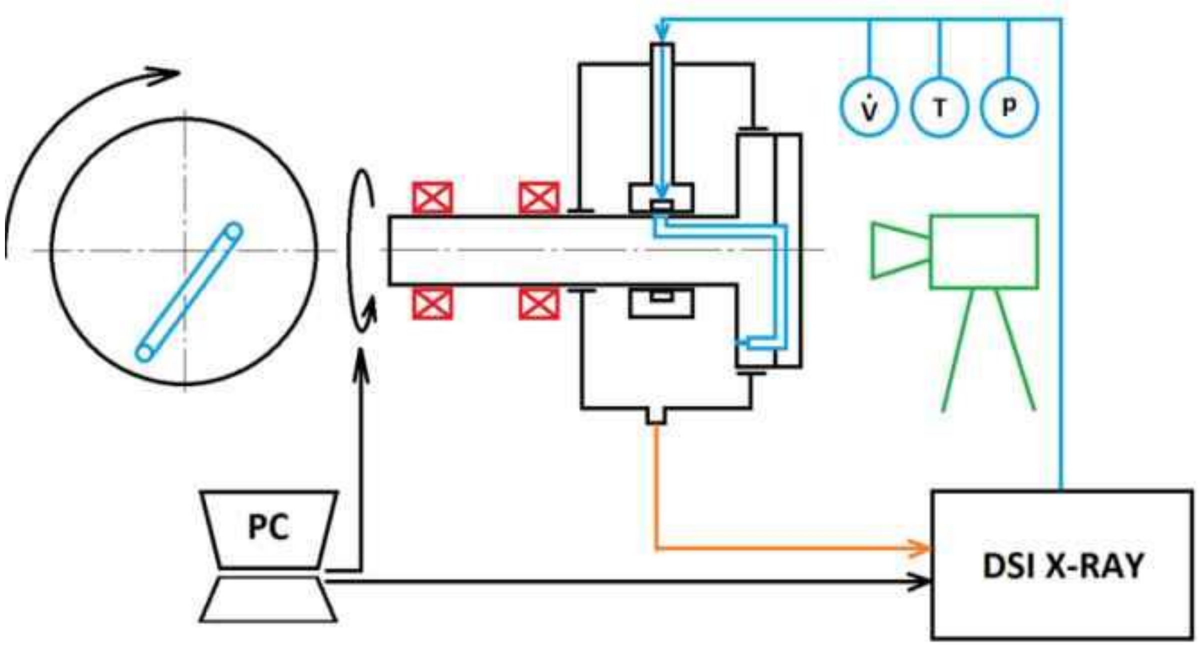
- Main topics (for the current time period):
  - Design modifications of the whole experimental setup to improve ability to monitor important parameters & properties.
  - To test different designs of lubrication channel/circuit while focusing on wide range of operating conditions.
  - To create computer models to improve understanding of important phenomena and to support analysis of the experimental data.
  - Main goal is to focus on reliable lubrication function/operation under entire range of operating conditions while lowering energy consumption/requirements of the whole lubrication circuit.

Activities in 4-WP08: Advanced Design Solutions for Future Automotive ICEs

4-WP08-002: Lubrication channel of the experimental driving unit system

- <u>Oil flow trough the rotating channel + control of camshaft adjusters:</u>

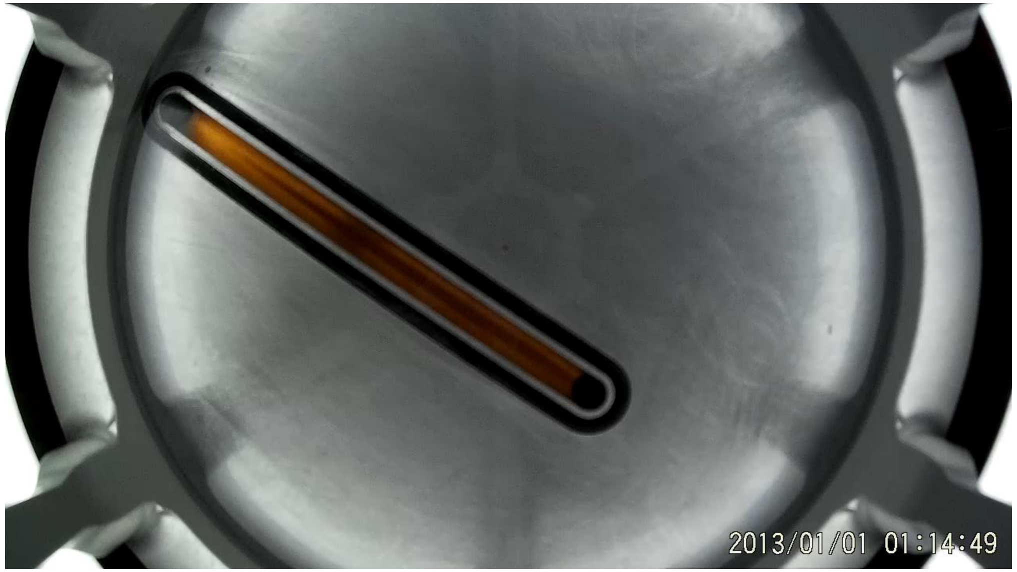




Activities in 4-WP08: Advanced Design Solutions for Future Automotive ICEs

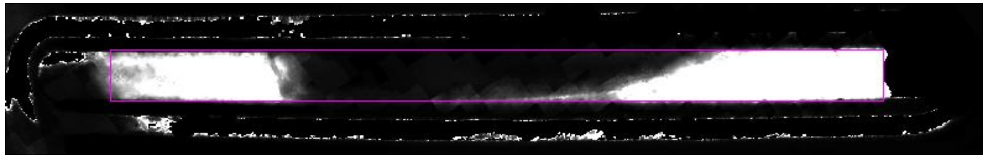
4-WP08-002: Lubrication channel of the experimental driving unit system

- <u>Measurement engine oil system on specialised test bench:</u>

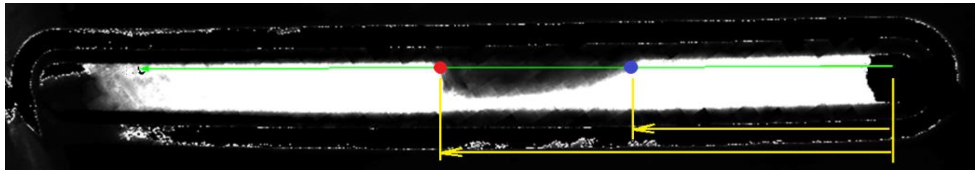


Machine processing and image analysis

Determine the percentage of each phase in the image



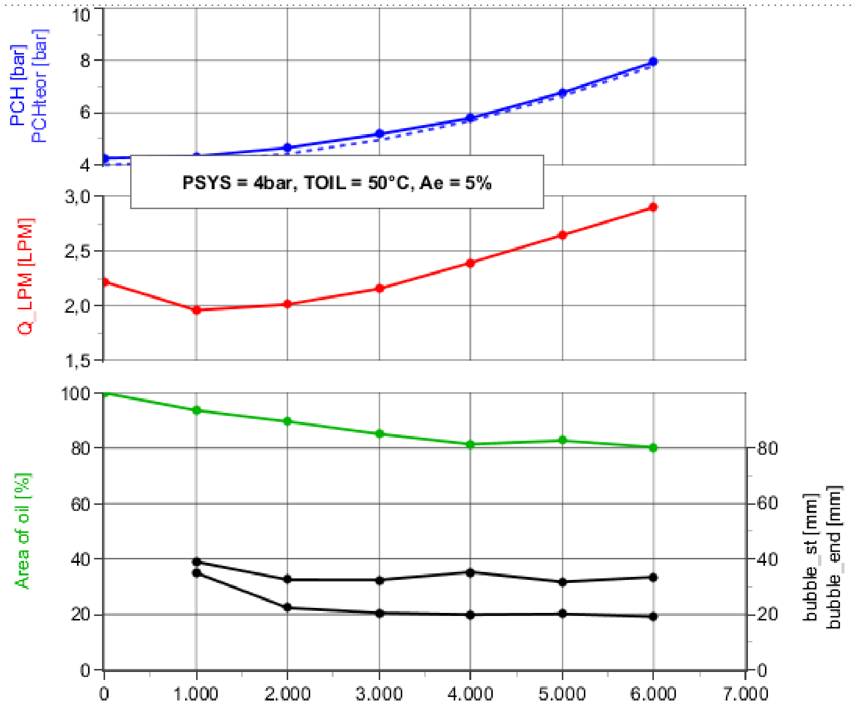
Identifying phase interfaces and determining their position

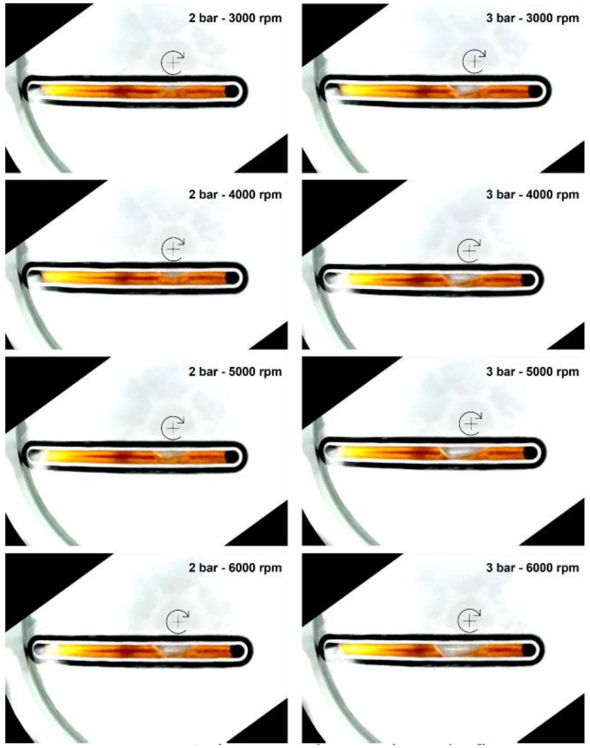


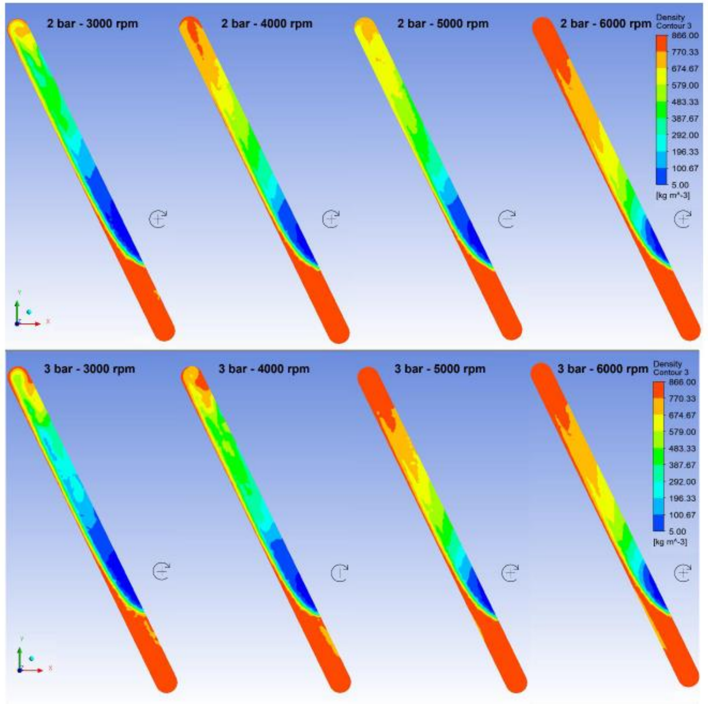
Activities in 4-WP08: Advanced Design Solutions for Future Automotive ICEs

4-WP08-002: Lubrication channel of the experimental driving unit system

- Evaluation of measurement results and development of simulation model







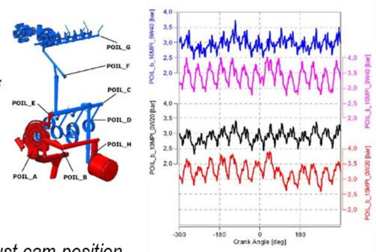
Activities in 4-WP08: Advanced Design Solutions for Future Automotive ICEs

4-WP08-002: Lubrication channel of the experimental driving unit system

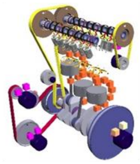
- Evaluation of measurement results

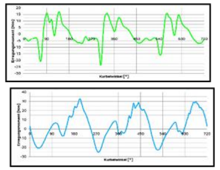
Inputs

Courses of pressures in the oil system



- *Engine speed*
- *Oil temperature*
- *Oil viscosity*
- *Intake and exhaust cam position*
- *3-cylinder and 4-cylinder layouts*
- *Oil pressure in the system*
- *Engine loadCourse of moments on camshafts*



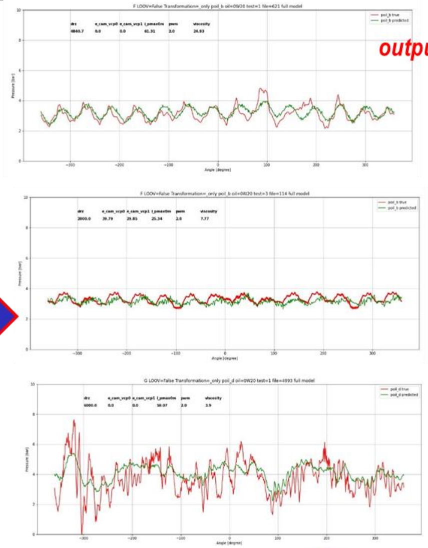


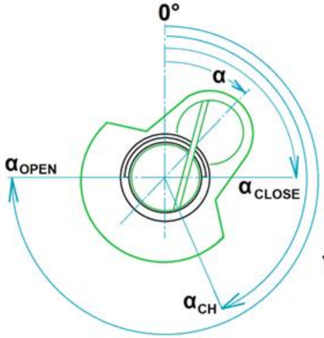
neural network

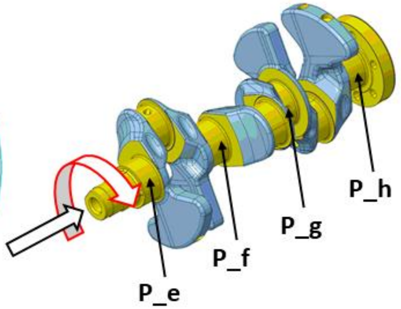
159 nodes

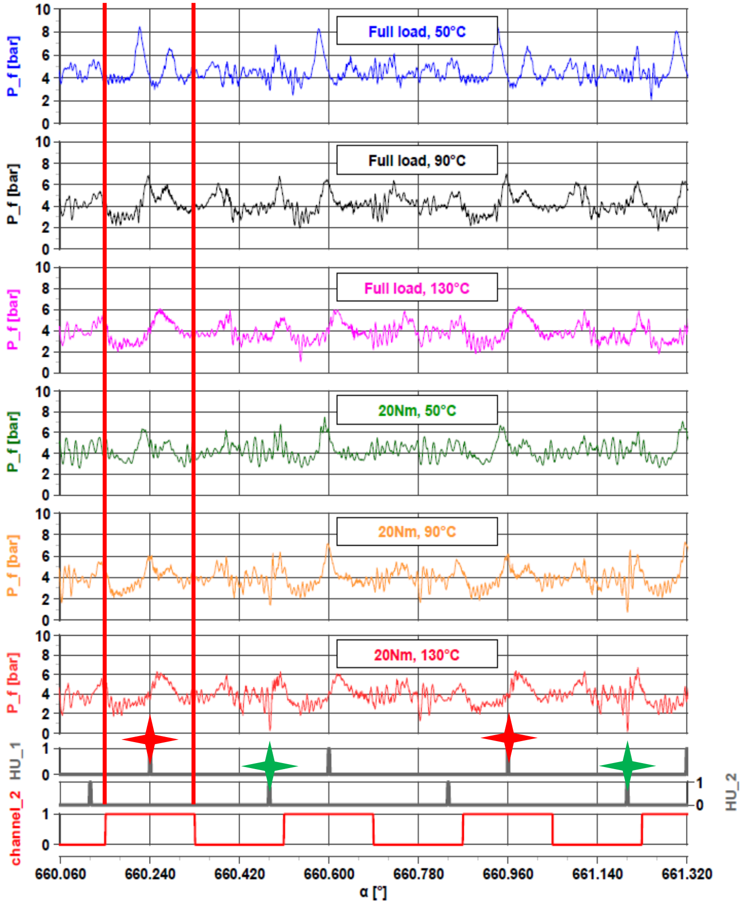
577 thousand weight coefficients

outputs









Activities in 4-WP08: Advanced Design Solutions for Future Automotive ICEs

4-WP08-003: Key component parts and subassemblies for optimized engine of a hybrid power train

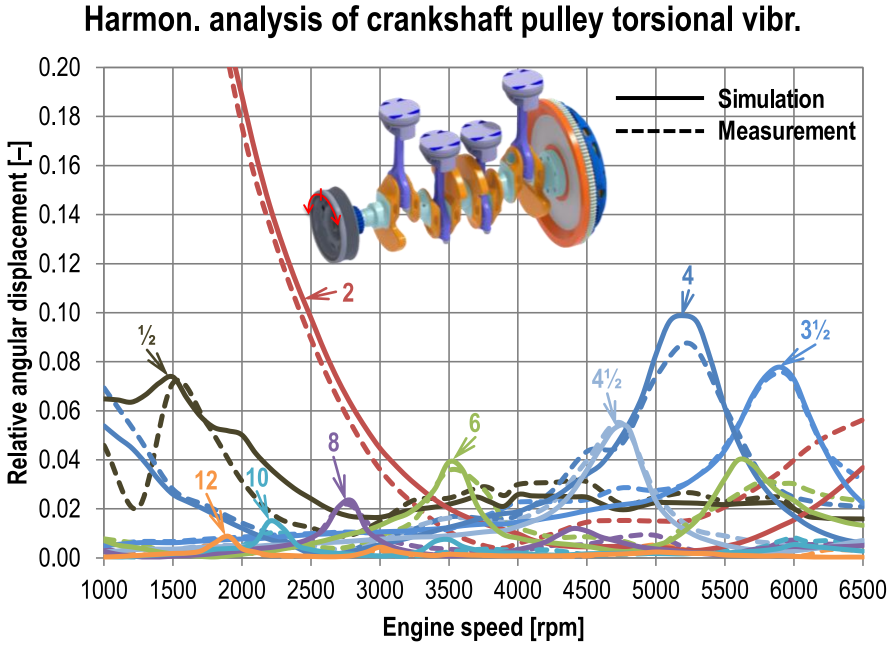
- A modern engine for a hybrid powertrain is a complex machine requiring considerable research and development effort. This result includes reaching the functional component parts and subassemblies of ICE, such as the crank train, engine block, etc. The following activities should lead to the achievement of the result: the choice of the basic layout regarding the existing manufacturing program of the ŠKODA AUTO, conceptual engine design, advanced computational modeling of engine component parts and subassemblies, computational parametric studies and creation of CAD models of engine component parts including drawing documentation, manufacturing of key component parts and subassemblies.
- <u>Methods: design modifications, advanced simulations and experiments.</u>

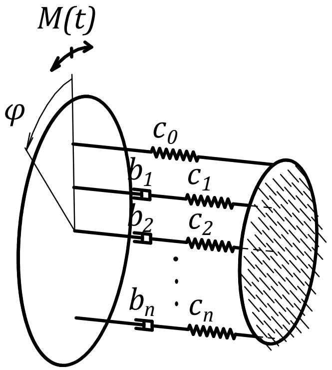
- Main topics (for the current time period):
  - Selection of target ICE and key components.
  - Dedicated experiments to calibrate computation models (relation to 4-WP08-004).
  - Detailed analysis of possible deactivation modes (relation to 3-WP02-002, DCDA/DSF).
  - Proposal/analysis of solution(s) to decrease torsional vibration(s) when cylinder deactivation is active.

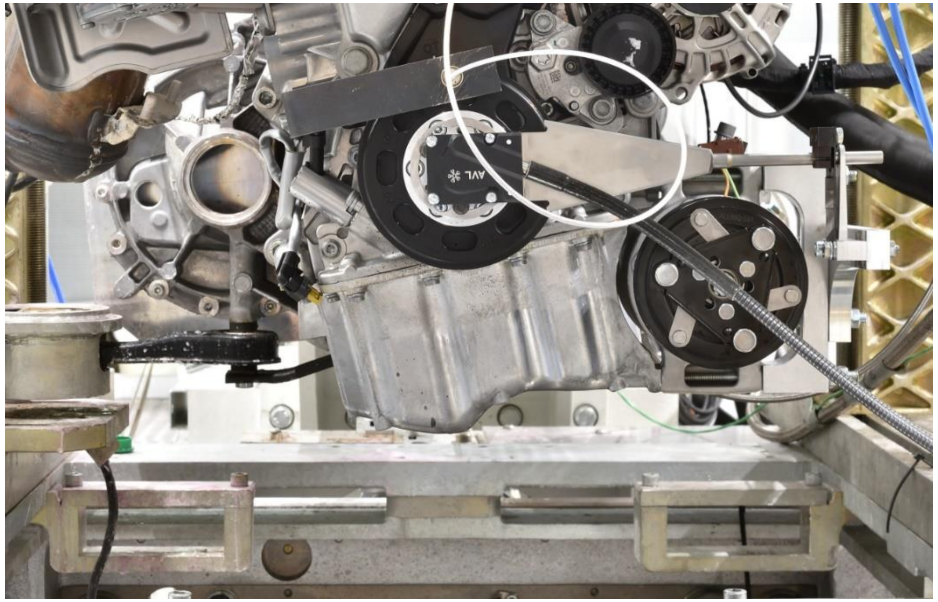
Activities in 4-WP08: Advanced Design Solutions for Future Automotive ICEs

4-WP08-003: Key component parts and subassemblies for optimized engine of a hybrid power train

- Functional tests of the default engine (SI NA I4 MPI Škoda Auto engine) on a dynamometer under different conditions with torsional damper
- Statistical processing of engine test data



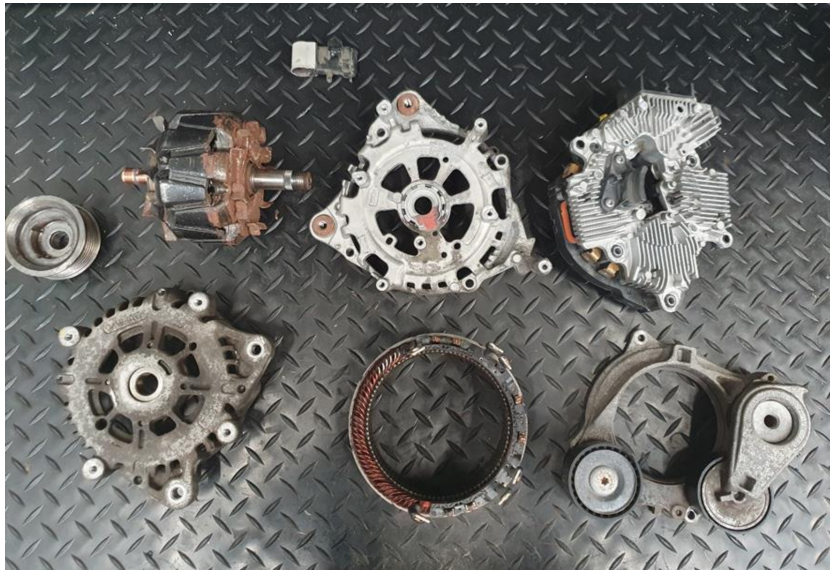


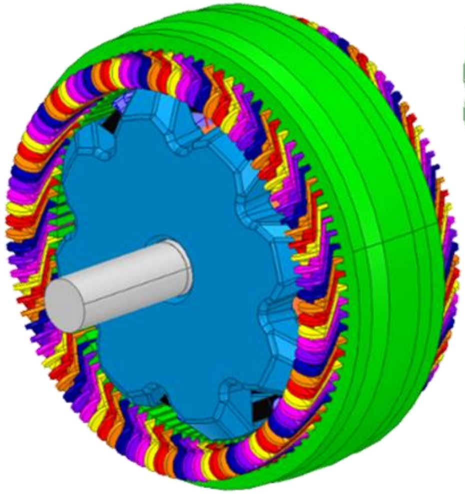


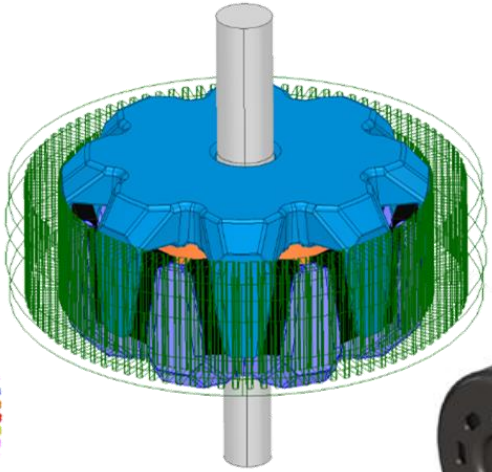
Activities in 4-WP08: Advanced Design Solutions for Future Automotive ICEs

4-WP08-003: Key component parts and subassemblies for optimized engine of a hybrid power train

- Measurement and experiments of a synchronous electric machine with a hybrid rotor design (both coil and permanent magnets)
- The new way of utilization of the electric machine in the dynamic mode (possible torque smoothing in terms of CDA mild-hybrid system)







Activities in 4-WP08: Advanced Design Solutions for Future Automotive ICEs

4-WP08-004: Advanced computational model of dynamics and tribology of the engine for a hybrid power train

- This advanced computational model of the dynamics and tribology of the key component parts of the newly developed engine will enable parametric studies to be carried out and the engine subsequently optimized for high mechanical efficiency and low vibration with high robustness and low production costs. The model will be based on the principles of FEM, MBS and will allow to include many physical effects during simulations in the time domain. The following activities should lead to the achievement of the result: discretization of CAD models of engine component parts, simulation of the excitation effects of the computational model, building of an advanced computational model of dynamics and tribology of a modern ICE-based hybrid power unit, building of own submodels, advanced computational model debugging, results dissemination & student engagement.
- <u>Methods: advanced simulations and experiments.</u>

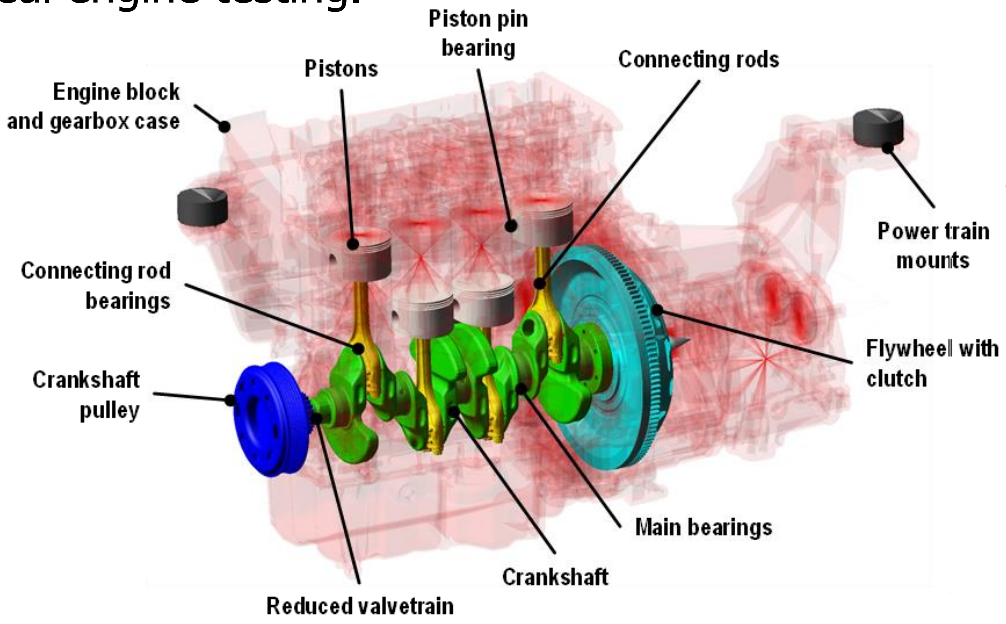
- Main topics (for the current time period):
  - Calibration & verification of computation models.
  - Sensitivity studies and detailed analysis of consequences of cylinder deactivation application.

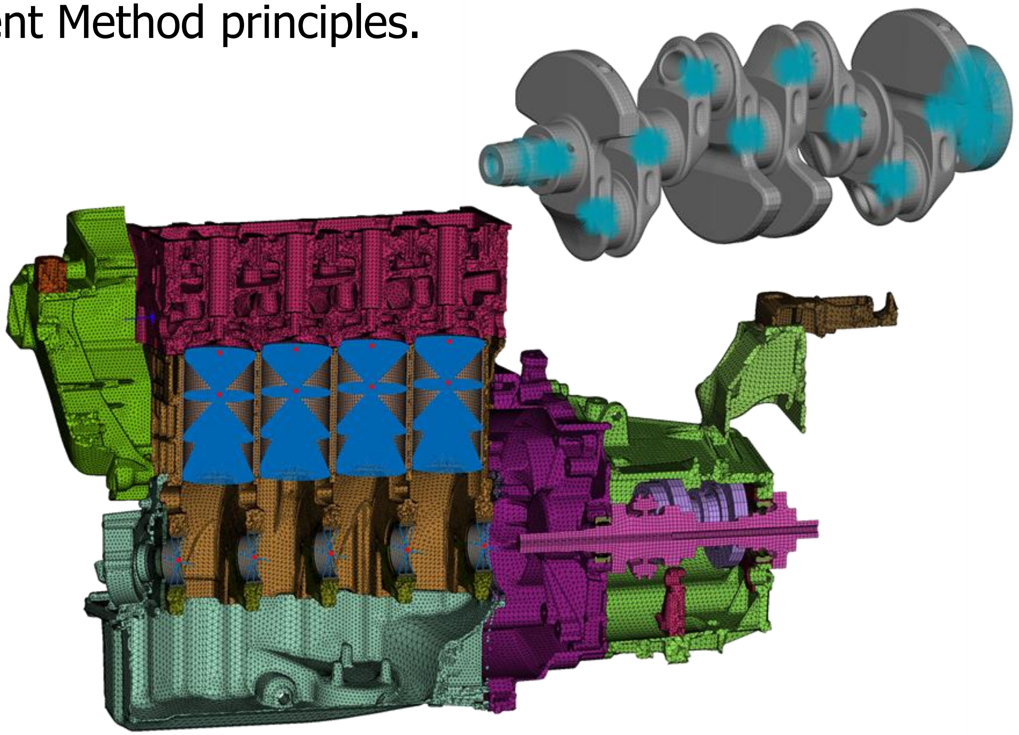
Activities in 4-WP08: Advanced Design Solutions for Future Automotive ICEs

4-WP08-004: Advanced computational model of dynamics and tribology of the engine for a hybrid power train

- Modeling of important parts/subassemblies:

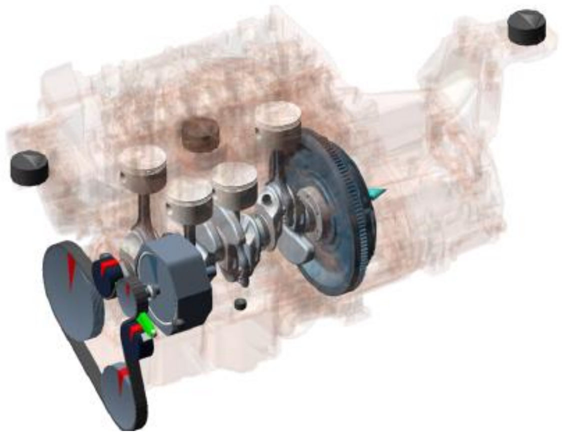
– Virtual engine based on Multi-Body Dynamics and Finite Element Method principles.
– Simulations in the time domain.
– Verified by real engine testing.

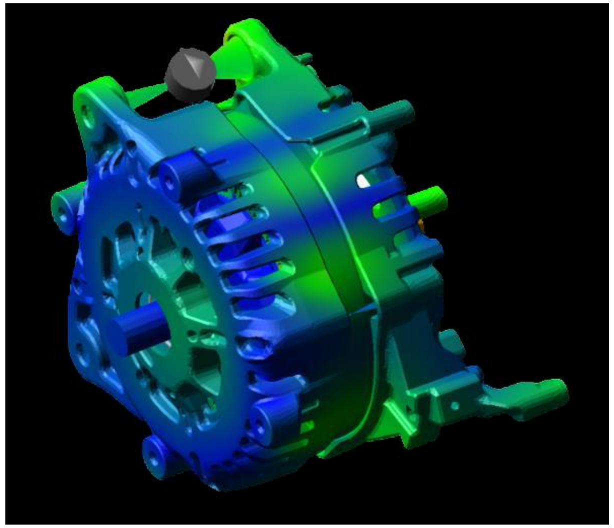


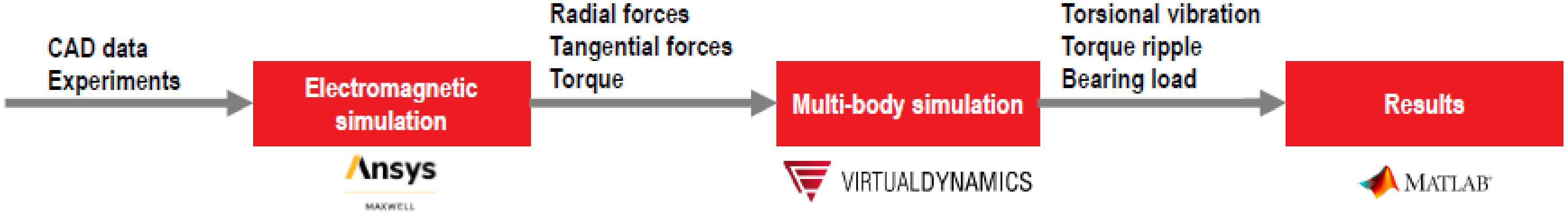


Activities in 4-WP08: Advanced Design Solutions for Future Automotive ICEs

4-WP08-004: Advanced computational model of dynamics and tribology of the engine for a hybrid power train



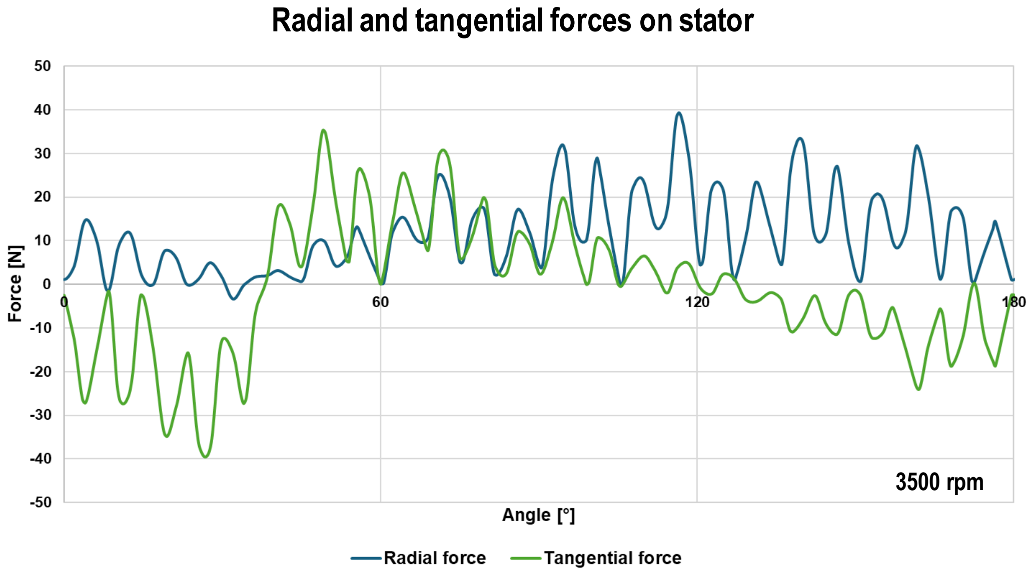


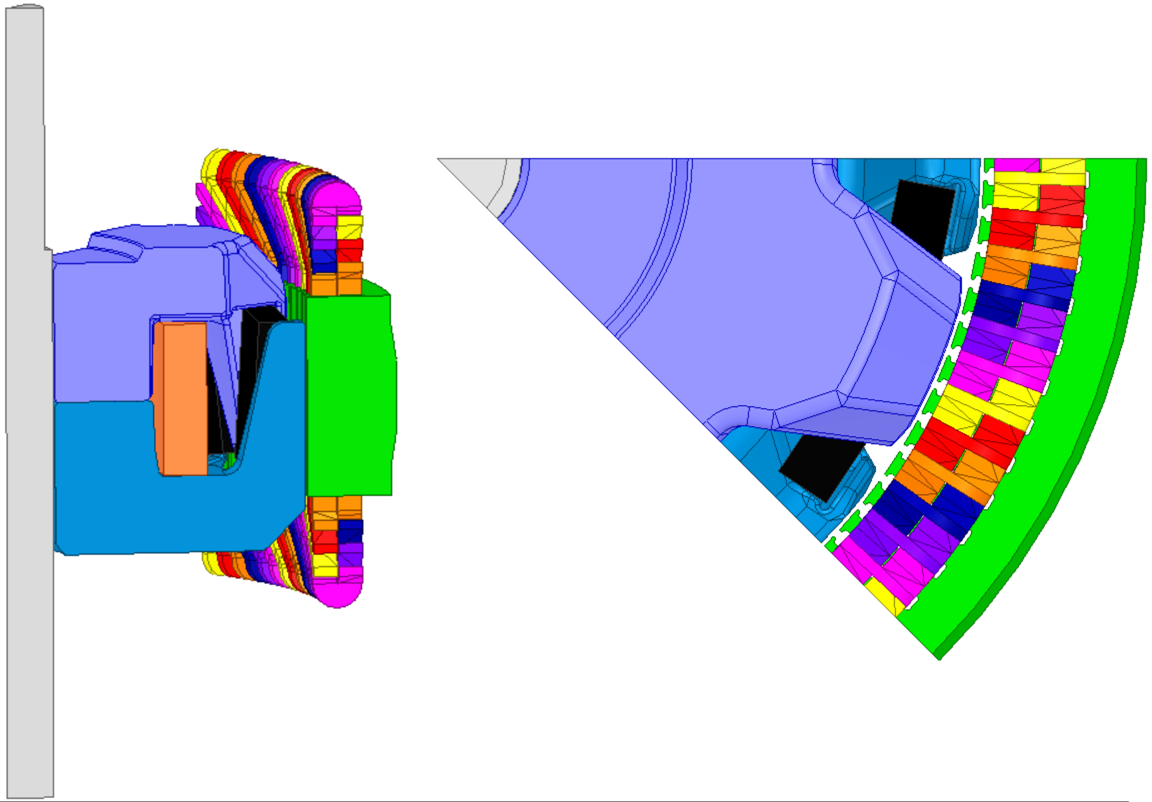


Activities in 4-WP08: Advanced Design Solutions for Future Automotive ICEs

4-WP08-004: Advanced computational model of dynamics and tribology of the engine for a hybrid power train

- Electromagnetic simulations of an electric machine (different modes and speed)
- Electromagnetic simulation results
  - Radial forces on stator teeth
  - Tangential forces on stator teeth
  - Torque of the electric machine

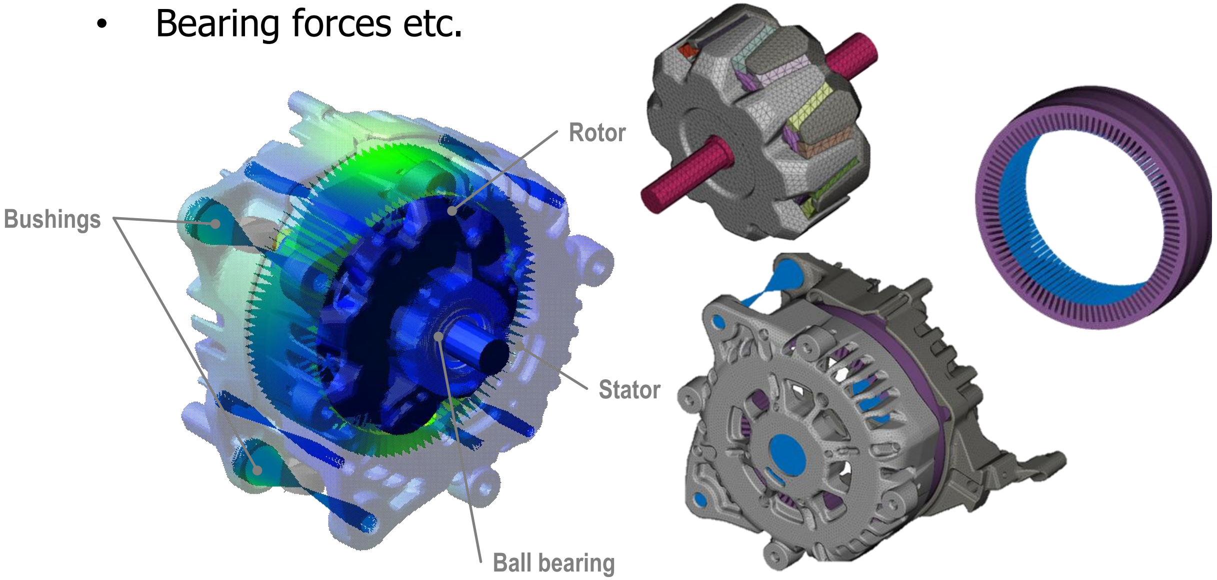


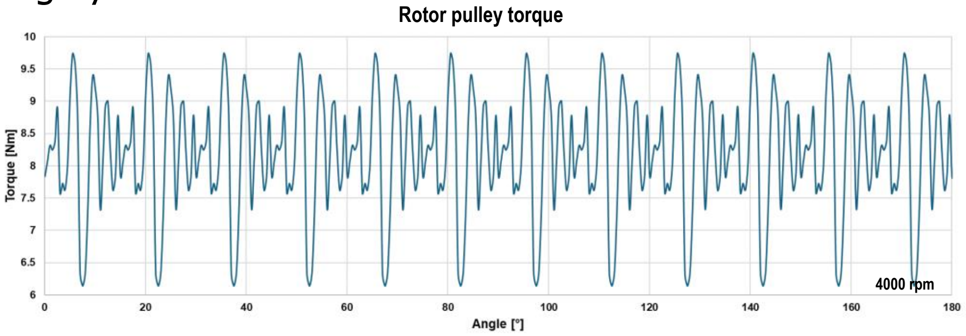


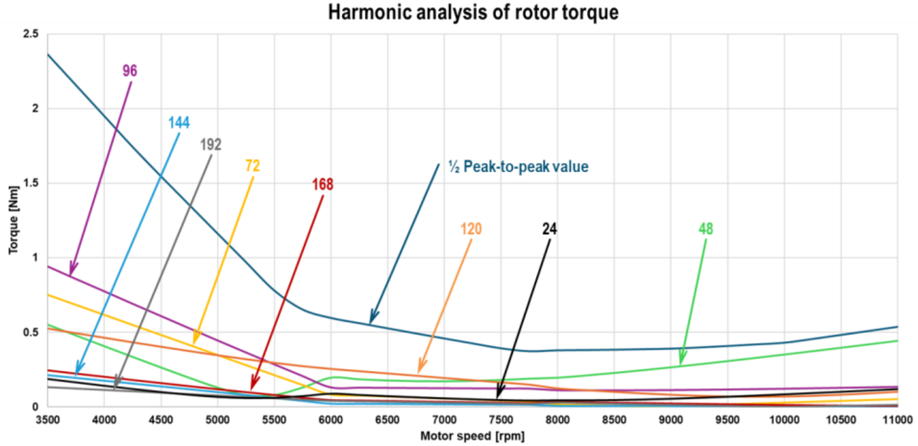
Activities in 4-WP08: Advanced Design Solutions for Future Automotive ICEs

4-WP08-004: Advanced computational model of dynamics and tribology of the engine for a hybrid power train

- Multi-body model of the electric machine containing modally reduced bodies, joints and bushings
  - Precalculated database from electromagnetic simulations for solving dynamics
- Multi-body simulation results
  - Rotor pulley torque
  - Rotor pulley angluar displacement
  - Bearing forces etc.







Fulfillment of goals and deliverables of 4-WP08: Advanced Design Solutions for Future Automotive ICEs

4-WP08 (4-WP08-001 + 4-WP08-002 + 4-WP08-003 + 4-WP08-004)

- Conclusions & Future Outlook:
  - LP injector visualization provides data for SW data processing => automated process.
  - ICE performance data (measurement) are being linked to processed visualization data to build the knowledge/links between injection event and ICE operation.

  - Rotating lubrication channel provides deeper insight into processes taking place in a real lubrication system of a crank shaft.
  - Both experimental data (processed visual data & global/integral parameters) and 3-D CFD simulations were carried out to improve understanding => engine/rotational speed and oil pressure are critical parameters, clear channel blockage is detected.

  - DCDA/DSF may provided significant thermodynamic benefits (3-WP02), however significant worsening of mechanical load of a crank train is avoidable <= outcome of detailed analysis (based on advanced simulations).
  - Hybrid powertrain (P0 hybrid configuration with suitable e-machine was selected) could be used to minimize that negative effect => detailed simulations are being prepared (e.g., calibration of sub-models) to find optimal solution.

Fulfillment of goals and deliverables of 4-WP08: Advanced Design Solutions for Future Automotive ICEs

Current State of Deliverables and Fulfillment of Goals

- 4-WP08-001 | **Intake module with an innovative position for new-generation of fuel injectors**, G-funk, XII./2025, Skoda Auto 0.9; TUL 0.1 – **in progress & no major delays:**
  - Extensive measurements associated with fuel jet visualization were performed.
  - Supporting automated software for processing and quantifying events during the formation of a fuel-air mixture based on image recording is creating.
  - Processing of a large amount of data is ongoing, efforts will be made to make a more comprehensive evaluation also using indications.

Fulfillment of goals and deliverables of 4-WP08: Advanced Design Solutions for Future Automotive ICEs

Current State of Deliverables and Fulfillment of Goals

- 4-WP08-002 | **Lubrication channel of the experimental driving unit system**, G-funk, XII./2025, Skoda Auto 0.9; TUL 0.1 – **in progress & no major delays:**
  - Extensive measurements associated in the oil flow through the lubrication channel are underway also using visualization.
  - Preparation of simulation models of the oil flow through the lubrication channel is underway.
  - The design of the lubrication channel modification is underway.

- Result dissemination:
  - RYCHTÁŘ, V., MALÝ, M. and ZVOLSKÝ, T. **Analysis of Dynamic Phenomena in the Hydraulic Circuit of the Lubrication System The 12th International Conference (on) Machine and Industrial Design in Mechanical Engineering**. Novi Sad, Serbia: Faculty of Technical Sciences, Novi Sad, 2024. S. 110 – 111. ISBN 978-86-6022-339-7.

Fulfillment of goals and deliverables of 4-WP08: Advanced Design Solutions for Future Automotive ICEs

Current State of Deliverables and Fulfillment of Goals

- 4-WP08-003 | **Key component parts and subassemblies for optimized engine of a hybrid power train**, G-funk, Dec/2025, ŠA 0.5; BUT 0.5 – **in progress & no major delays**
  - Performed functional tests of the default engine.
  - Performed basic measurements and experiments of an electric machine.
  - Processed measured quantities.
  - The design of the dynamic control of an electric machine for torque smoothing of an ICE with cylinder deactivation system is in progress.

- 4-WP08-004 | **Advanced computational model of dynamics and tribology of the engine for a hybrid power train**, O-ostatní, Dec/2025, ŠA 0.5; BUT 0.5 – **in progress & no major delays**
  - Built the computational model for electromagnetic simulations.
  - Prepared the computational model for dynamic simulations of the electric machine.
  - The integration of the computational model of the electric machine into the dynamics model of the entire power train is being prepared.

Fulfillment of goals and deliverables of 4-WP08: Advanced Design Solutions for Future Automotive ICEs

List of Due Deliverables and Their Added Value

- **4-WP08-001** – deeper inside into fuel mixture preparation of future automotive applications, close cooperation with industrial partner (Skoda Auto) – both funded R&D projects and commercial ones.
- **4-WP08-002** – deeper inside into improvement of the lubrication system of future automotive applications, close cooperation with industrial partner (Skoda Auto) – both funded R&D projects and commercial ones.
- **4-WP08-003** – finding out whether it is possible to combine a naturally-aspirated engine, cylinder deactivation system and mild-hybrid technique to further increase the overall efficiency of the power unit (the mild-hybrid part is used to compensate for uneven engine running). Project and commercial cooperation with industrial partner (Škoda Auto).
- **4-WP08-004** – a tool for predictive assessment of the dynamics of hybrid power units, assesment of appropriate sequences for cylinder deactivation. Project and commercial cooperation with industrial partner (Škoda Auto).

Fulfillment of goals and deliverables of 4-WP08: Advanced Design Solutions for Future Automotive ICEs

Assessment of the Contribution of Deliverables

- The **4-WP08** is closely related to **3-WP07** as it is directly focused on ICE design & operation.
- New fuels for ICE – (3-WP07).
- Lubrication systems for ICE/turbochargers - (3-WP05), (3-WP06).
- Mechanical losses of ICE – (3-WP07-006).
- Cylinder deactivation – **3-WP02**.
- Concept design of future power trains – 4-WP02

Current contribution of 4-WP08: Advanced Design Solutions for Future Automotive ICEs

Assessment of the Formal/Administrative Goals of the Work Package

All formal and administrative requirements are expected to be fulfilled.

	Skoda Auto	TUL	BUT
Finances (reporting/spending)	OK	OK	OK
Commercialization (the whole organization)	OK	OK	OK
Deliverables	OK	OK	OK

Current contribution of 4-WP08: Advanced Design Solutions for Future Automotive ICEs

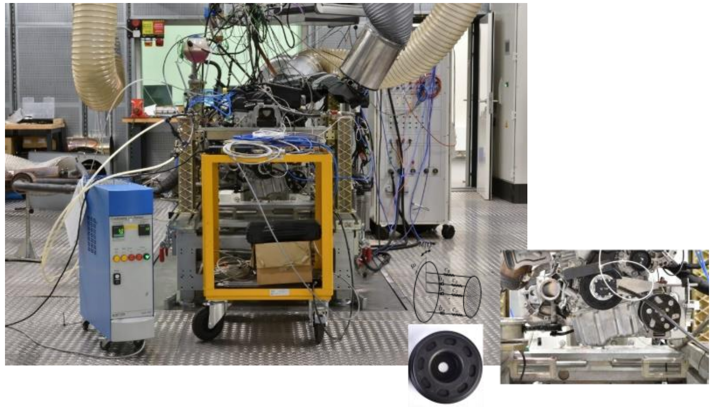
Acknowledgment

This research has been realized using the support of Technological Agency, Czech Republic, programme National Competence Centres II, project # TN02000054 Božek Vehicle Engineering National Center of Competence (BOVENAC).

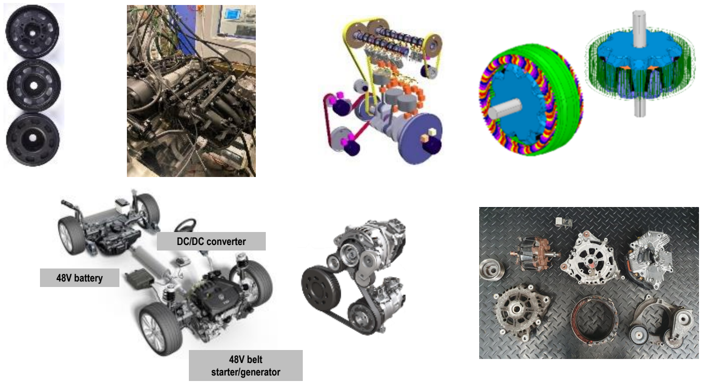
Výtah z prací 2023-2025 za 4-WP08: Advanced Design Solutions for Future Automotive ICEs

Skoda Auto: konstrukce

Experimenty na cílových motorech

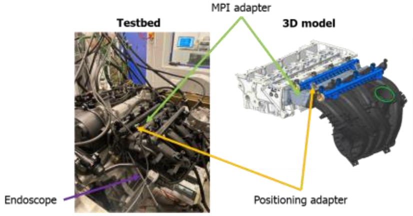


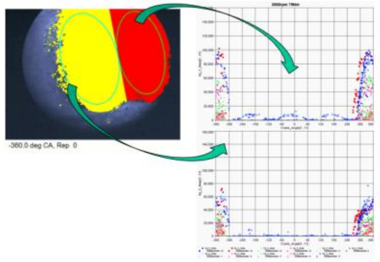
Podpora VO– motory pro testy, data, CAD/CAE modely, detailní výpočetní modely, testovací vybavení, atp.



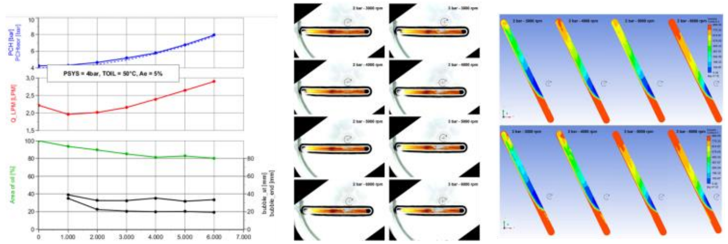
TUL: experimenty & hydraulika

Vizualizace paprsku paliva a automatizované zpracování dat



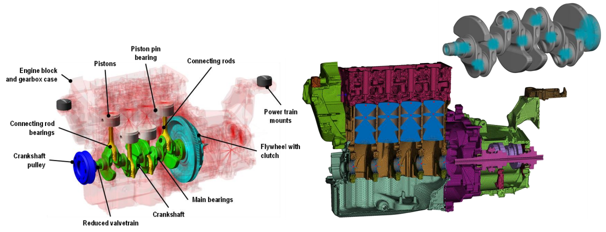


Analýza mazacího okruhu – simulace & experimenty

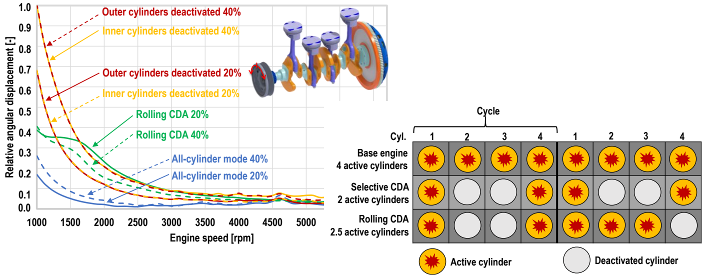


BUT: návrh & mechanika

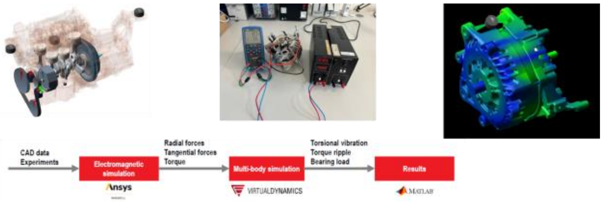
MKP model původního motoru i s převodovkou



Torzní kmity motoru s deaktivací válců



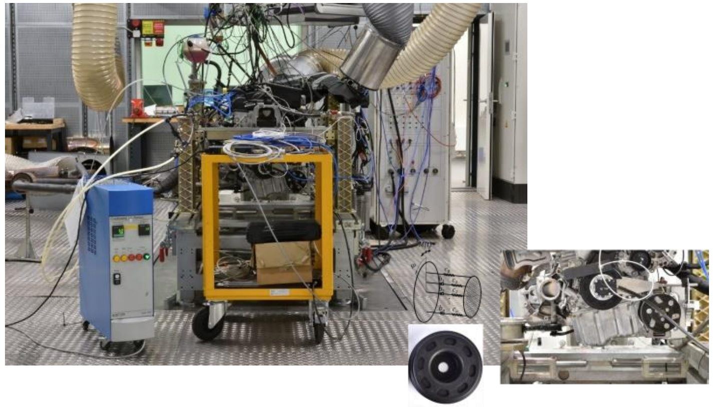
Komplexní simulační proces včetně elektromagnetismu



Results of 4-WP08: Pokročilé motory pro budoucí automobily – Achieved 2023-2025

Skoda Auto: ICE design

Measurement(s) on target ICE(s)



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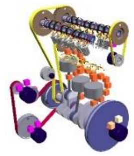
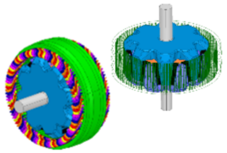
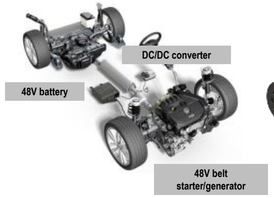
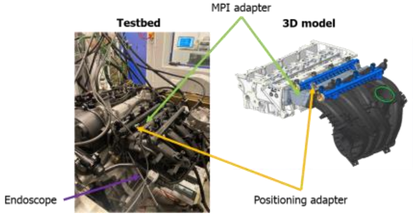
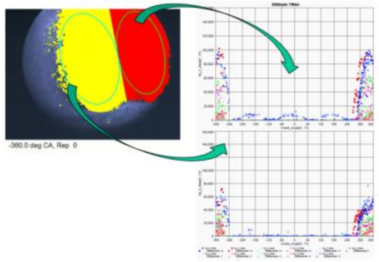




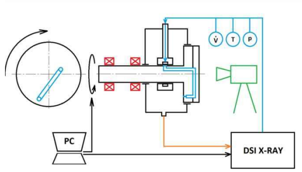

TUL: experiments & hydraulics

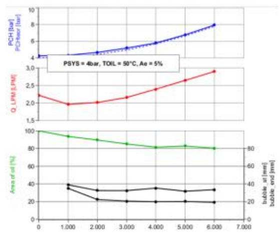
Fuel jet visualizations and automated data processing

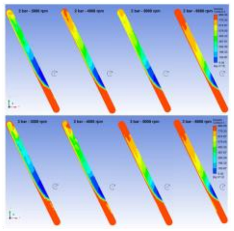




Analysis of lubrication circuit performance – experiments & simulations

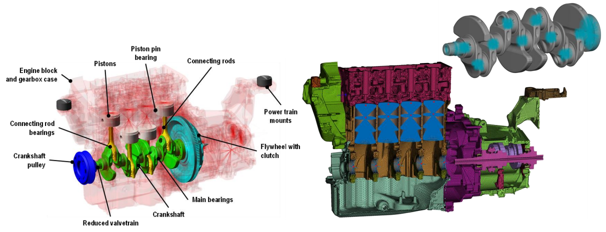


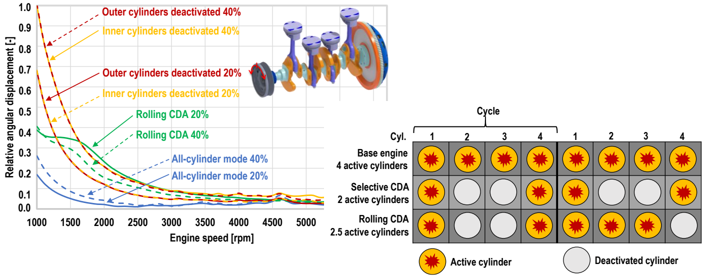


BUT: design & mechanics

FEM model of the default engine and gearbox



Torsional vibration of ICE with cylinder deactivation

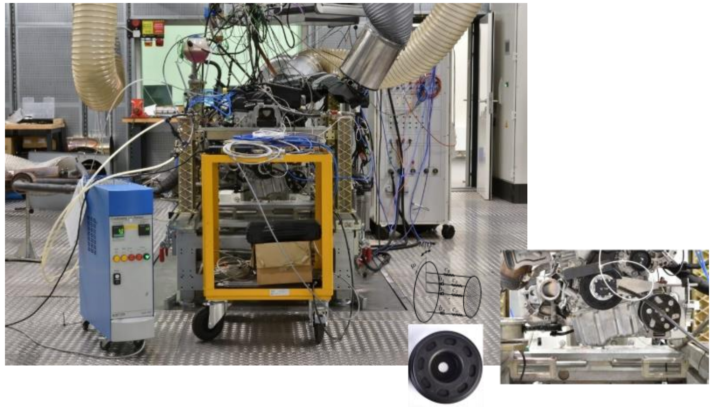


Complex simulation process including electromagnetics


Výtah z prací 2024 za 4-WP08: Pokročilé motory pro budoucí automobily

Skoda Auto: konstrukce

Experimenty na cílových motorech



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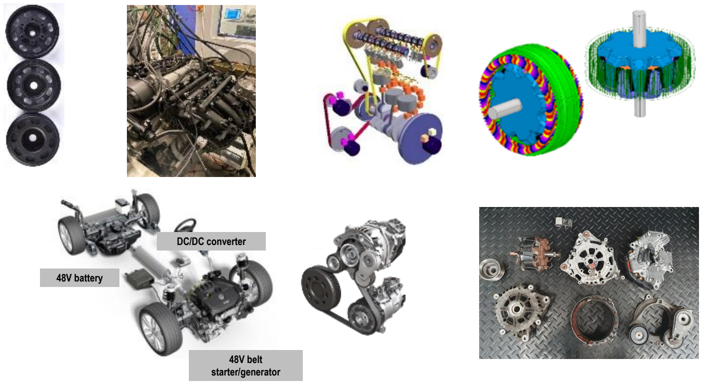

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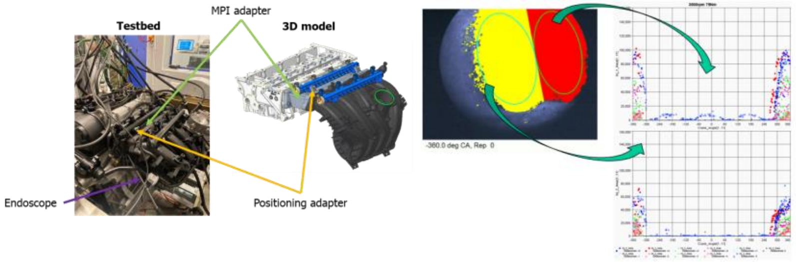

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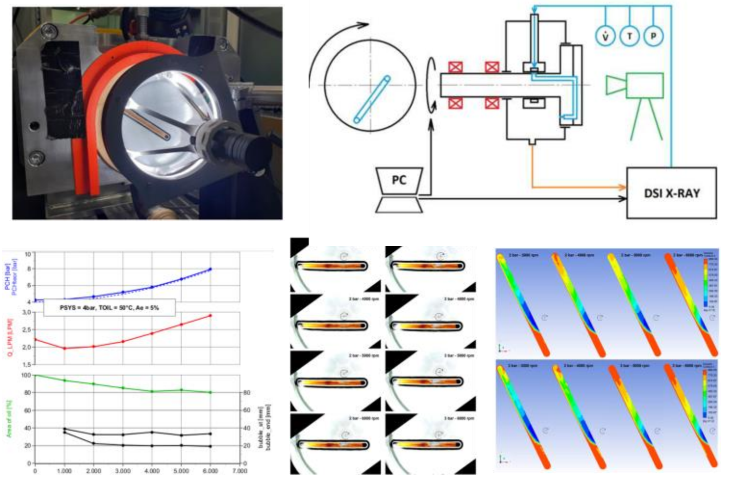

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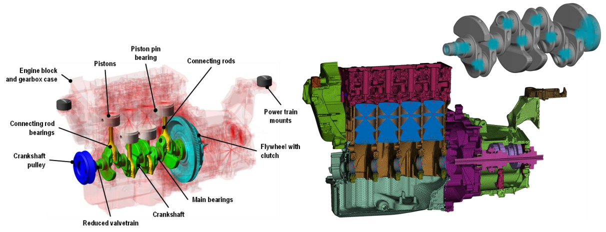
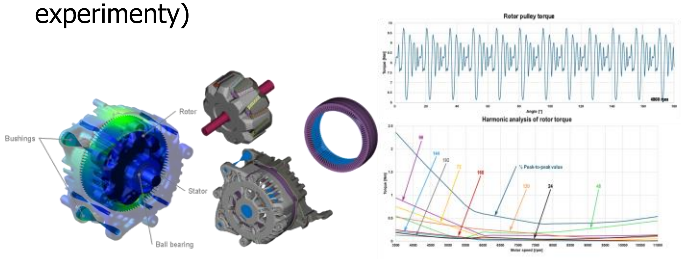


Detailní kalibrace elektromotoru (simulace & experimenty)



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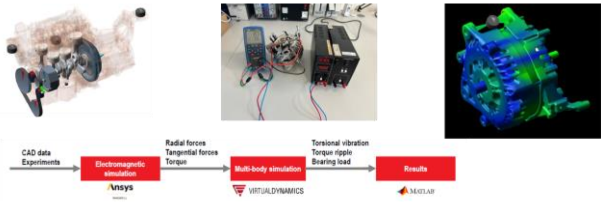

Results of 4-WP08: Advanced Design Solutions for Future Automotive ICEs – Achieved 2024

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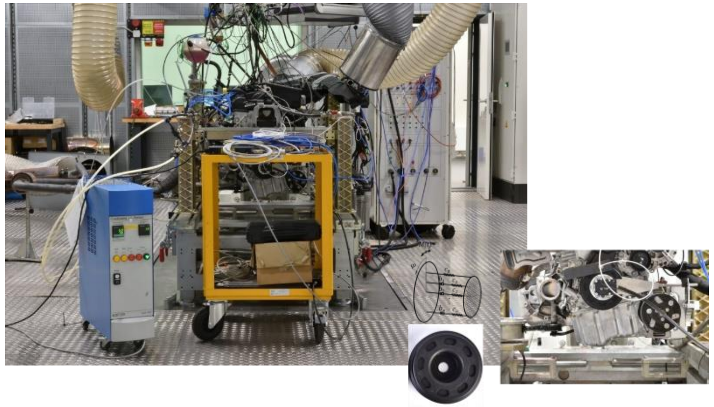
Measurement(s) on target ICE(s)



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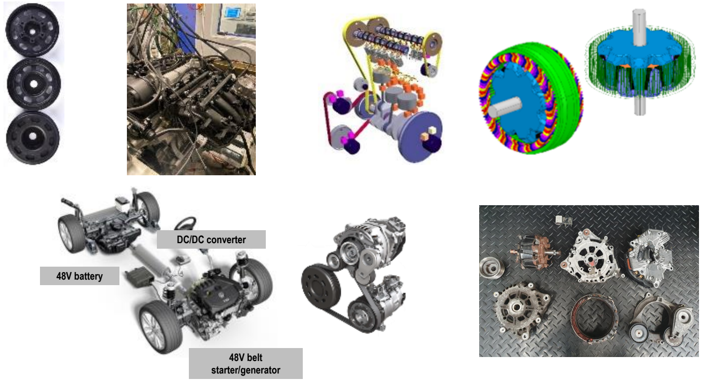

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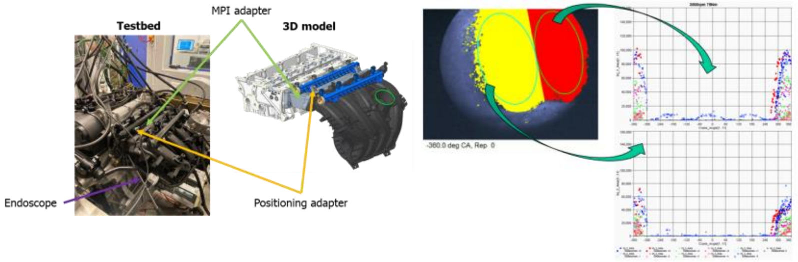

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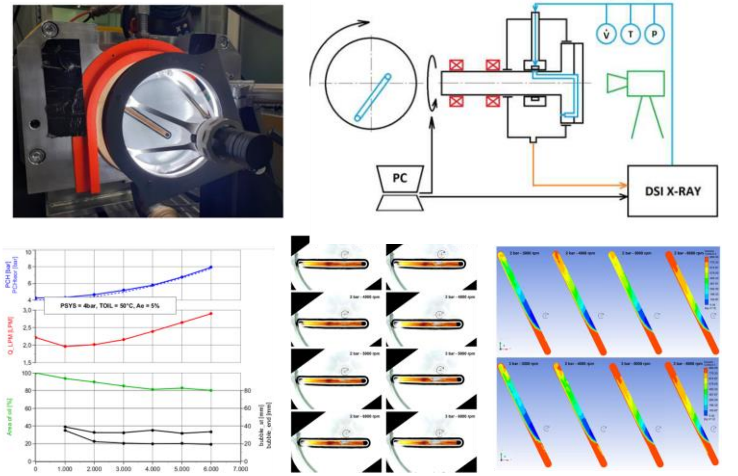

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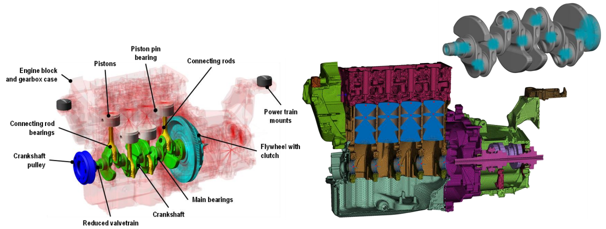
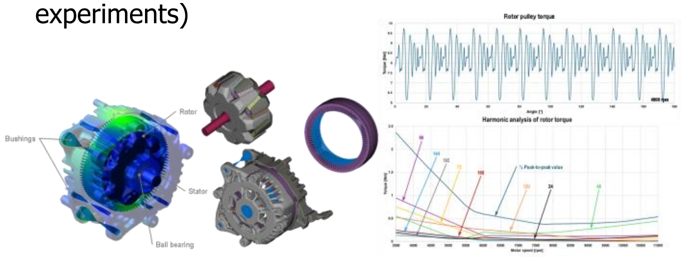


Detailed calibration of e-machine (simulation & experiments)



Complex simulation process including electromagnetics