Contents of Work Package **3-WP02**: Digital twin of advanced valve-train system(s)

Coordinator of the WP

České vysoké učení technické v Praze, Ing. Radek Tichánek, Ph.D.

Participants of the WP

Eaton Elektrotechnika s.r.o. - Ing. Ondřej Bolehovský

Main Goal of the WP

Development of a digital twin (i.e., a multipurpose simulation model) of advanced valve train systems that captures manufacturing tolerances and wear over the engine lifecycle. Predict performance and other critical engine characteristics to avoid/limit degradation.

The software for DCDA simulations that enables detailed thermodynamic analysis of a general DCDA system applied to any type of ICE. Large-scale optimizations will be carried out to find theoretical limits/benefits.

Partial Goals for the Current Period

- DT: Refinement of the combined mechanical and hydraulic model
- DT: Testing of model behavior during mode switching
- DCDA: Constraining the DCDA mode by real engine operating conditions
- DCDA: Performed Variable Valve Actuation in DCDA mode – new optimization

Contents of Work Package **3-WP02**: Digital twin of advanced valve-train system(s)

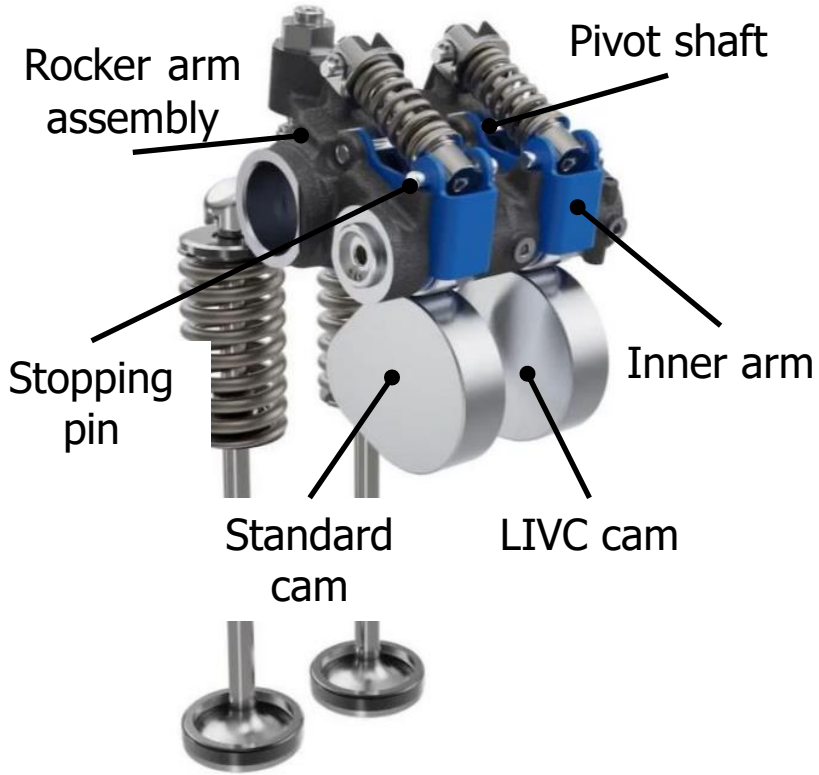
3-WP02: Digital twin of advanced valve-train system(s)

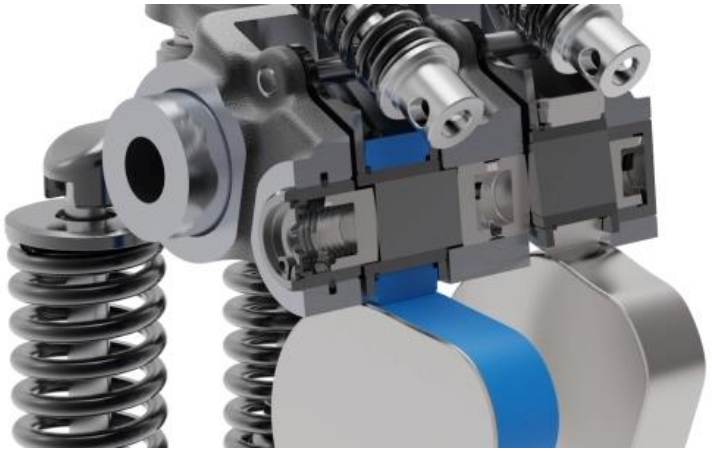
Official 3-WP02 Deliverables:

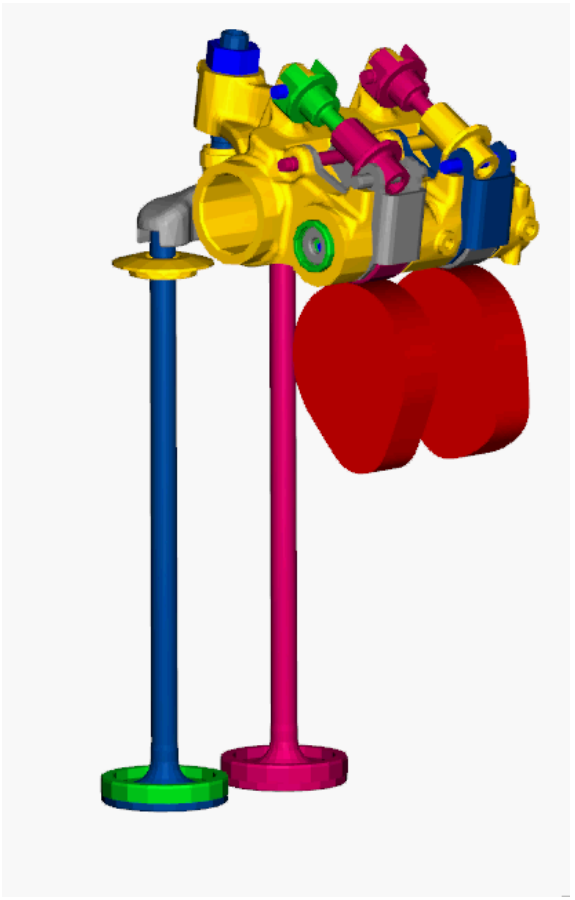
- 3-WP02-001 | **Digital twin of advanced valve-train system(s)**, R-software, VI./2026, EATON 0.6; CTU 0.4;
- 3-WP02-002 | **Report on Milestones - Valve train**, O-other, VI./2026, CTU 0.9; EATON 0.1 – Ing. Ondřej Bolehovský

Activities in **3-WP02**: Digital twin of advanced valve-train system(s)

3-WP02-001 | **Digital twin of advanced valve-train system(s)**





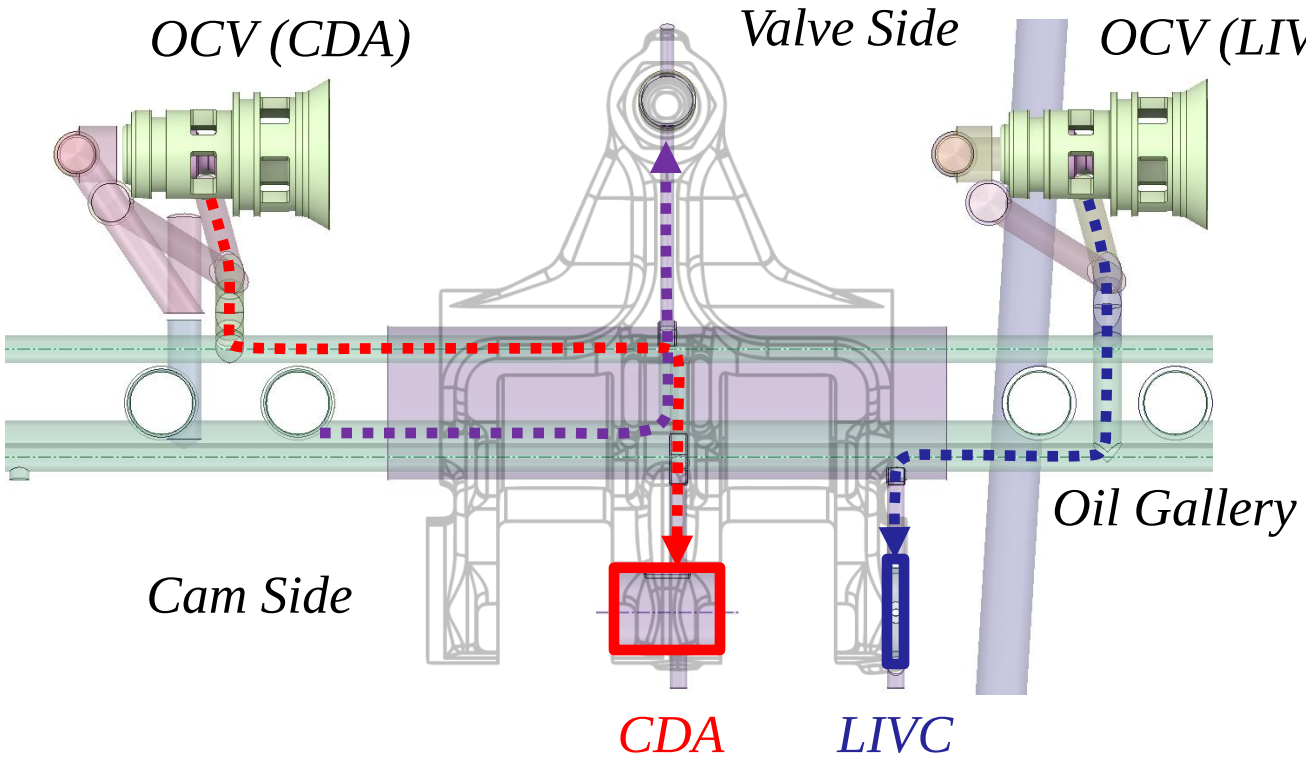


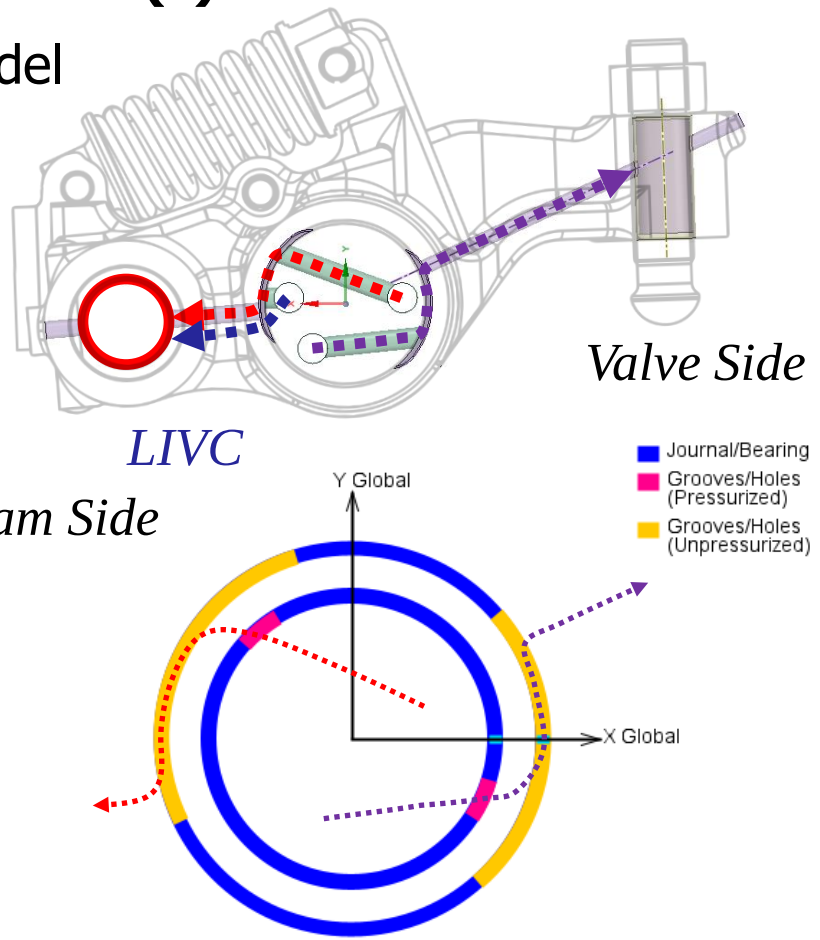
Eaton Dual Deactivating Roller Rocker (2DR Rocker)

Activities in **3-WP02**: Digital twin of advanced valve-train system(s)

3-WP02-001 | **Digital twin of advanced valve-train system(s)**

Refinement of the combined mechanical and hydraulic model

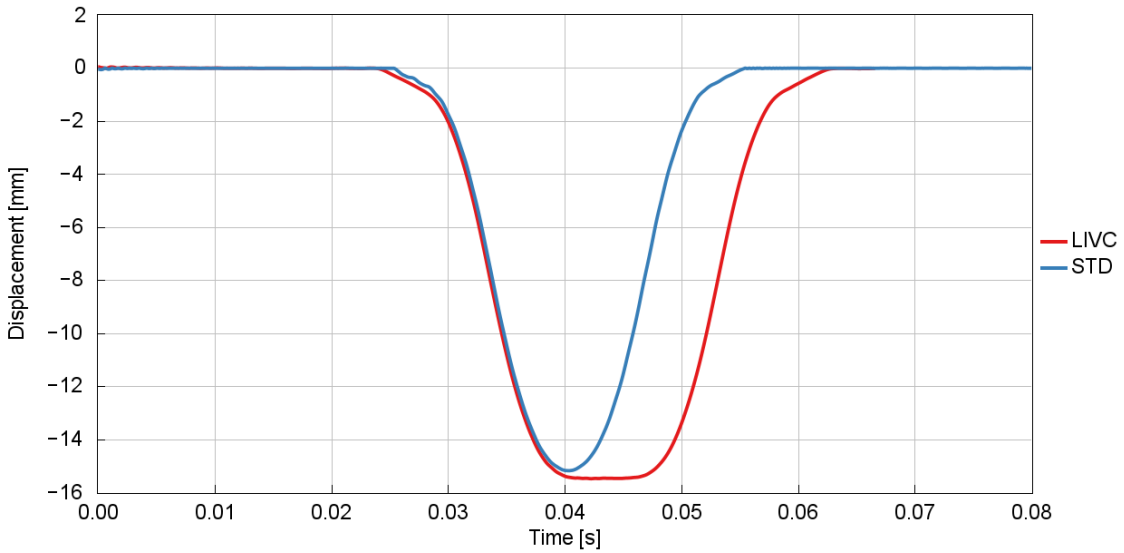


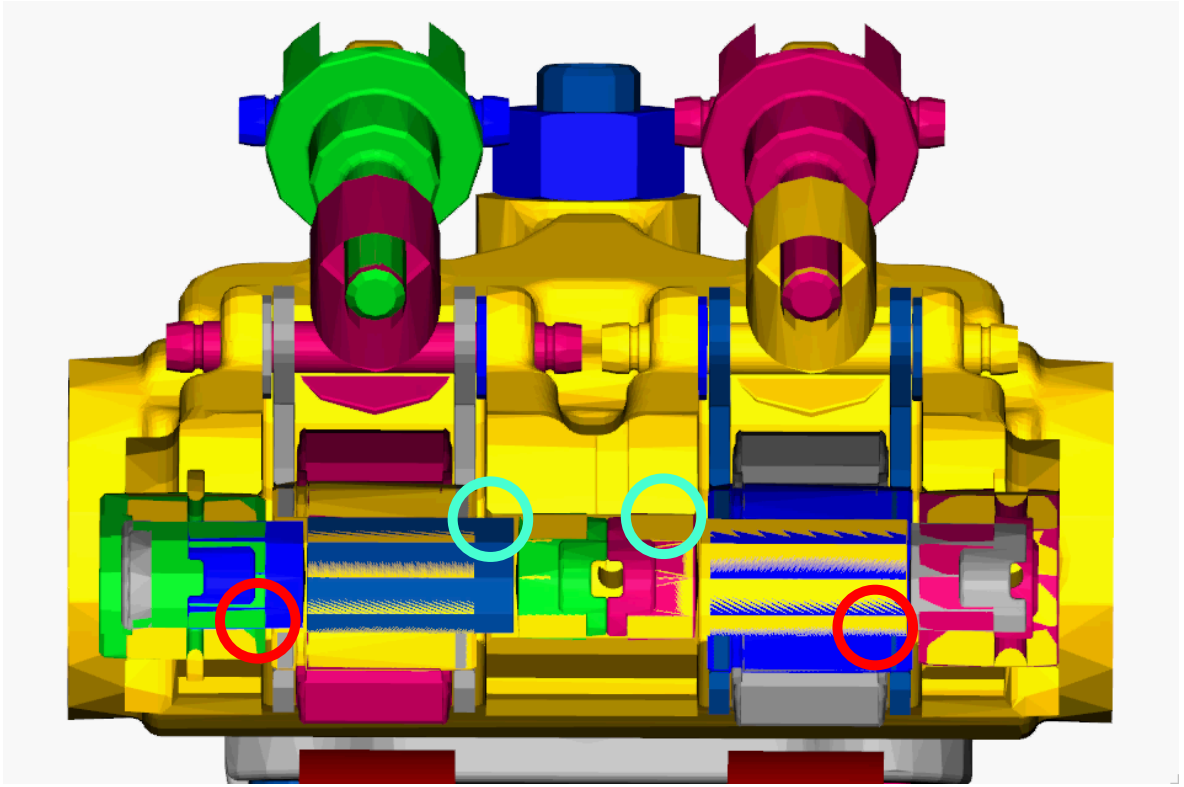


Activities in **3-WP02**: Digital twin of advanced valve-train system(s)

3-WP02-001 | **Digital twin of advanced valve-train system(s)**

Testing of model behavior during mode switching

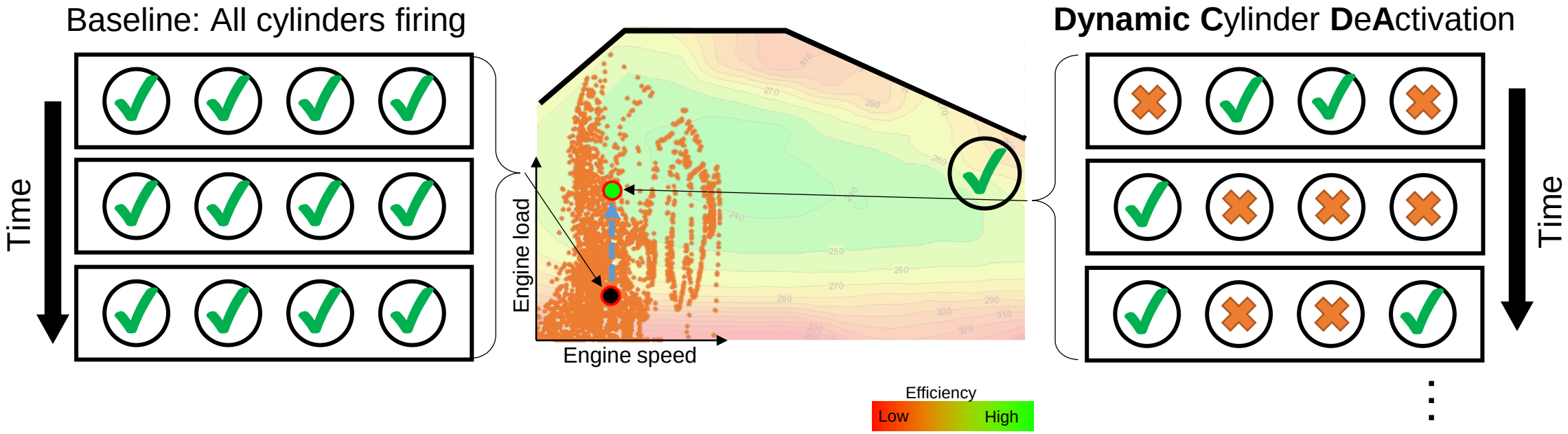




Activities in **3-WP02**: Report on Milestones - Valve train

3-WP02-002 | **Report on Milestones - Valve train**

Dynamic Cylinder DeActivation (**DCDA**) - Explanation



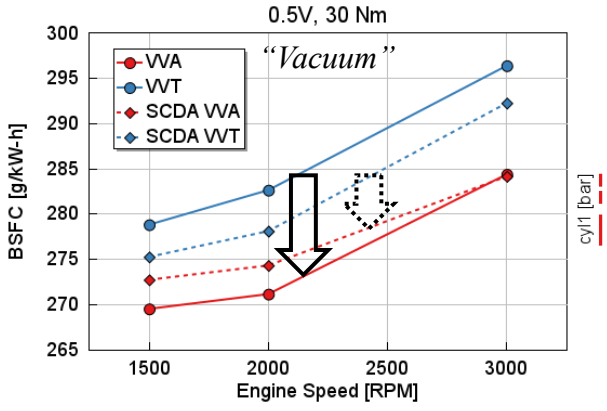
Bolehovsky O, Vitek O, Mares B. Dynamic cylinder deactivation: Thermodynamic mapping for the case of stoichiometric SI ICE. International Journal of Engine Research. 2023;24(4):1724-1743.

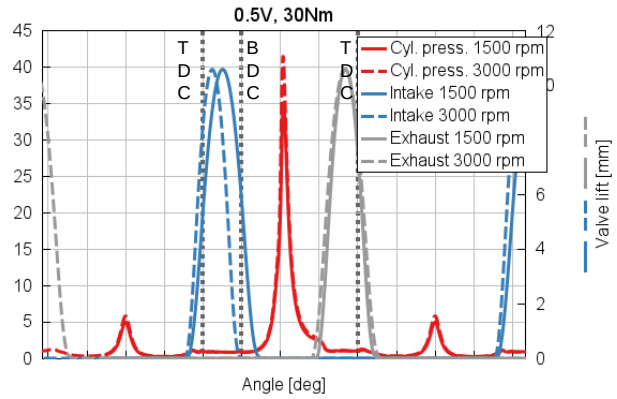
Activities in **3-WP02**: Report on Milestones - Valve train

3-WP02-002 | **Report on Milestones - Valve train – Year 2024**

Optimization – VVA in DCDA mode:

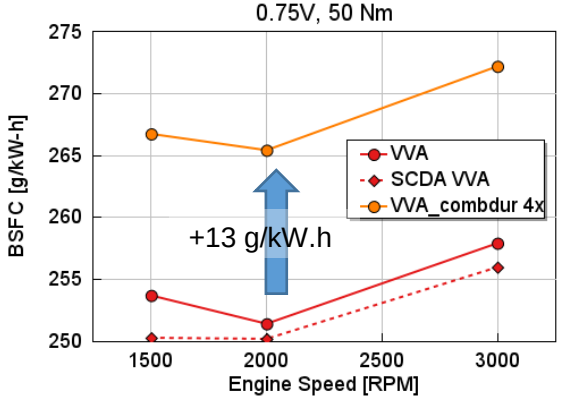
- Fully **V**ariable **V**alve **A**ctuation = variable valve lift profile (previous activity: VVT=timing)
- Both conventional and dynamic cylinder deactivation optimized
- <u>Greater benefit with VVA for the DCDA (vacuum)</u>

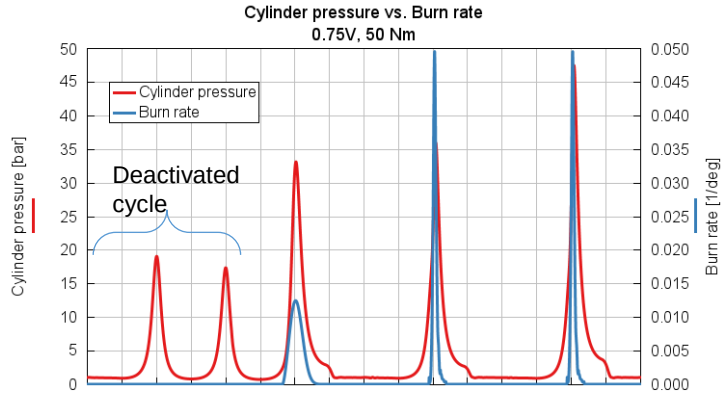




Combustion duration modification:

- For the "Air" mode - air is captured in the deactivated cylinder and then ignited as combustible mixture
- The charge (air) motion decreases during the deactivated cycles➔combustion is 4x prolonged (3D CFD analysis)





Fulfillment of goals and deliverables of **3-WP02**: Digital twin of advanced valve-train system(s)

Current State of Deliverables and Fulfillment of Goals

- 3-WP02-001 | **Digital twin of advanced valve-train system(s)**, R-software, VI./2026, EATON 0.6; CTU 0.4 – in progress & no major delays:
  - Refinement of the combined mechanical and hydraulic model was performed.
  - The model's behavior is being tested during mode switching.

- 3-WP02-002 | **Report on Milestones - Valve train**, O-other, VI./2026, CTU 0.9; EATON 0.1 – in progress & no major delays:
  - Constraining DCDA mode by real engine operating conditions (blow-by, combustion duration modification – 3D CFD support)
  - Improvement of DCDA mode efficiency by advanced valve actuation (individual VVT for each cylinder, VVA for the engine)

Fulfillment of goals and deliverables of **3-WP02**: Digital twin of advanced valve-train system(s)

List of Due Deliverables and Their Added Value

- **3-WP02-001** – offer the Dual Deactivating Roller Rocker (2DR Rocker) for medium- and heavy-duty engines allows Eaton to keep its position on the market. Eaton expects 1-2% CO2 emission decrease, higher compression ratio and better aftertreatment thermal performance (LIVC)
- **3-WP02-002** – Eaton expects reduction NOx in low load cycle by around 40% while reducing CO2 by 5-8% (CDA) and NOx reduction up to 90% when combined with advanced aftertreatment.

Current contribution of **3-WP02**: Digital twin of advanced valve-train system(s)

Assessment of the Contribution of Deliverables

- 4-WP08 of FEFEFOV project (VUT) – cooperation in 2023; in future possible as well

Current contribution of **3-WP02**: Digital twin of advanced valve-train system(s)

Assessment of the Formal/Administrative Goals of the Work Package

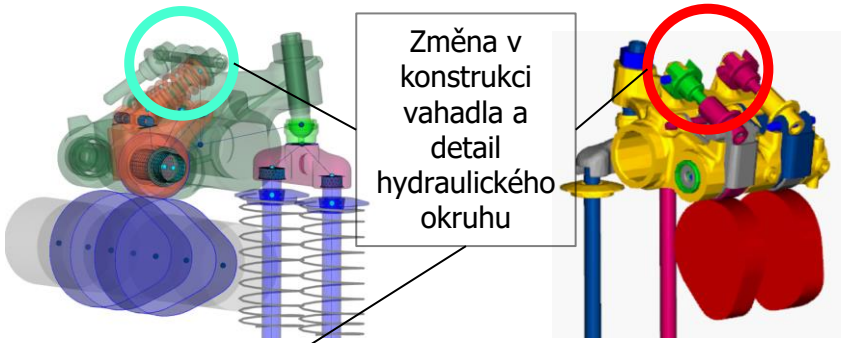
	CTU	Eaton
Finances (reporting/spending)	OK	OK
Commercialization (for whole organization)	OK	OK
Deliverables	OK	OK

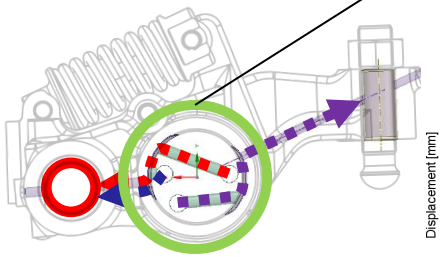
Výtah z prací 2023-2025 na **3-WP02**: Digital twin of advanced valve-train system(s)

3-WP02-001

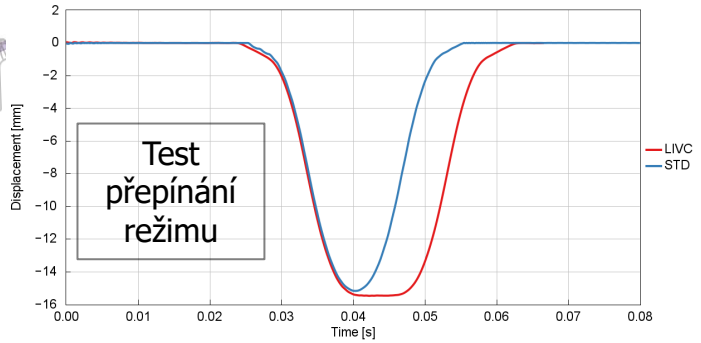
2023 – byly vybrány přístupy k modelování: 3D MBS + CFD, shromážděna měřená data a byl rozpracován základního model

2024 – byl aktualizován mechanický a hydraulický model a testovány jeho vlastnosti při přepínání režimů





Zdvih ventilu STD >> LIVC



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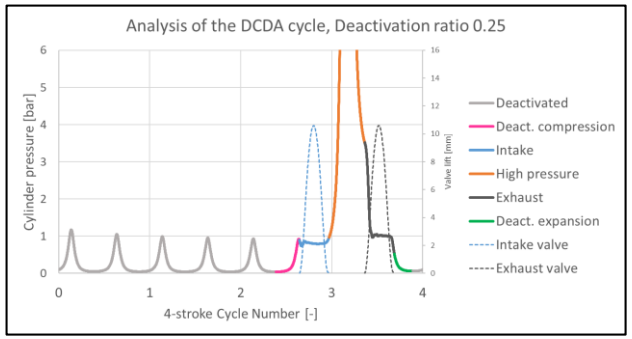
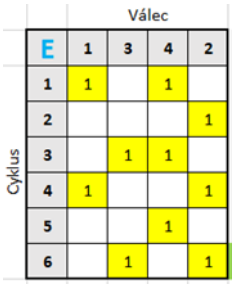
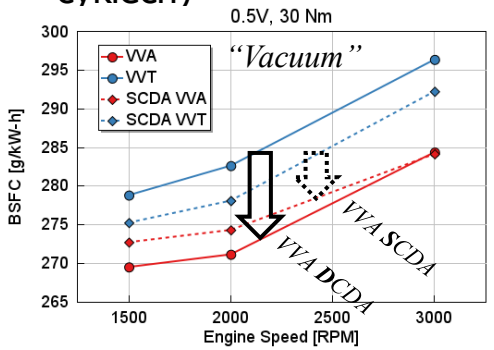
3-WP02-002

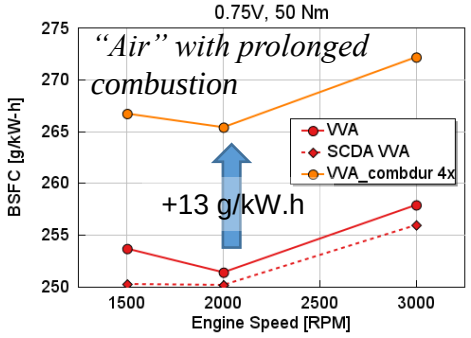
2023: Energetická bilance v módu dynamické deaktivace; Testování modularity nástroje DCDA (aplikace na jiný model)





2024: Vylepšení účinnosti motoru v DCDA módu (individuální VVT/válec, VVA pro všechny válce); Zahrnutí vlivu reálných podmínek běhu motoru (blow-by, délka hoření po protáčných cyklech)



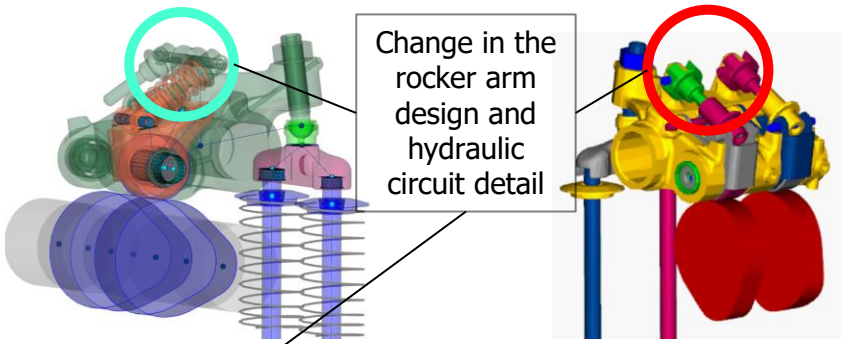


Results of **3-WP02**: Digital twin of advanced valve-train system(s) – Achieved 2023-2025

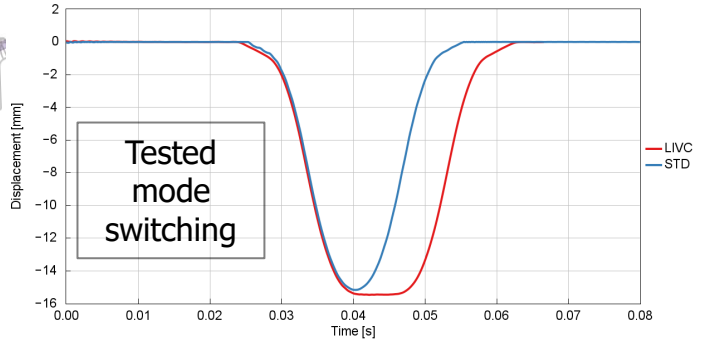
3-WP02-001

2023 – selected the appropriate modeling approaches: 3D MBS + CFD, collected measured data, and a basic model was developed

2024 - mechanical and hydraulic model was updated, and its behavior was tested during mode switching.



Valve lift STD >> LIVC



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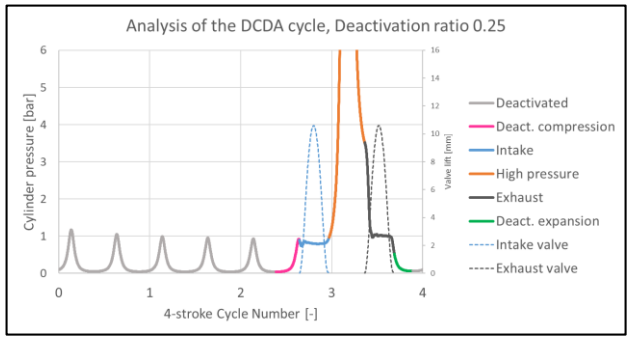
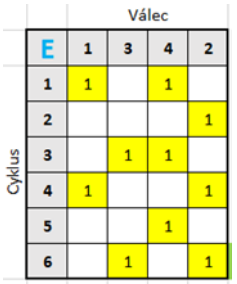
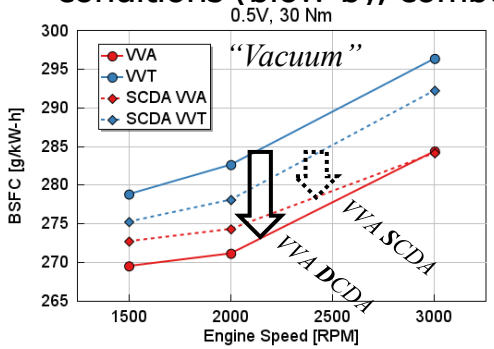
3-WP02-002

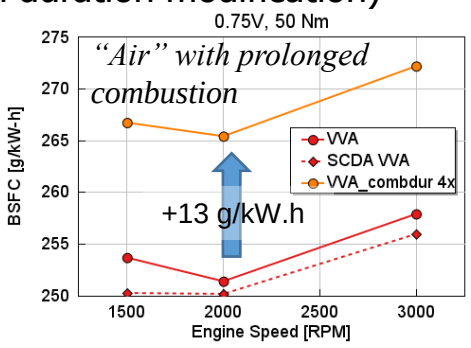
2023: Energy balance analysis for DCDA mode; Testing of DCDA tool modularity (application on another ICE model)





2024: Improvement of DCDA mode efficiency by advanced valve actuation (individual VVT for each cylinder, VVA for the engine); Constraining DCDA mode by real engine operating conditions (blow-by, combustion duration modification)

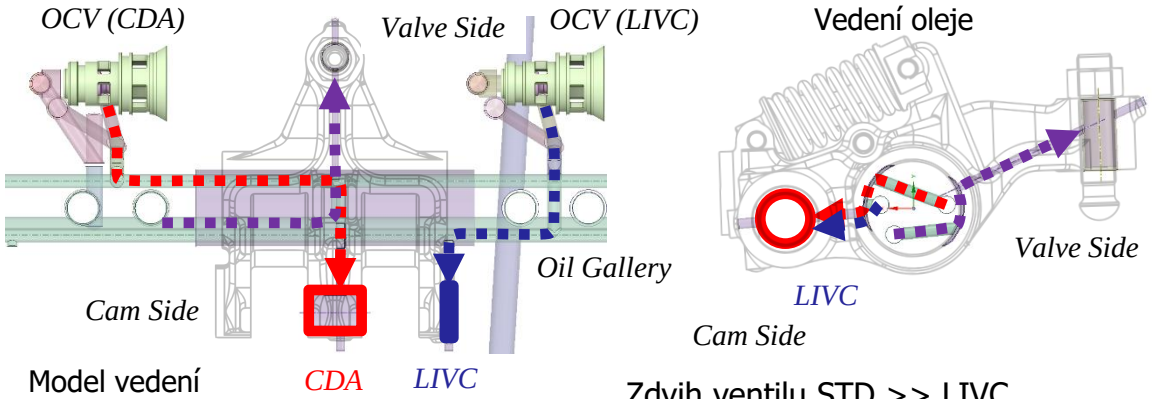




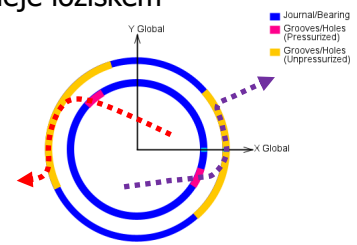
Výtah z prací 2024 na **3-WP02**: Digital twin of advanced valve-train system(s)

3-WP02-001

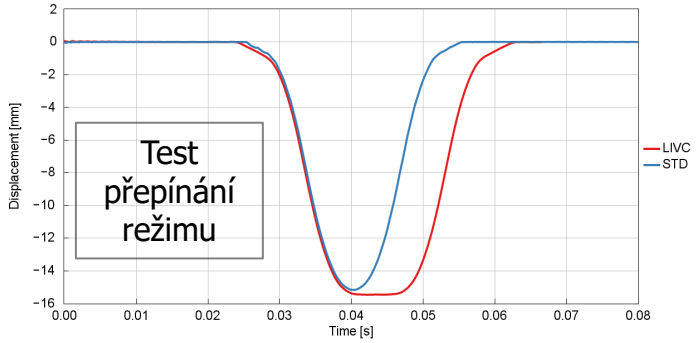
Byl aktualizován mechanický a hydraulický model podle aktuální geometrie, byly testovány vlastnosti modelu při přepínání režimů.



Model vedení oleje ložiskem



Zdvih ventilu STD >> LIVC



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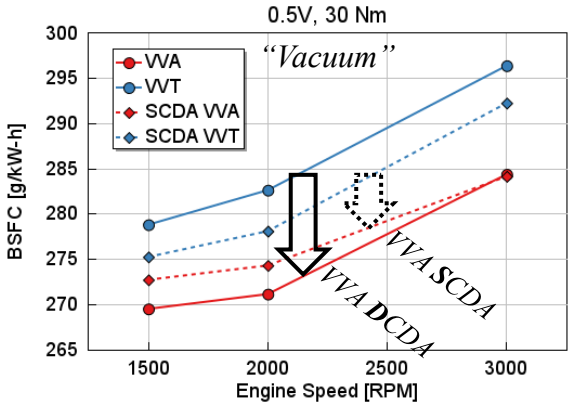
3-WP02-002

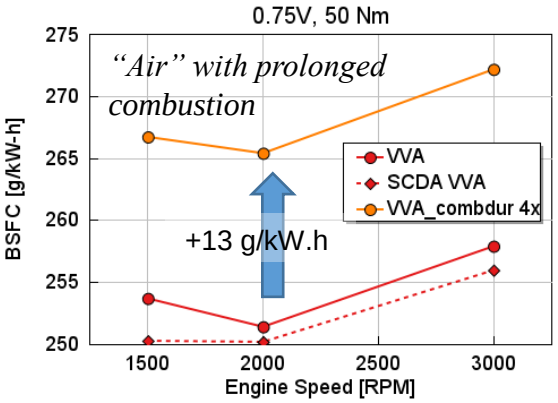
Optimalizace – VVA v módu DCDA:

- Plné variabilní profil zdvihu ventilu (předchozí aktivita: VVT=pouze časování)
- Větší benefit VVA pro DCDA než konvenční deakt.

Modifikace délky hoření:

- Pohyb vnitřní náplně válce se po sérii deakt. cyklů snižuje (náplní deakt. cyklů je vzduch)➔délka hoření prodloužena 4x (3D CFD analysis)

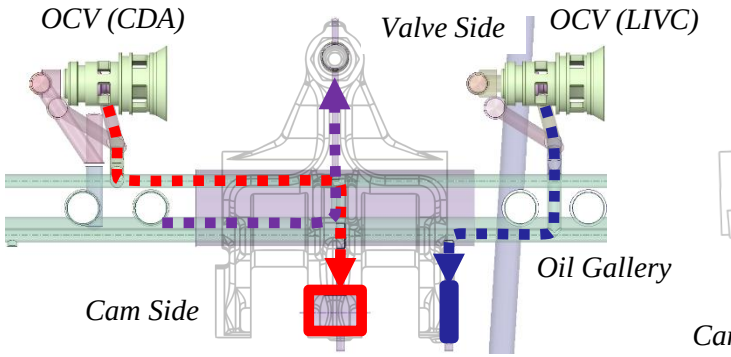


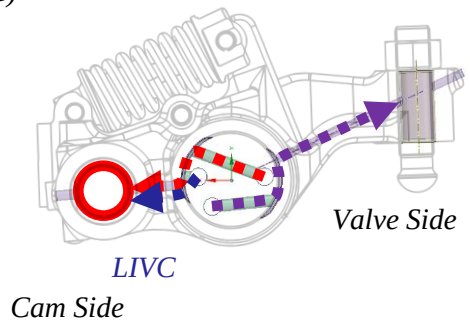


Results of **3-WP02**: Digital twin of advanced valve-train system(s) – Achieved 2024

3-WP02-001

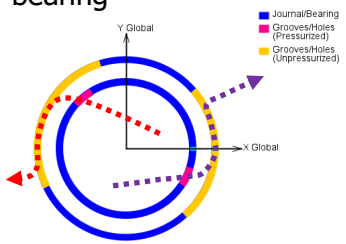
The year's activities included refining the combined mechanical and hydraulic model and testing its behavior during mode switching.



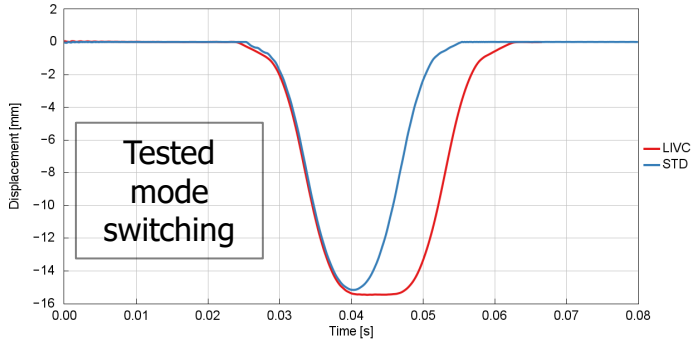


Flow model of bearing

CDA LIVC



Valve lift STD >> LIVC



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3-WP02-002

Optimization – VVA in DCDA mode:

- Fully **V**ariable **V**alve **A**ctuation = variable valve lift profile (previous activity: VVT=timing)
- Greater benefit with VVA for the DCDA (vacuum)

Combustion duration modification:

- The charge (air) motion decreases during the deactivated cycles (Air capture mode)➔combustion is 4x prolonged (3D CFD analysis)