Contents of Work Package 1-WP10 Advanced Control of ICE Gas Exchange Process

1-WP10: Advanced Control of ICE Gas Exchange Process

Coordinator of the WP

České vysoké učení technické v Praze, zodpov. osoba Ing. Ondřej Bolehovský

Participants of the WP

Eaton European Innovation Center (Eaton Elektrotechnika s.r.o.)

Main Goal of the WP

Dynamic firing/cylinder deactivation and potential of advanced valve train application to minimize both pollutant formation and CO2 while improving engine performance while using advanced simulation techniques and complex ICE control.

Partial Goals for the Current Period

Control tool and inherent modification of an ICE 1-D model in GT-SUITE enabling reliable and stable 1-D simulation in the dynamic cylinder deactivation mode. The control tool enables optimization process in steady state mode and ensures modularity (is transferrable to other engine layouts).

Activities in 1-WP10 Advanced Control of ICE Gas Exchange Process

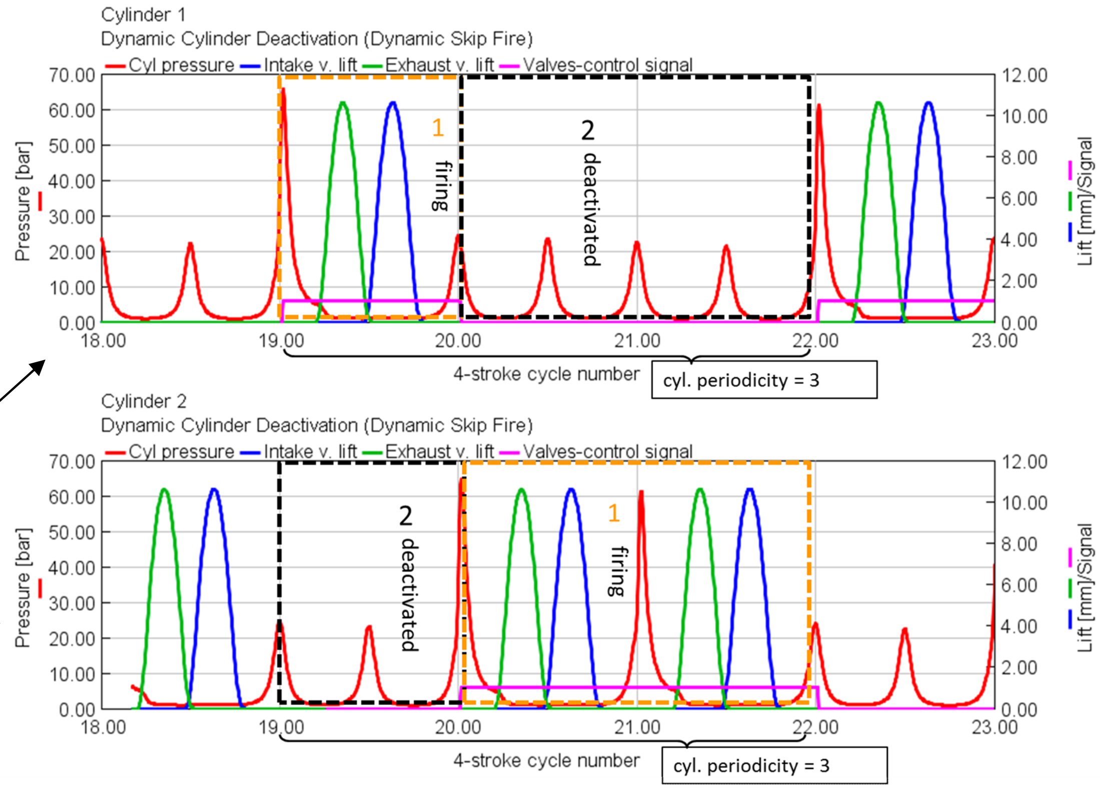
Advanced Dynamic Cylinder Deactivation – Cylinder Cycling Patterns

- Each/some cylinder(s) run in a cyclic pattern, in which a certain number of cycles is deactivated
- Cyl. cyclic pattern defined by:
  - Cylinder periodicity
  - Cylinder firing cycles
  - ➢ Cyl. deactivation ratio:

$$= \frac{Number\ of\ actual\ firing\ cycles}{Number\ of\ potential\ firing\ cycles}$$

$=1/3$

$=2/3$



Activities in 1-WP10 Advanced Control of ICE Gas Exchange Process

Advanced Dynamic Cylinder Deactivation – Cylinder Cycling Patterns

- Each cylinder runs in different periodicity → the overall periodicity of the engine is defined as the least common multiple of periodicities of all cylinders → all results (and converg. criteria) must be averaged over the engine periodicity/supercycle

Cyl. periodicity	Nr. of firing cycles	Cylinder	Cycle Number 1	2	3	4	5
4	1	1	x	0	0	0	x
4	3	2	0	x	x	x	0
2	1	3	x	0	x	0	x
2	1	4	0	x	0	x	0
Engine periodicity:		**4**	Deactivation ratio:			**8**	**/16**

Cyl. periodicity	Nr. of firing cycles	Cylinder	Cycle Number 1	2	3	4	5	6	7
3	1	1	x	0	0	x	0	0	x
2	1	2	0	x	0	x	0	x	0
3	1	3	0	0	x	0	0	x	0
2	1	4	x	0	x	0	x	0	x
Engine periodicity:		**6**	Deactivation ratio:			**10**	**/24**		

Cyl. periodicity	Nr. of firing cycles	Cylinder	Cycle Number 1	2	3	4	5	6	7	8	9	10	11
5	3	1	0	0	x	x	x	0	0	x	x	x	0
2	1	2	0	x	0	x	0	x	0	x	0	x	0
5	2	3	x	x	0	0	0	x	x	0	0	0	x
2	1	4	0	x	0	x	0	x	0	x	0	x	0
Engine periodicity:		**10**	Deactivation ratio:			**20**	**/40**						

$$Engine\ periodicity = LCM(Cyl1_{period}, Cyl2_{period}, \dots).$$

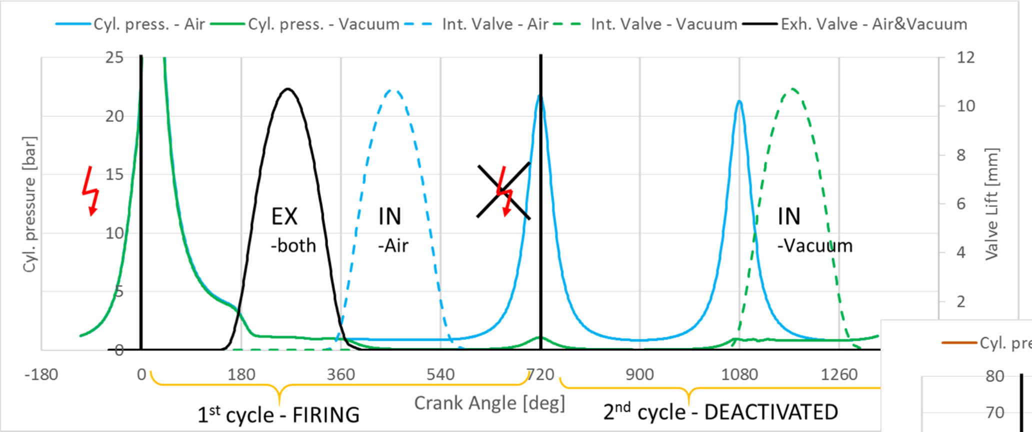
$$Engine\ deact.ratio = \frac{\sum_{Eng\ periodicity} Actual\ Firing\ cycles}{\sum_{Eng\ periodicity} Potential\ Firing\ cycles}$$

$$Avg.quantity = \frac{\int_{Eng\ period} Inst.quantity\ d\alpha}{\int_{Eng\ period} d\alpha}$$

Activities in 1-WP10 Advanced Control of ICE Gas Exchange Process

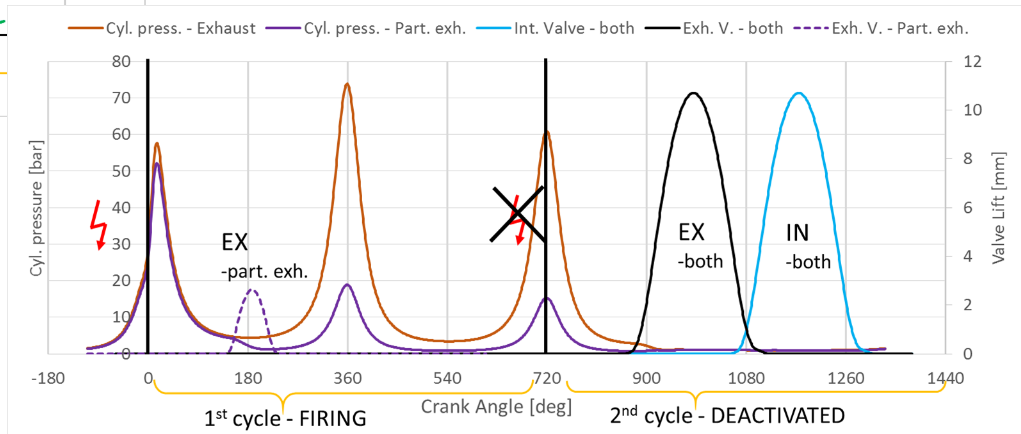
Cylinder Content in Deactivated Cycles

- The deactivated cylinder can be filled either with fresh air or residuals → this requires different sequence of valve deactivation and influences thermal losses and combustion efficiency of the next firing cycle ("fresh air" content)



Fresh air & "Vacuum"
(Cyl. deactivation ratio: 1/2)

Residuals: Full & Partial
(Cyl. deactivation ratio: 1/2)



Activities in 1-WP10 Advanced Control of ICE Gas Exchange Process

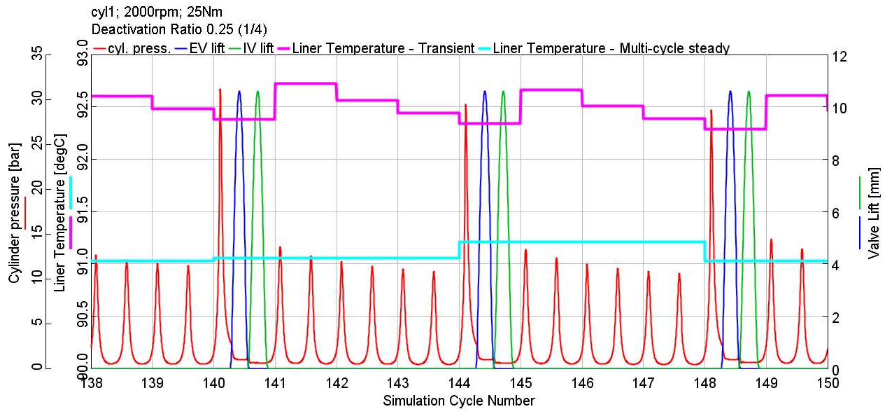
Modular Simulation Model of Dynamic Cylinder Deactivation

Advanced control logic that handles:

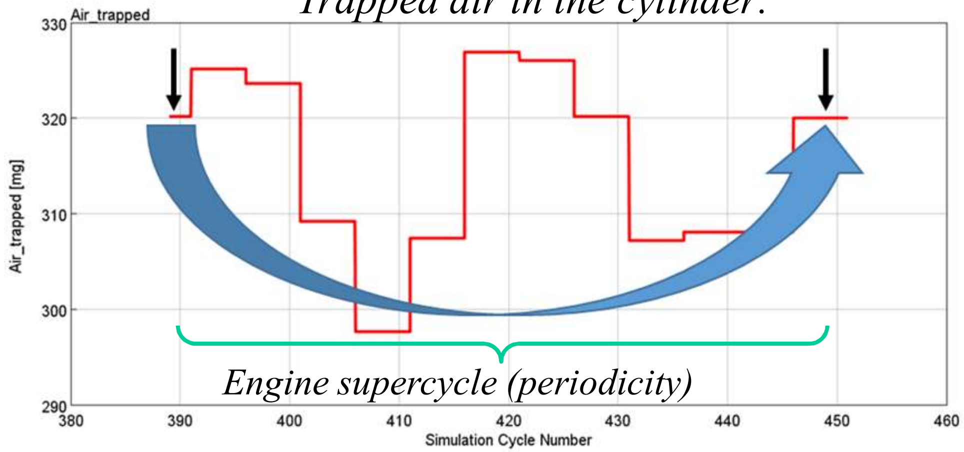
- Valve actuation – simple inputs
- Lambda control
- Results averaging
- Results from firing cycles
- Instantaneous plots viewing
- Numerical convergence

Supercycle calculation

	DCDA mode enabled	Periodicity (nr.)	Firing cycles (nr.)	CDA starts with	CDA cylinder content
Cylinder 1	1	5	2	1	2
Cylinder 2	0	2	1	0	2
…					



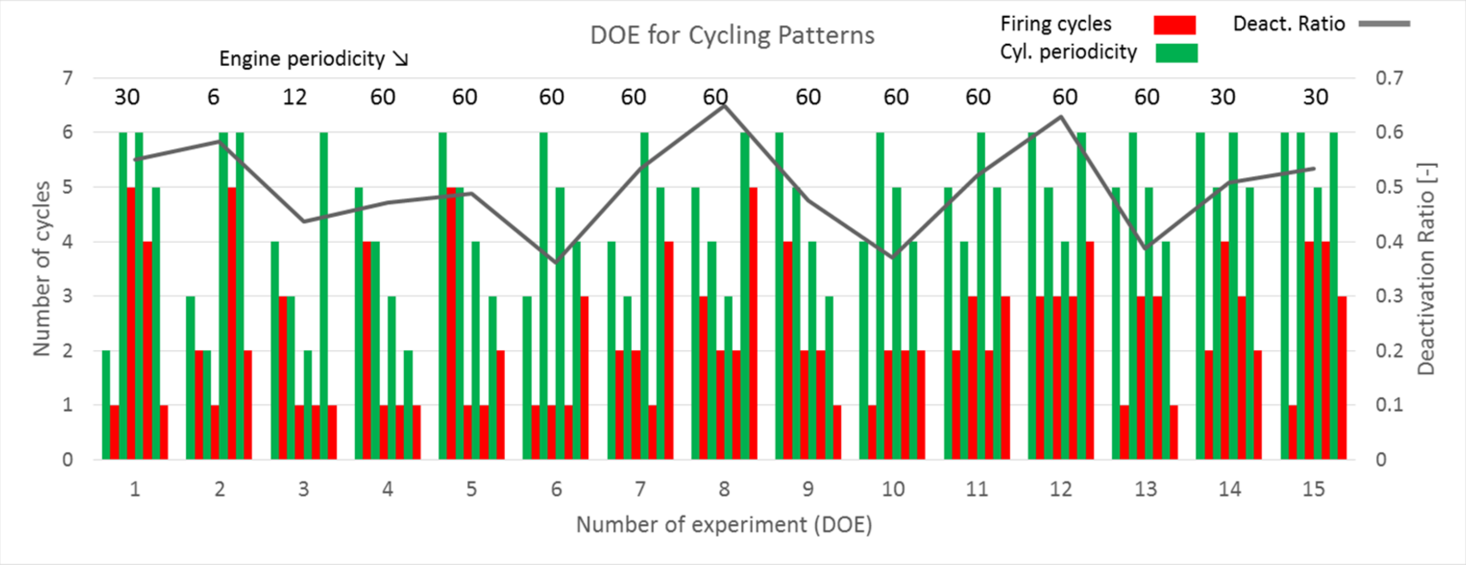
Trapped air in the cylinder:



Activities in 1-WP10 Advanced Control of ICE Gas Exchange Process

Preliminary Results – Case Study – DOE from Testing

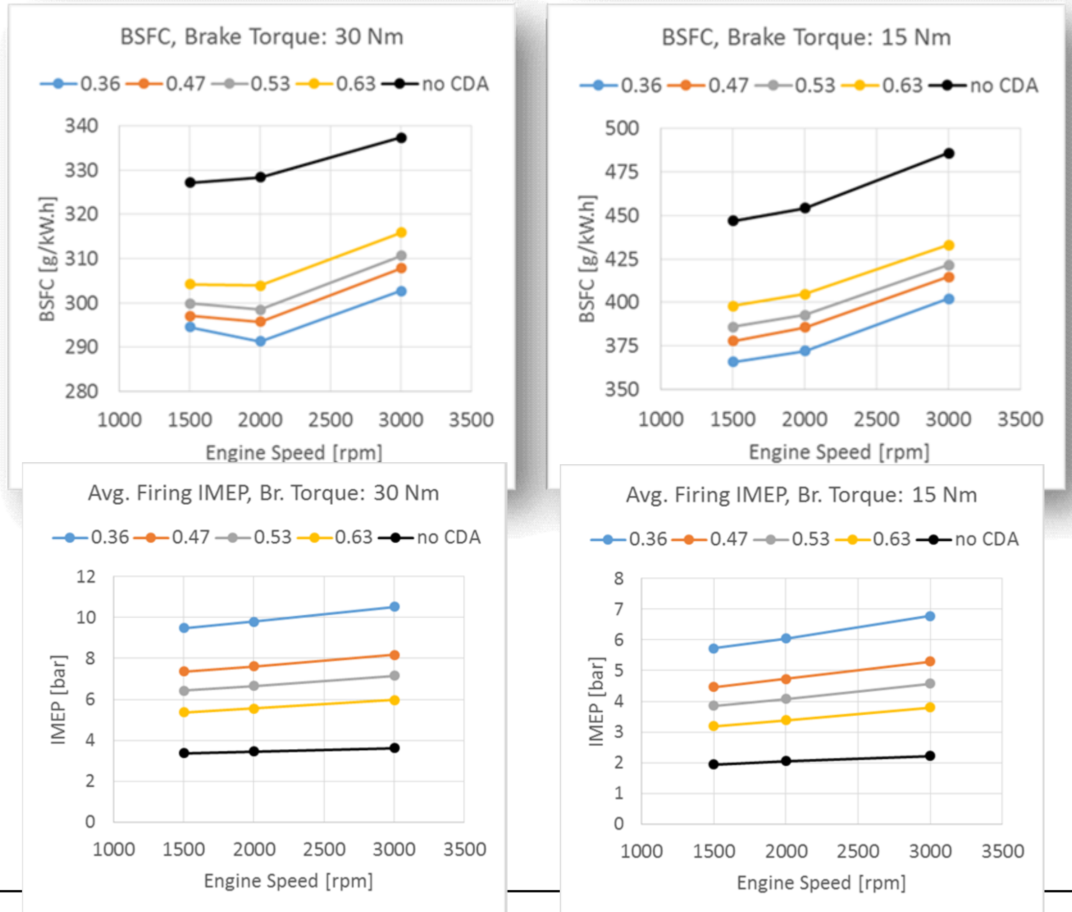
- SI turbocharged 4-cylinder 1.4 L engine – Fast Running Model
- Model testing – DOE of cycling patterns, engine load 15 and 30Nm, engine speed 1500, 2000, 3000 rpm
- DOE setting – DCDA mode inputs:
- Cylinder periodicity range: 2 ÷ 6 → engine periodicity up to 60



Activities in 1-WP10 Advanced Control of ICE Gas Exchange Process

Preliminary Results – Case Study – DOE from Testing

- Parameter in the plots: DEACTIVATION RATIO (utilization of engine displacement)
- BSFC reduction due to DCDA mode up to 20%



Fulfillment of goals and deliverables of 1-WP10 Advanced Control of ICE Gas Exchange Process

Current State of Deliverables, Milestones and Fulfillment of Goals

1-WP-10-001 (ZV) | Detailed thermodynamic model of dynamic cylinder deactivation with advanced valve train. | • R – software

- The software has been built and by the due date will be ready to reliably predict fuel efficiency of any engine layout

1-WP10-002 | Papers related to advanced valve train application. | • O - ostatní výsledky |

- Bolehovsky O., Vitek O. Dynamic Skipping of ICE Cycles - Advanced 1-D Simulation Model. 51th KoKa Conference. September 9th-10th, 2020 – CTU Prague, Czech Republic

List of Due Deliverables and Their Added Value

1-WP-10-001 (ZV) | Detailed thermodynamic model of dynamic cylinder deactivation with advanced valve train. | • R – software

- Such detailed model will enable to assess benefits of dynamic cylinder deactivation and bring deep insight into thermodynamic occurrences and control issues for any engine manufacturer or OEM

Current contribution of 1-WP10 Advanced Control of ICE Gas Exchange Process

Assessment of the Contribution of Deliverables

- The developed simulation model/tool (and mainly the methodology) is generally utilizable in all simulation of combustion engines, including all working packages dealing with combustion engines concepts
- The model/methodology and gained experience will be utilized in other projects at the university and the partner's commercial projects

Výtah z prací 2019-2020 na 1-WP10 Advanced Control of ICE Gas Exchange Process

2019: Definice deaktivačních cyklů, pokročilá aktuace ventilů umožňující různé formy výměny náplně válce a logiku deaktivačních cyklů, vývoj řídicího algoritmu modelu motoru

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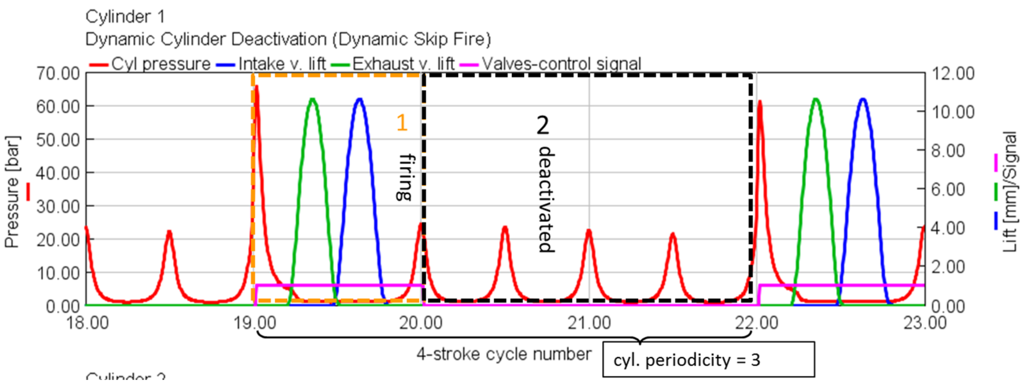
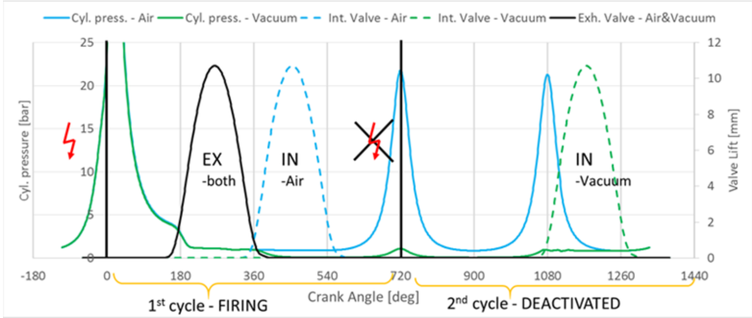
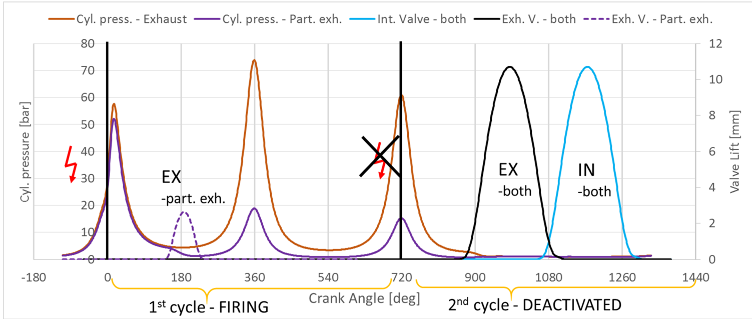


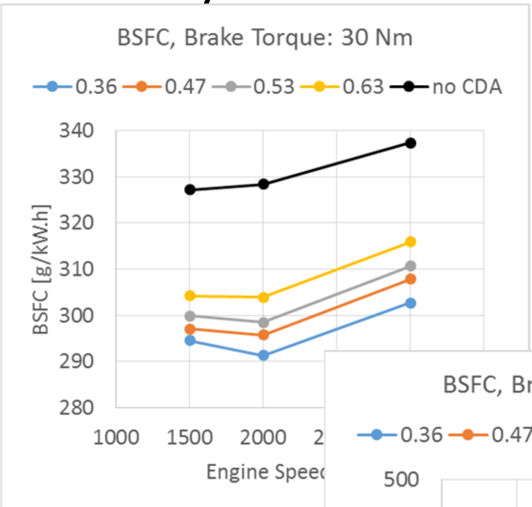


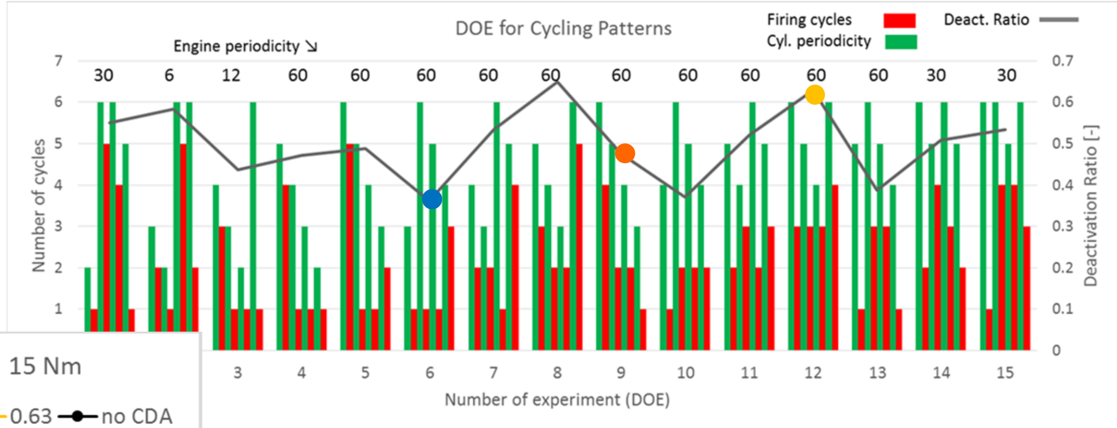


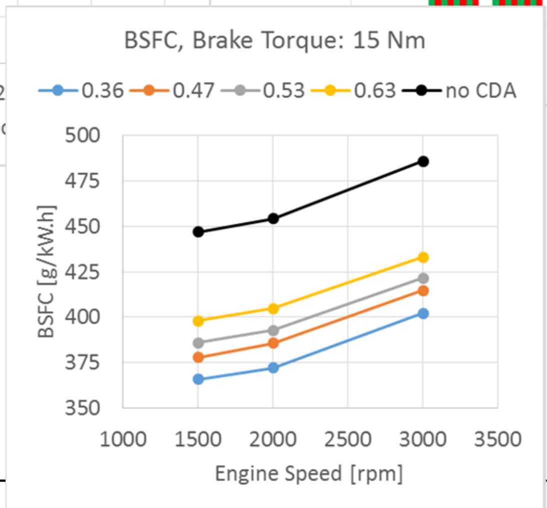
Cyl. periodicity	Nr. of firing cycles	Cylinder	Cycle Number										
			1	2	3	4	5	6	7	8	9	10	11
5	3	1	0	0	x	x	x	0	0	x	x	x	0
2	1	2	0	x	0	x	0	x	0	x	0	x	0
5	2	3	x	x	0	0	0	x	x	0	0	0	x
2	1	4	0	x	0	x	0	x	0	x	0	x	0
Engine periodicity:		**10**	Deactivation ratio:		**20**	**/40**							

Výtah z prací 2019-2020 na 1-WP10 Advanced Control of ICE Gas Exchange Process

2020: Detailní modulární 1-D model s pokročilou aktivací ventilů a řízením umožňující predikci úspory paliva (snížení produkce CO2) v libovolných ustálených režimech a libovolných deaktivačních cyklech







Results of 1-WP10 Advanced Control of ICE Gas Exchange Process –Achieved 2019-2020

2019: Definition of cycling patterns, advanced valve actuation enabling various gas exchange process and deact. patterns, development of control algorithm

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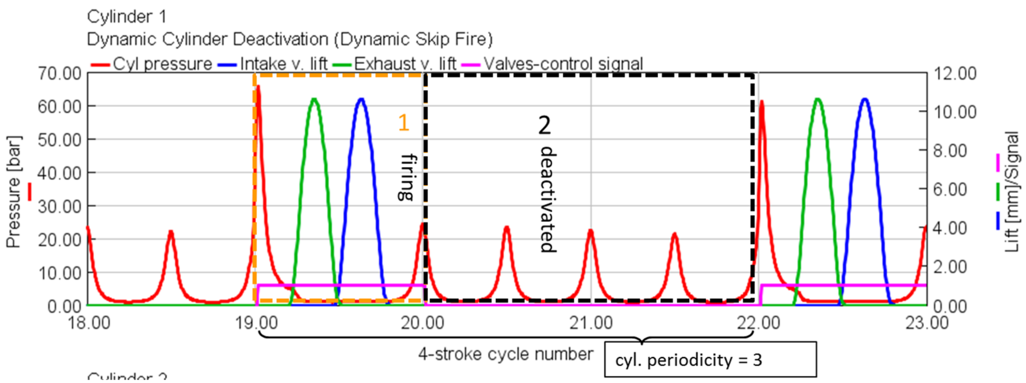

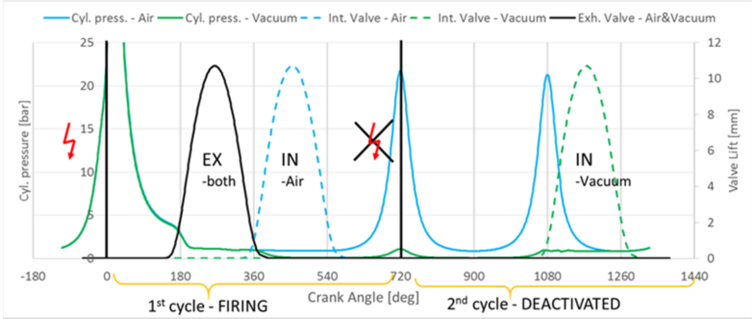

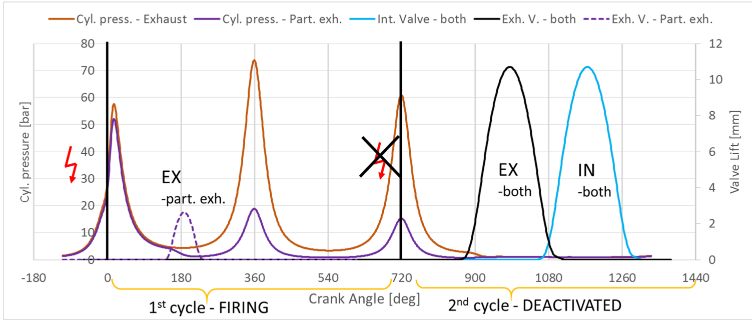

Cyl. periodicity	Nr. of firing cycles	Cylinder	Cycle Number										
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5	3	1	0	0	x	x	x	0	0	x	x	x	0
2	1	2	0	x	0	x	0	x	0	x	0	x	0
5	2	3	x	x	0	0	0	x	x	0	0	0	x
2	1	4	0	x	0	x	0	x	0	x	0	x	0
Engine periodicity:		**10**	Deactivation ratio:		**20**	**/40**							

Results of 1-WP10 Advanced Control of ICE Gas Exchange Process –Achieved 2019-2020

2020: A detailed and modular 1-D model enabling prediction of fuel saving (CO_2 production decrease) in different steady states and arbitrary selected cycling patterns