



GT Technical Conference 2022

3D-MBD simulation model of the DuoCam

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Agenda

- 1 Introduction
- 2 Simulation model of the DuoCam
- 3 Valvetrain features
- 4 DuoCam with valvetrain
- 5 Summary and next step

Introduction

Description

- An assembled camshaft that enables the timing of one set of cam lobes to be moved relative to a second set of lobes

Technical Benefits

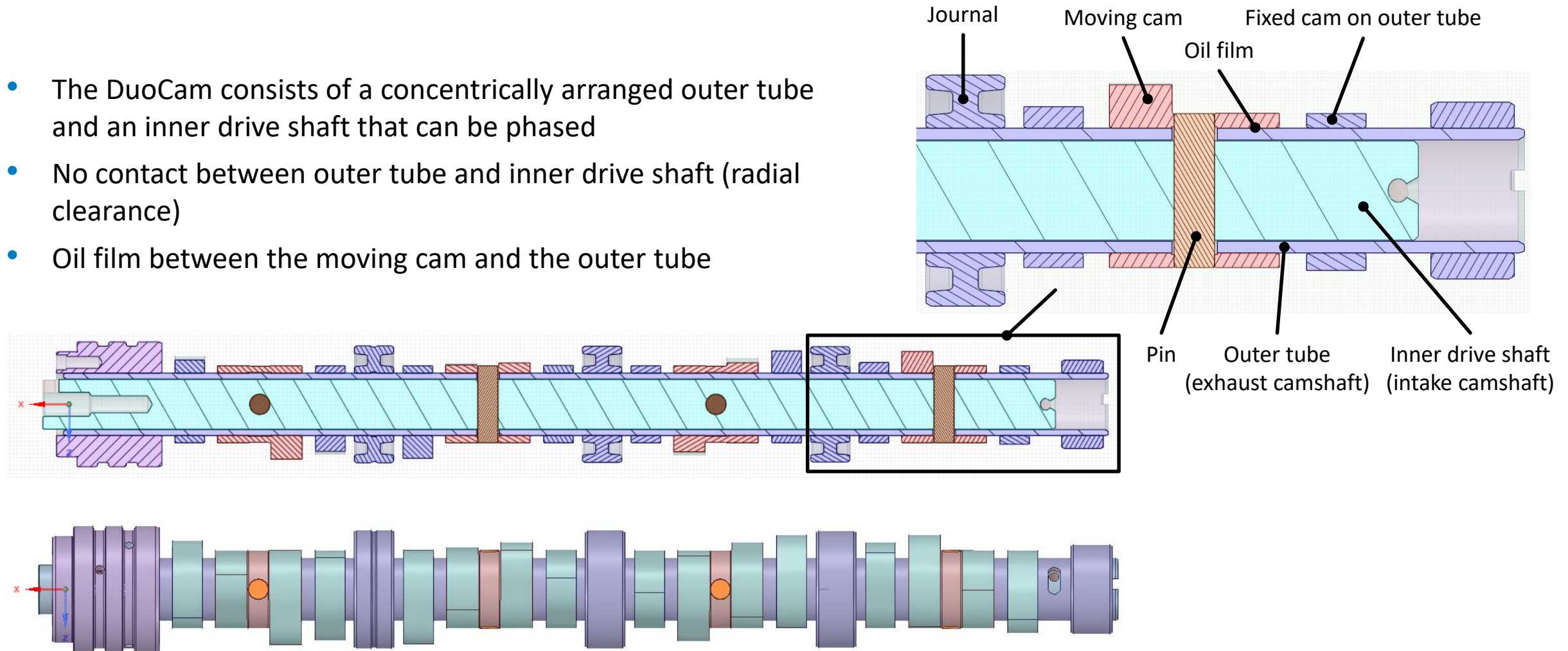
- Reduced NOx emissions - via Warm Up (EEVO) and Keep Warm (LIVC) strategies
- Reduced CO₂ emissions - for exhaust thermal management (compared to a fuel post injection strategy)
- Miller cycle - retarding the cam lobe for just one intake valve of a cylinder pair to give effective variable duration
- Improved fuel economy



EVVO: Early Exhaust Valve Opening, LIVC: Late Intake Valve Closing

Introduction

- The DuoCam consists of a concentrically arranged outer tube and an inner drive shaft that can be phased
- No contact between outer tube and inner drive shaft (radial clearance)
- Oil film between the moving cam and the outer tube



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Simulation model of the DuoCam

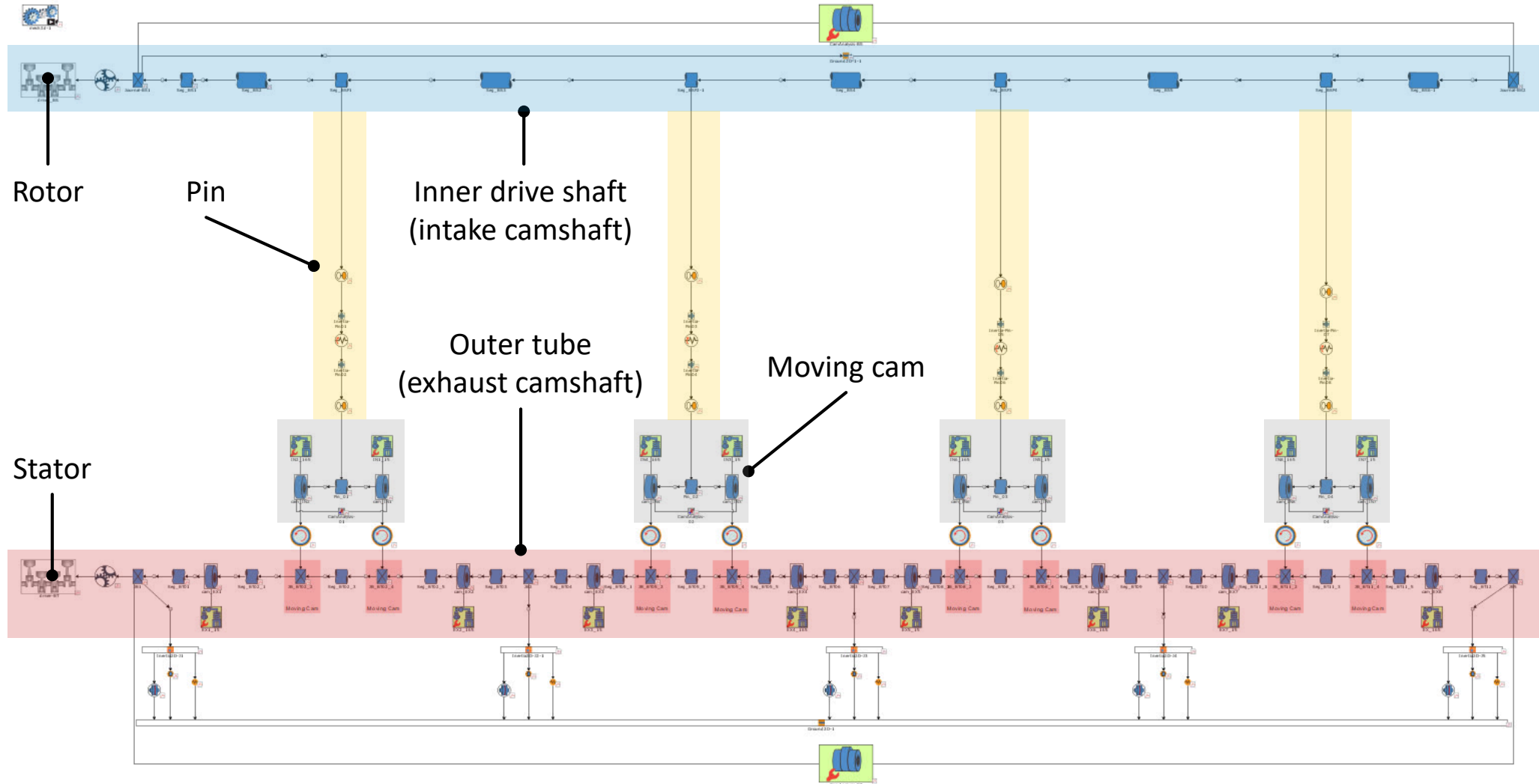
Target...

- Assembly of the DuoCam for an 8-cylinder gasoline engine as a 3D multi-body simulation model in GT-SUITE
- Robust simulation behavior
- Multi-body dynamic simulation with elastic components for dynamic drag torque investigation
- Combine whole valvetrain model with a virtual combustion engine (future task)

...and further procedure

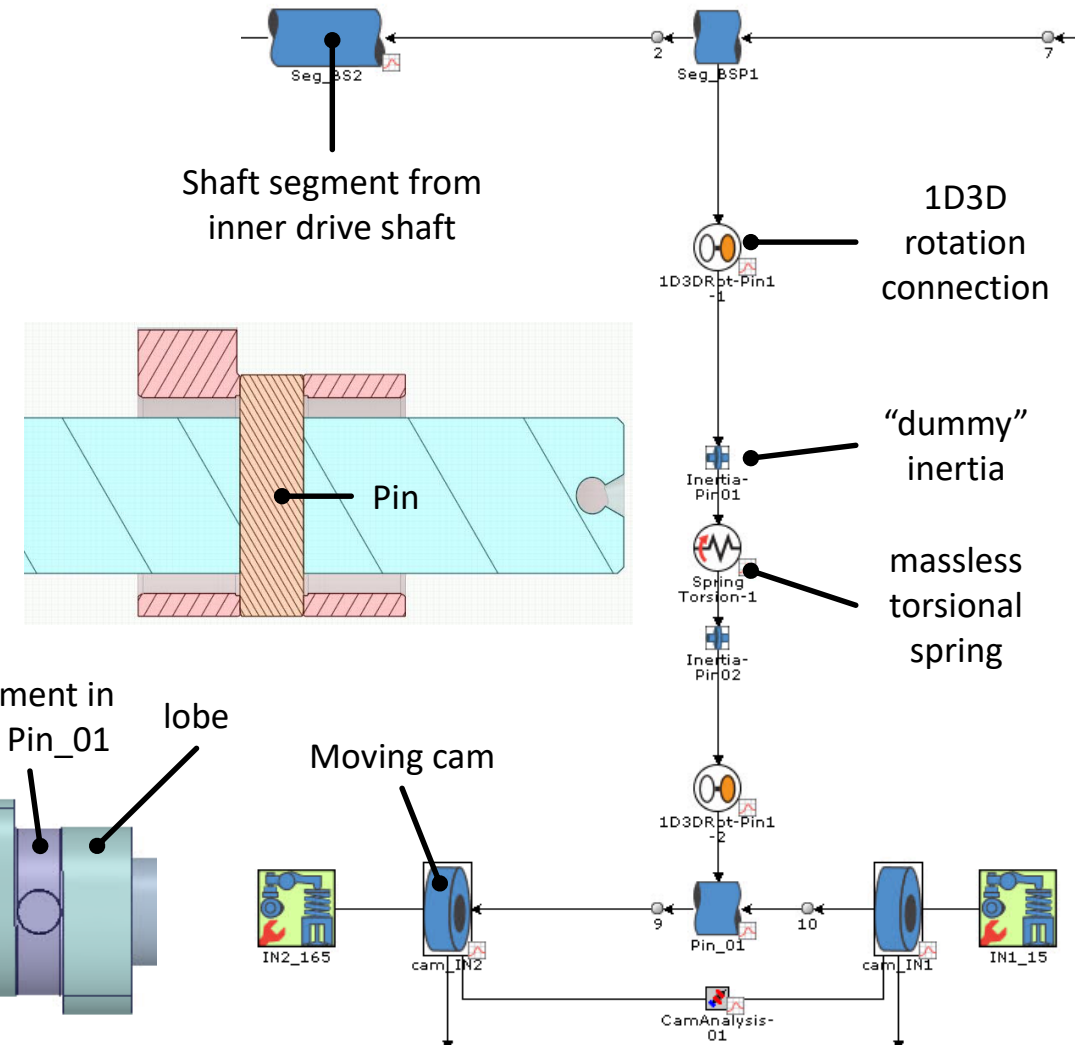
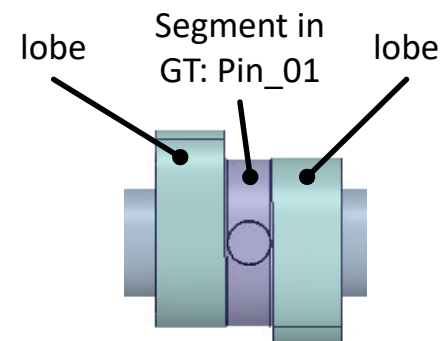
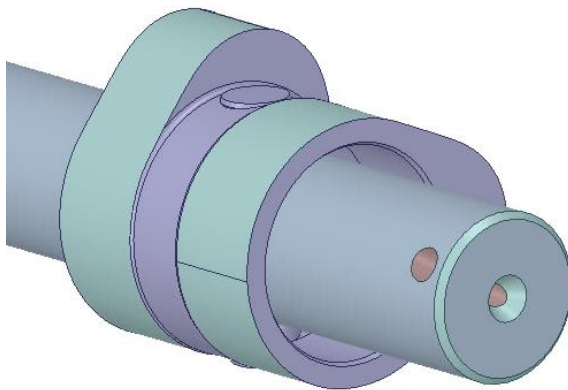
- FEA with an ANSYS software tool to determine the torsional and bending stiffness of the DuoCam
- Integration of a cylinder deactivation mechanism into the used valvetrain to investigate different firing sequences

GT-SUITE model of the DuoCam



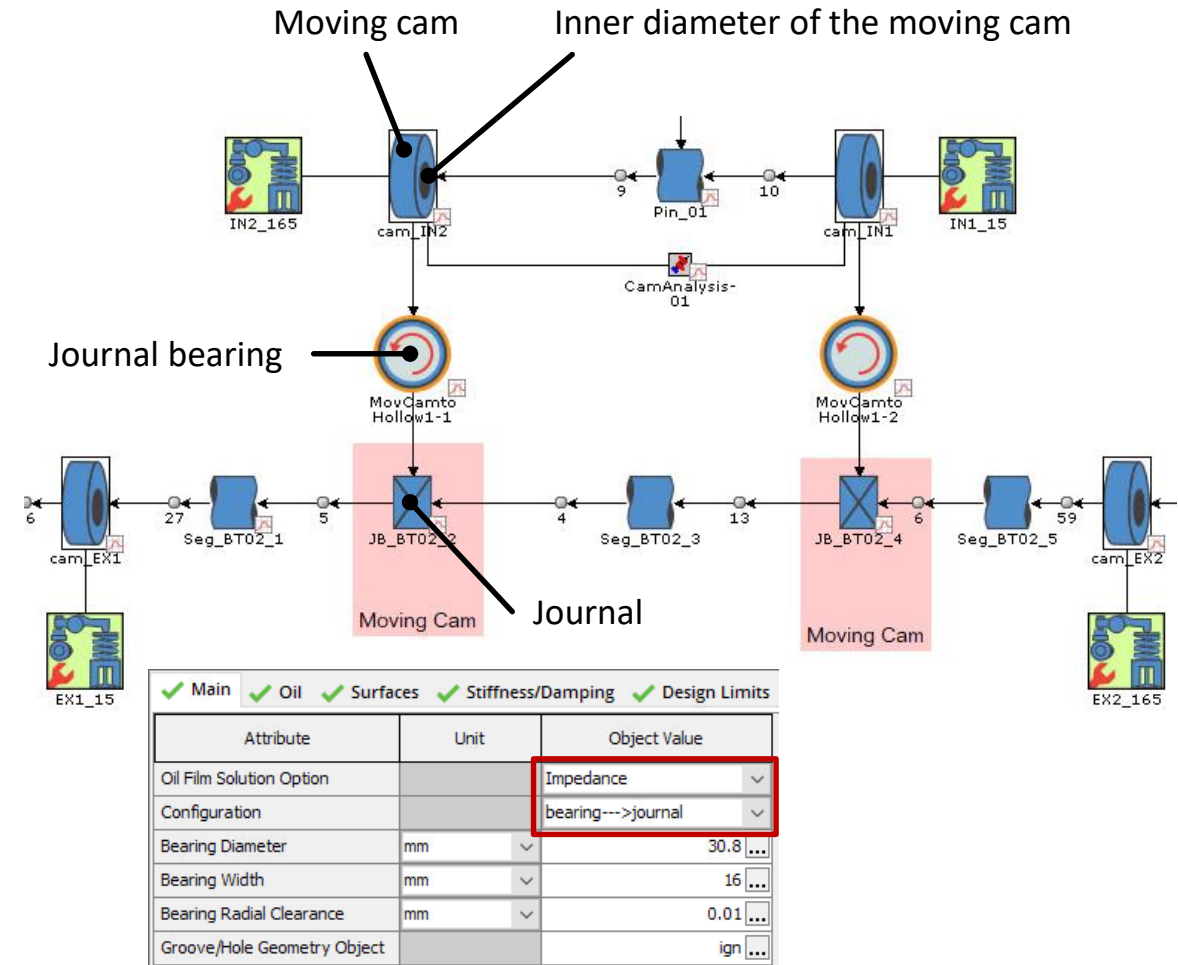
Moving cam modelling with connection to inner drive shaft

- 1D3DRot connection between shaft segment and inertia.
This template enforces zero relative rotational displacement between a 1-D rotational part and the z-rotation of 3D parts
- “Dummy” inertia template with a low value to enable connection between templates
- The torsional spring transfers the power from the inner drive shaft to the moving cam with a very high torsional stiffness



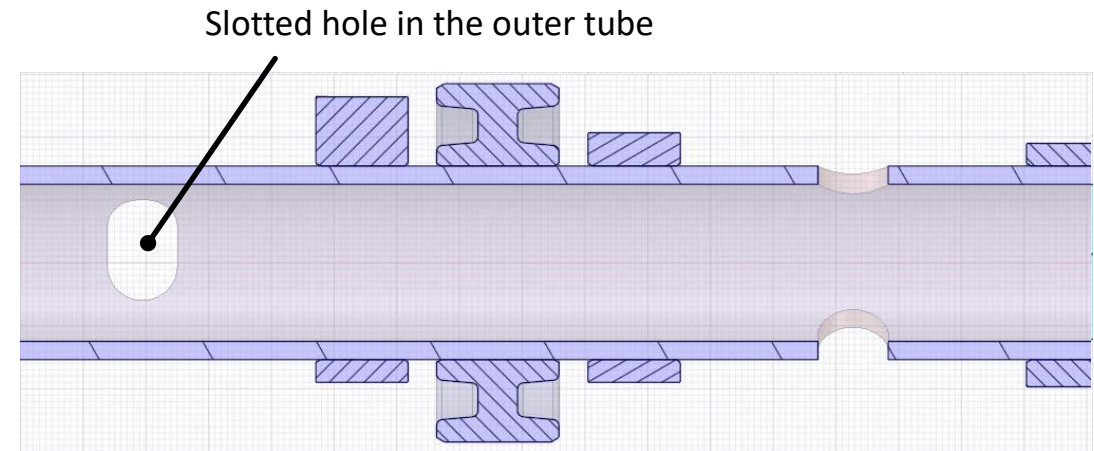
Connection between moving cam and outer tube

- A patch from *Gamma Technologies* in V2021 enables the connection between the inner diameter of the moving cam to the outer tube
- A journal bearing is used to transfer the forces
 - Materials for the journal/bearing surface and the journal surface roughness were integrated
 - Additional friction force is transferred over the oil film
- Due to the use of a journal bearing the shaft segment of the outer tube is replaced with a journal
 - Oil film option is set to “impedance”
 - Right configuration consideration: bearing to journal!



Structural mechanical properties

- GT-SUITE calculates structural mechanical properties for the parts of the camshaft for a common geometry
 - Due to the arrangement of two concentric shafts, the geometry of the DuoCam deviates from a standard camshaft
 - The hole in the inner drive shaft and the slotted holes in the outer tube result in lower stiffness for the camshaft
 - FEA with an ANSYS software tool to calculate the **torsional and bending stiffness** of the DuoCam more accurately
 - This data is then transferred to the GT-SUITE model
 - Data input to the GT-SUITE template
 - Input for torsional stiffness available
 - NO** direct input for bending stiffness available
- ➔ Find a **workaround**: Excel sheet **BeamPropData.xlsx**

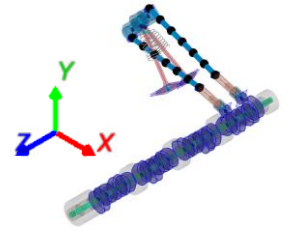


✓ Kinematic Geometry ✓ Common Geometry ✓ Properties ✓ Beam Properties		
Attribute	Unit	Object Value
Mass	g	def...
Moment of Inertia	kg-mm ²	def...
Material Property Object		Steel cam...
Torsional Stiffness	N-m/deg	...
Torsional Damping Coefficient	N-m-s/rad	def...
Structural Damping (Forced Freq. Analysis only)		ign...
Inertia Merging		NoMerging

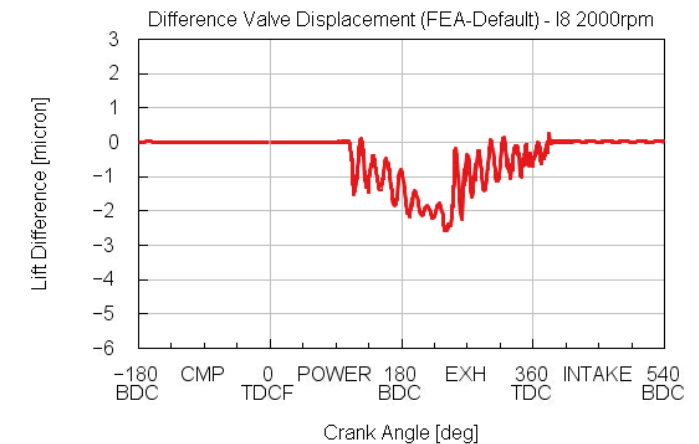
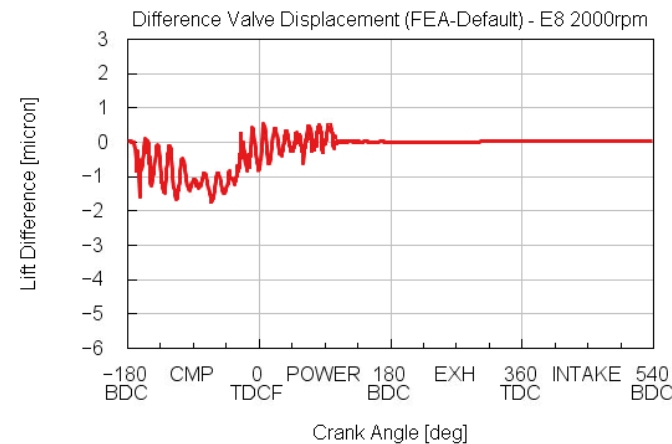
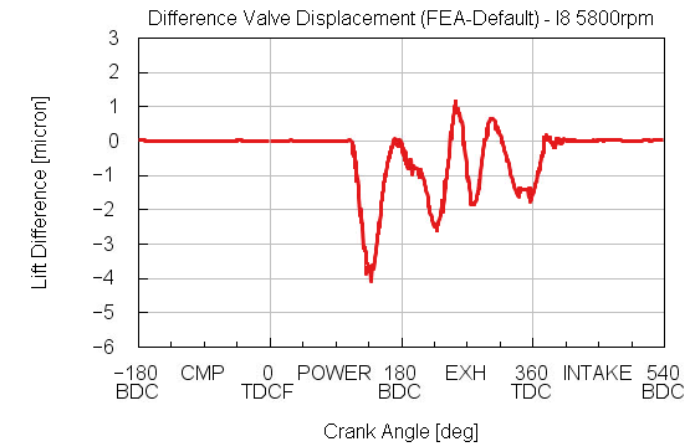
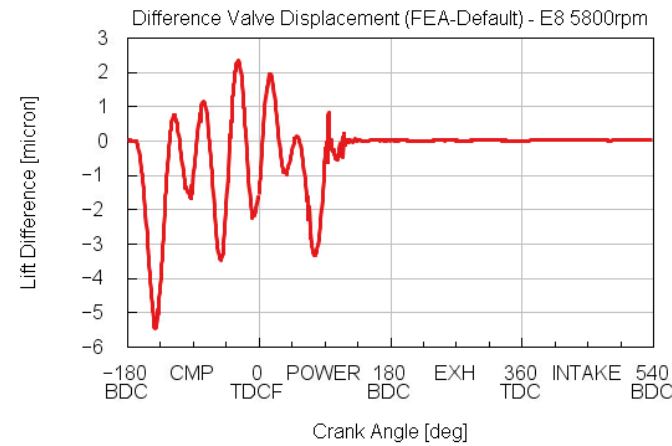
✓ Kinematic Geometry ✓ Common Geometry ✓ Properties ✓ Beam Properties		
Attribute	Unit	Object Value
Torsional Stiffness (GJz)	N-m ²	def...
Bending Stiffness (EIx)	N-m ²	def...
Bending Stiffness (EIy)	N-m ²	def...
Beam Element Type		quadratic
		linear
		quadratic
		cubic
		...

NO direct input for the bending stiffness!

Verification of the DuoCam model – result for one cylinder application



- Comparison to the default GT-SUITE calculation method
- One cylinder application (cylinder 8 w/ I8 & E8)
- Differences in the stiffness's calculated by
 - the FEA values from ANSYS tool and
 - the default GT-SUITE procedure
- Lift loss of FEA variant in comparison to the default calculation variant
- The lower bending stiffness of the FEA variant becomes visible
 - E8 @ 5800rpm: max. 5.5 microns
 - I8 @ 5800rpm: max. 4 microns
 - E8 @ 2000rpm: max. 1.8 microns
 - I8 @ 2000rpm: max. 2.5 microns



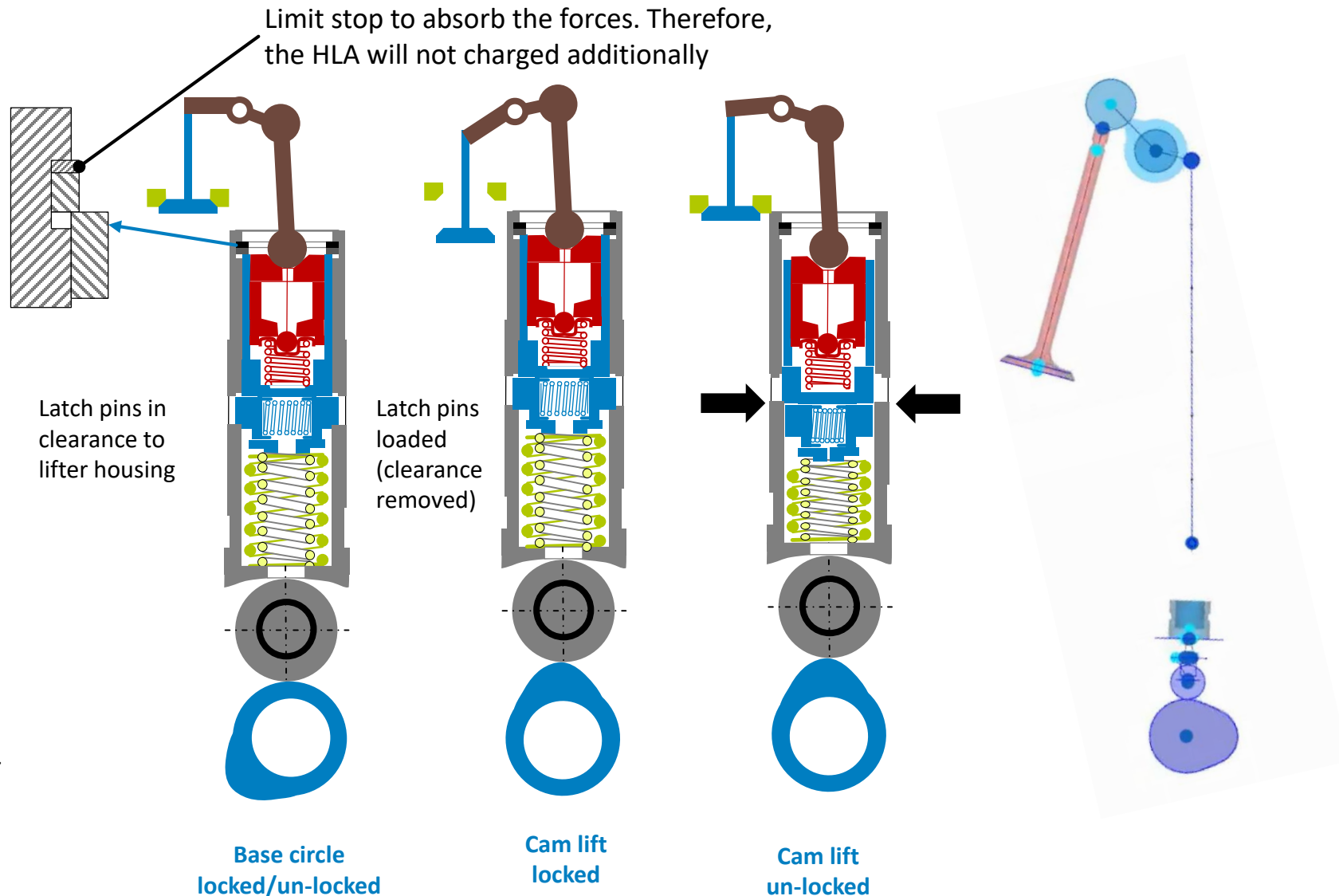
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Cylinder deactivation

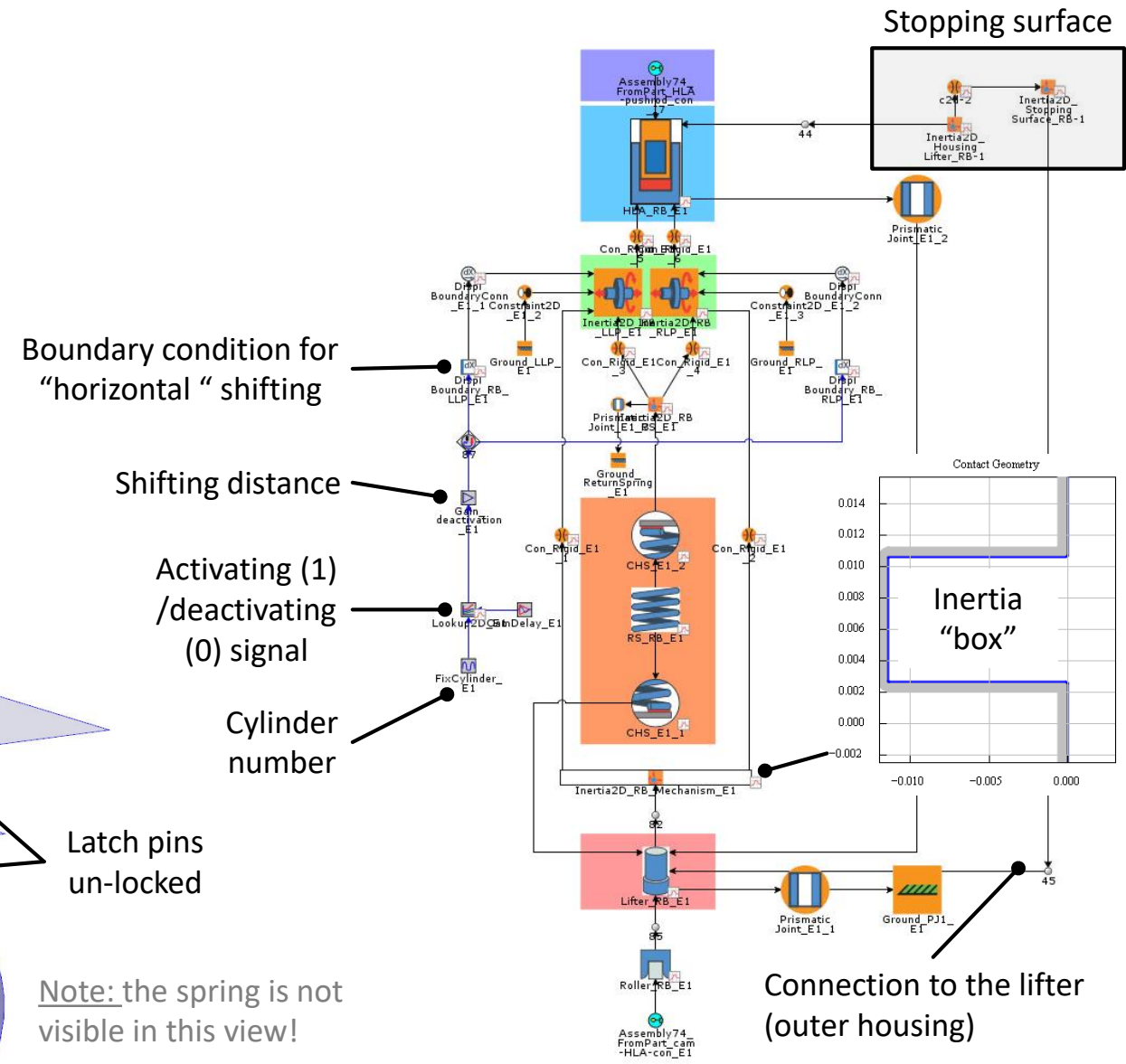
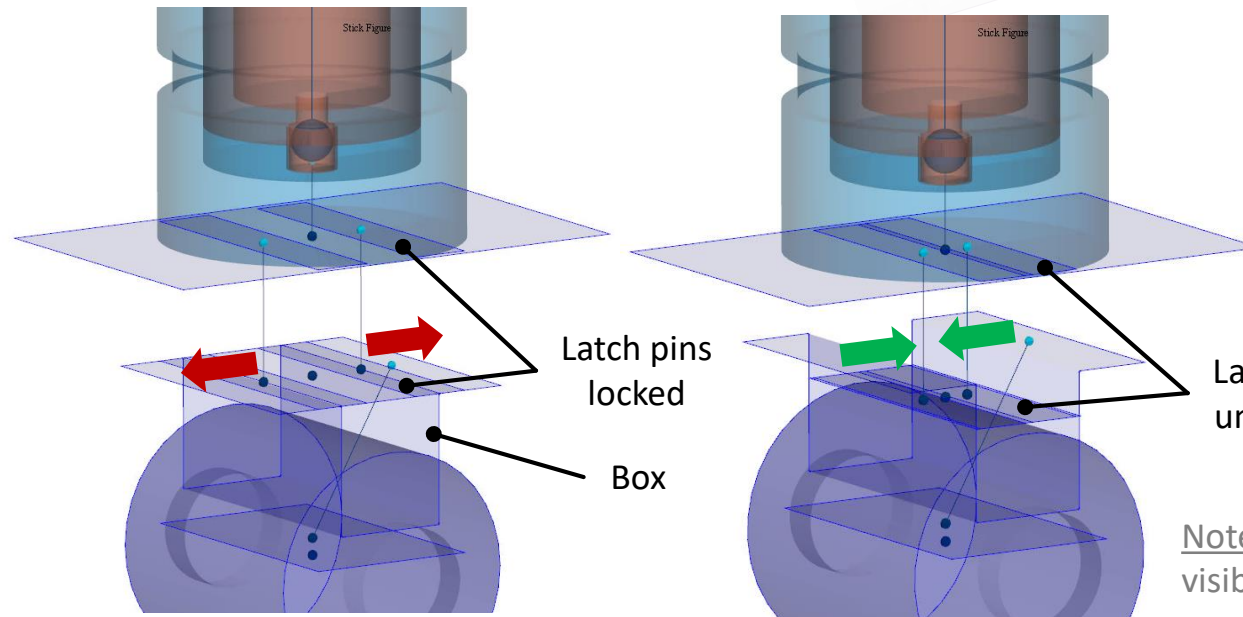
Introduction

- The cylinder deactivating mechanism is part of the HLA
- The HLA body includes the latch pins which activate or deactivate the mechanism
- To understand the working of the mechanism three different positions regarding the cam lobe are defined
 - Base circle: locked/un-locked
 - Cam lift in maximum position w/ locked modus
 - Cam lift in maximum position w/ un-locked modus



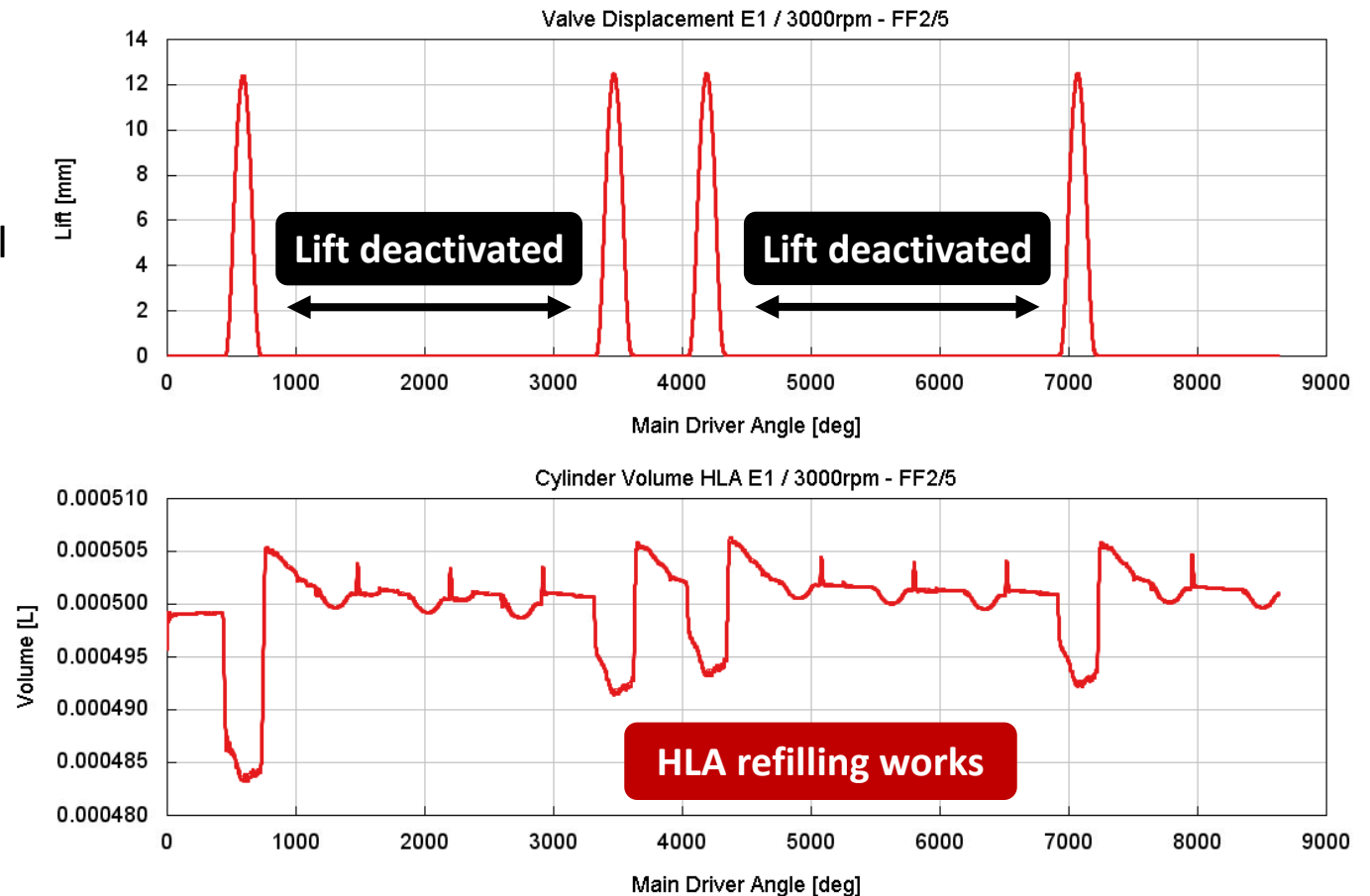
Cylinder deactivation – sub-model

- The latch pins are the central element in the mechanism, which can be moved inwards and outwards
- When moving inwards, they can plunge into the “box” and the spring will be compressed



Cylinder deactivation – results

- The results show that the cylinder deactivating mechanism is working fine
 - A wide variety of valve deactivation scenarios and different rotational speeds were carried out
 - The balance of forces at the HLA works very well
 - This can also be seen from the fact that the chamber in the HLA is repeatedly refilled with oil if it's necessary
 - No lift loss over the different cycles
- ➔ Overall, it could be shown that the mechanism works very robustly



Firing fraction control – selection in case setup

- Firing fraction integrated
- Selection in case setup via dropdown menu in super parameter
- Super parameter includes fraction table and cycle number
- Automated cycle number selection in run setup
- Additional neutral and full mode
- First cycle must be neutral, since initialization in GT
- Direct firing fraction data integration from Excel to GT

Firing Fraction - 3/4

Cylinder	1	8	4	3	6	5	7	2	
1	0	0	0	0	0	0	0	0	
2	1	1	1	0	1	1	1	0	First Full Cycle
3	1	1	1	0	1	1	1	0	Second Full Cycle
4	1	1	1	0	1	1	1	0	Third Full Cycle
5	0	0	0	0	0	0	0	0	
6	0	1	1	1	0	1	1	1	First Full Cycle
7	0	1	1	1	0	1	1	1	Second Full Cycle
8	0	1	1	1	0	1	1	1	Third Full Cycle
9	0	0	0	0	0	0	0	0	
10	1	0	1	1	1	0	1	1	First Full Cycle
11	1	0	1	1	1	0	1	1	Second Full Cycle
12	1	0	1	1	1	0	1	1	Third Full Cycle
13	0	0	0	0	0	0	0	0	
14	1	1	0	1	1	1	0	1	First Full Cycle
15	1	1	0	1	1	1	0	1	Second Full Cycle
16	1	1	0	1	1	1	0	1	Third Full Cycle

Excel sheet firing fraction

Simple copy + paste

Run Settings

Attribute	Unit	Object Value
Time Control Flag		periodic
☒ Maximum Simulation Duration (Cycles)		[Cycles] ...
☐ Maximum Simulation Duration (Time)	s	2
Automatic Shut-Off When Steady-State		off

Output Info
Number of Cases ON: 15
☒ Store Case RLT: ON
☐ Store Time RLT: OFF

Cancel < Back Next > Finish

Main Mysuper Design of Experiments All

Parameter	Unit	Description	Case 1
Case On/Off		Check Box to Turn Case On	☒
Case Label		Unique Text for Plot Legends	3000rpm / FiringFraction_3/4
CSDMODE		Camshaft Analysis Option	Bending
RotSpeed	RPM	Engine Speed	3000
Mysuper			FiringFraction_3/4

Main Mysuper Design of Experiments All

Parameter	Unit	Description	Option #1
Option Values			FiringFraction_3/4 ...
Firing_Fraction		Firing Fraction Mode	GreenFiringFraction3_4 ...
Cycles		Maximum Simulation Duration (Cycles)	17 ...

Firing fraction table

Attribute	Unit	Object Value
Exploit Data Specified Below		
☒ 3D Data Specified From External File		
☐ X Data Array Reference Object or File		
☐ Y Data Array Reference Object or File		
☐ Z Data Matrix Reference Object or File		

Z Data	Y Data #	1	2	3	4	5	6	7	8
1	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	2.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	3.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
4	4.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
5	5.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0
6	6.0	0.0	1.0	0.0	0.0	1.0	0.0	0.0	0.0
7	7.0	0.0	1.0	0.0	0.0	1.0	0.0	0.0	0.0
8	8.0	0.0	1.0	0.0	0.0	1.0	0.0	0.0	0.0
9	9.0	0.0	0.0	1.0	0.0	0.0	1.0	0.0	0.0
10	10.0	0.0	0.0	1.0	0.0	0.0	1.0	0.0	0.0
11	11.0	0.0	0.0	1.0	0.0	0.0	1.0	0.0	0.0
12	12.0	0.0	1.0	0.0	0.0	0.0	0.0	1.0	0.0
13	13.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
14	14.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
15	15.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
16	16.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
17	17.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

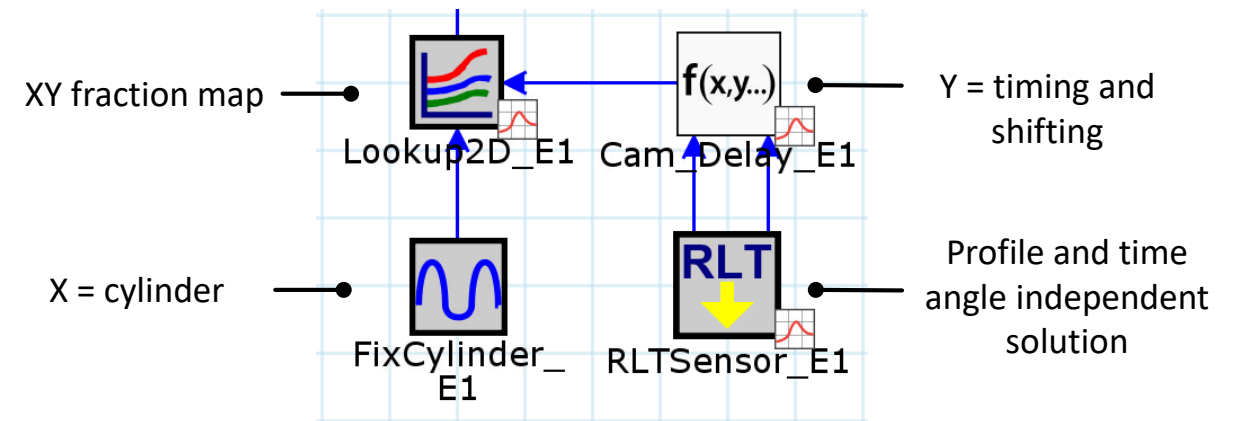
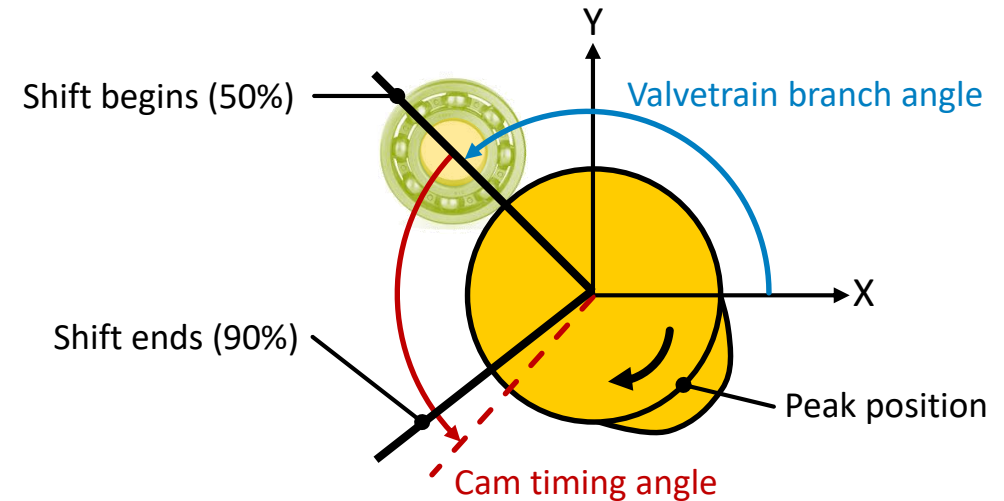
OK Cancel Apply

Firing fraction control – shifting duration and timing

- The shifting of the pins can only be done in the base circle
- To ensure the stability of the mechanism, the displacement of the pins starts 180° after the peak and ends before the profile rises

➡ Shifting time from 50% to 90% of base circle duration

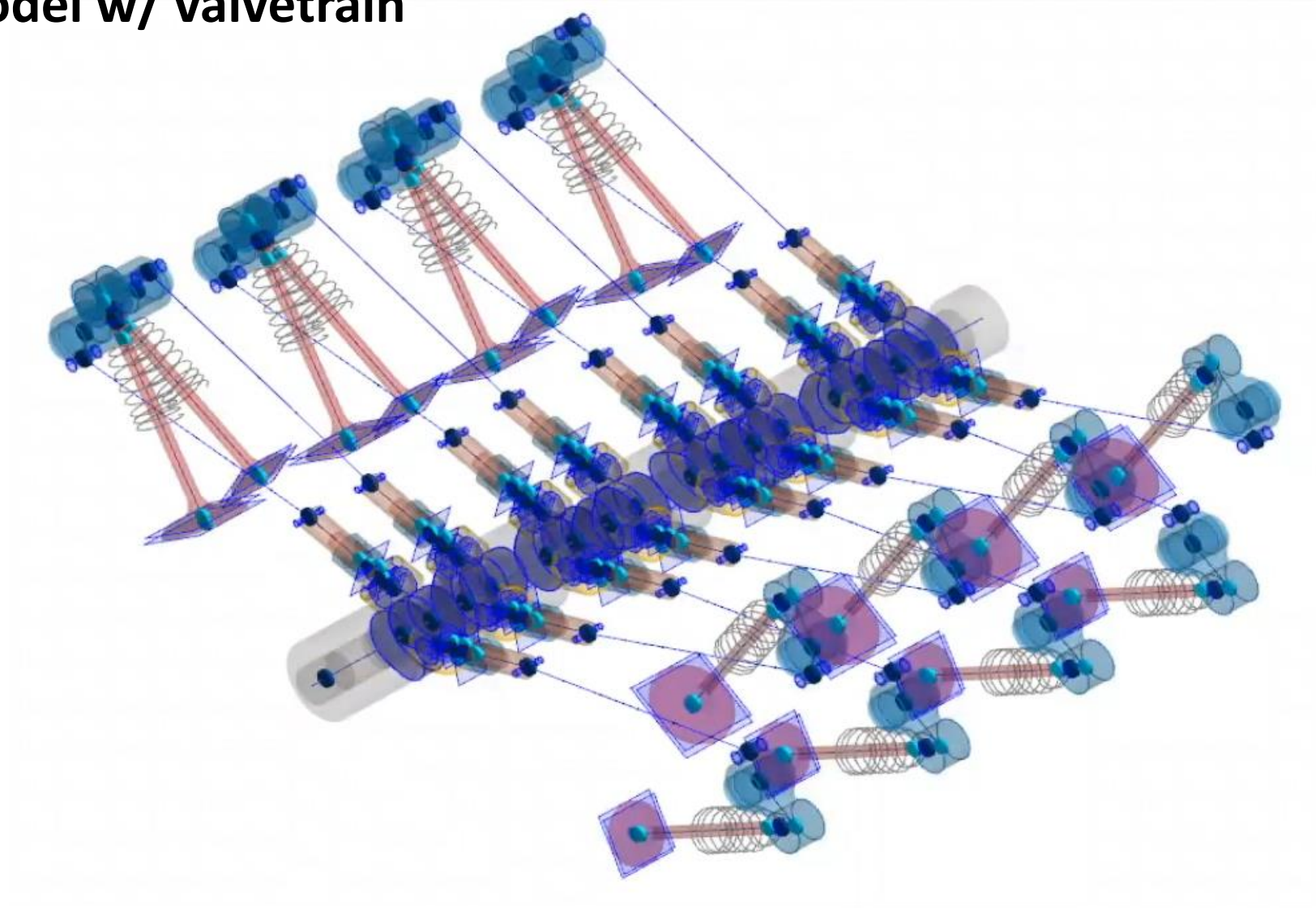
- Firing fraction XY map in Lookup2D integrated
- Cam profile and time angle independent solution realized with “RLTSensor” and Math Equation
- “RLTSensor” measures:
 - Total cam lobe angle
 - Relative max. radius cam angle



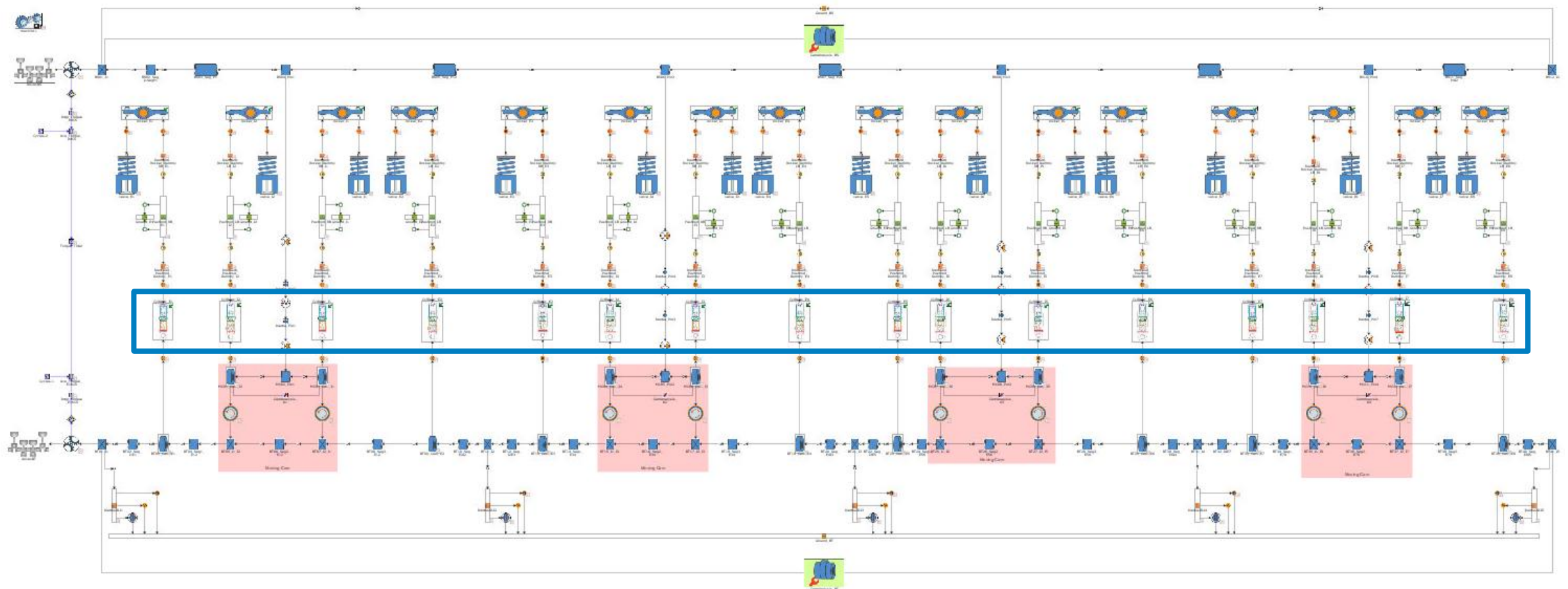
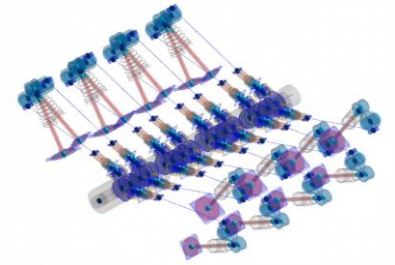
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Final DuoCam model w/ valvetrain

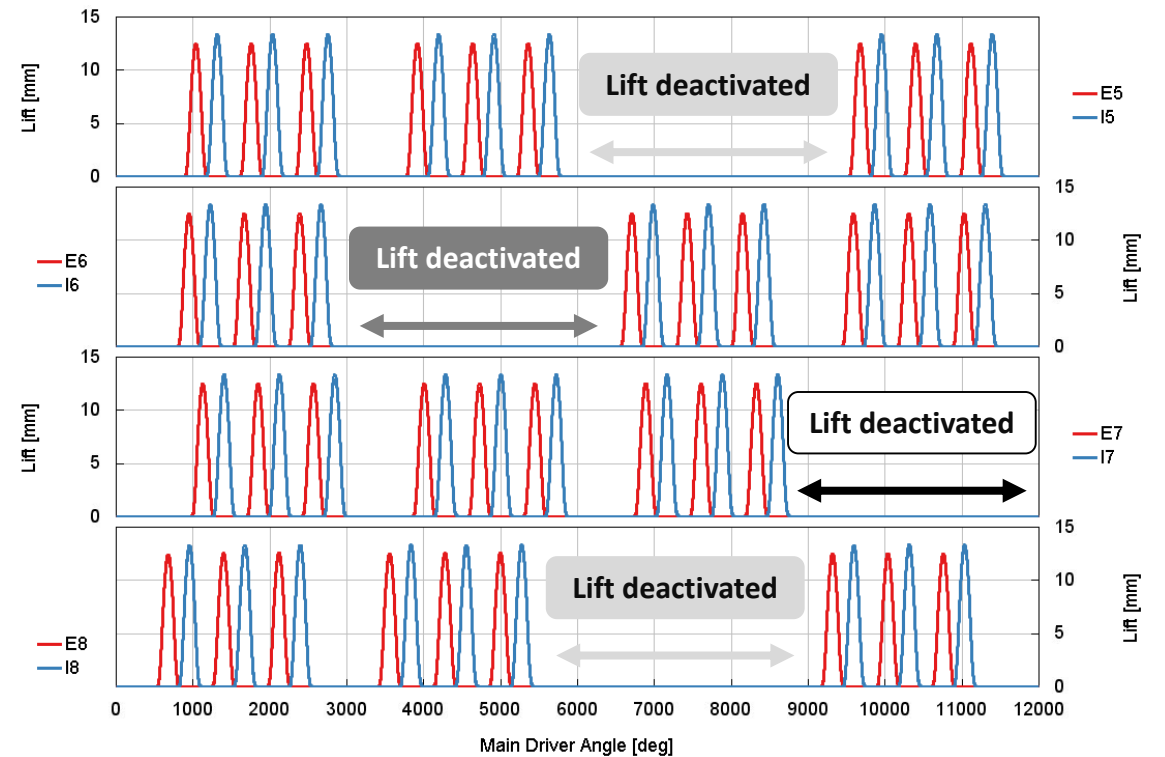
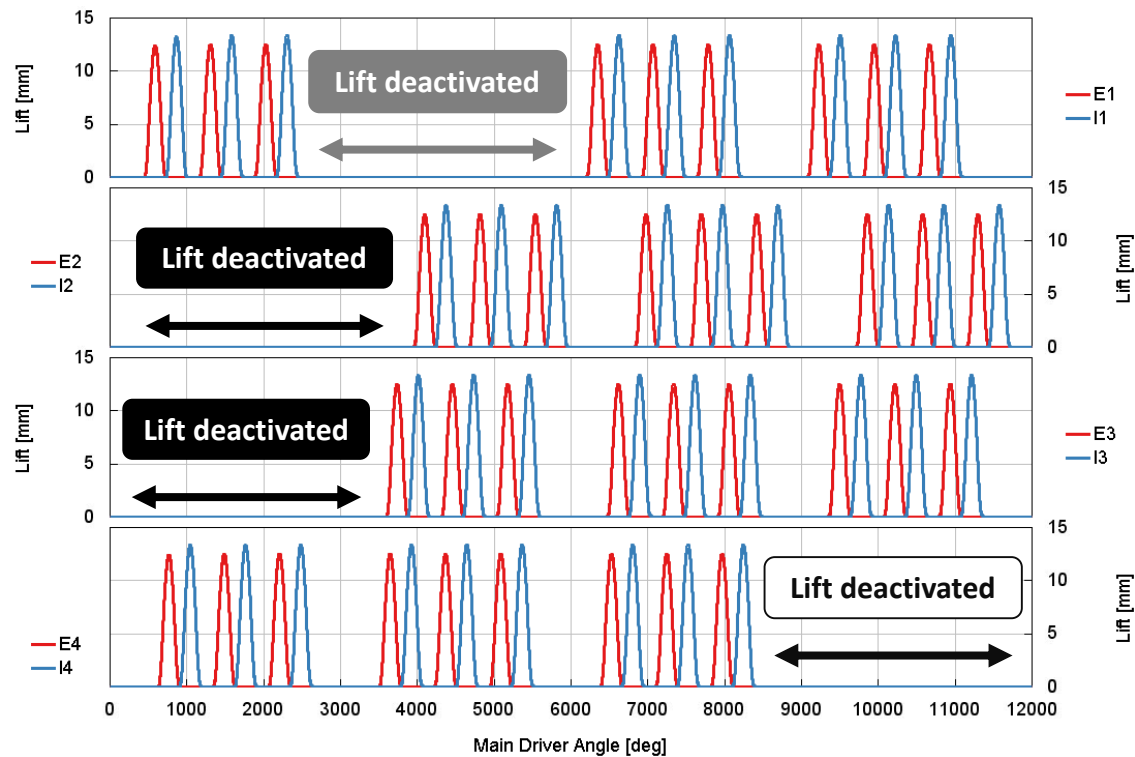


Final DuoCam model w/ valvetrain



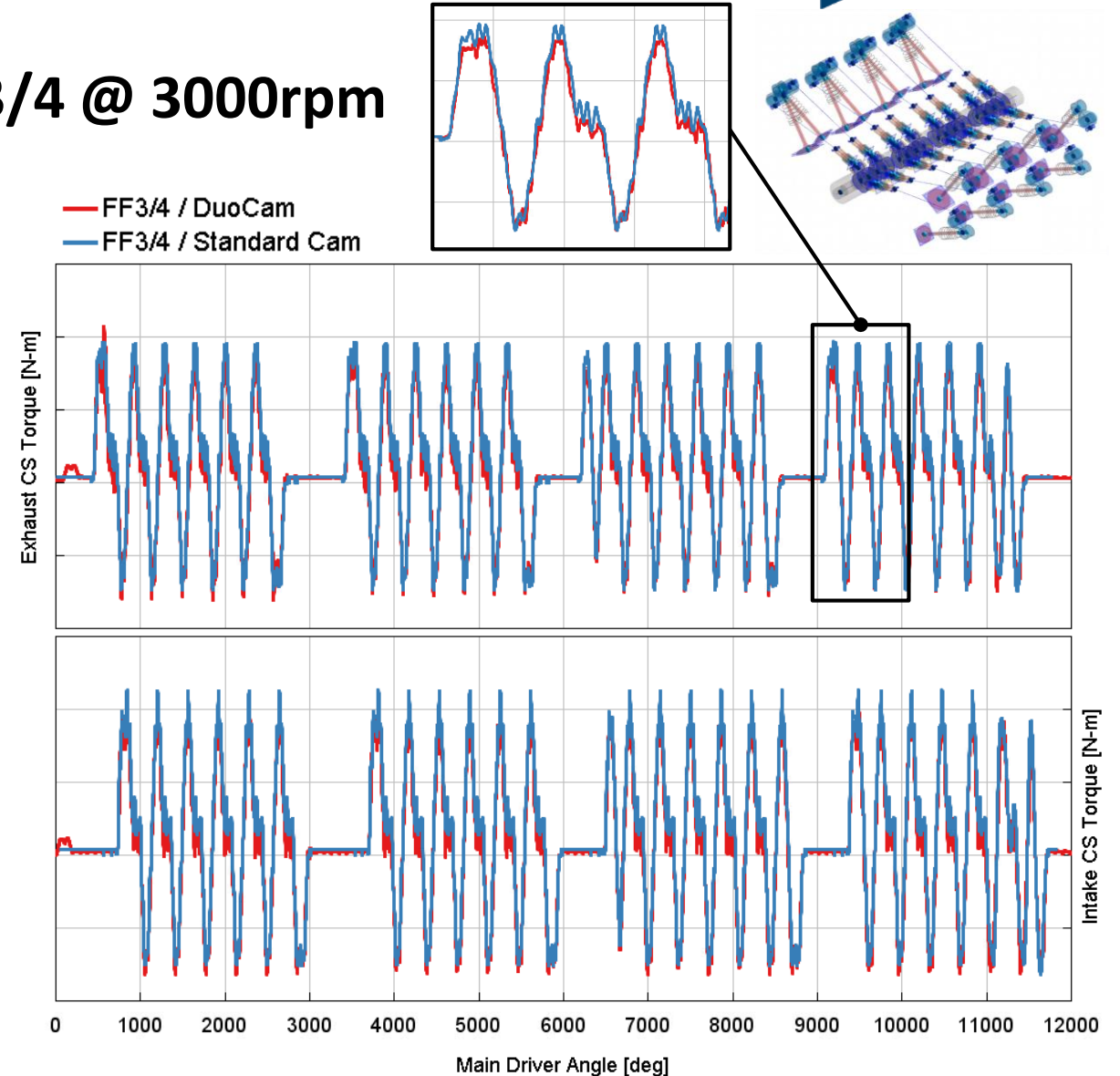
Results – valve displacement for firing fraction 3/4 @ 3000rpm

- Valve displacement for all cylinders



Results – drag torque for firing fraction 3/4 @ 3000rpm

- Shaft drag torque for the DuoCam in comparison w/ data for the standard camshaft
 - Both camshaft variants w/ same valvetrain
 - Identical lobe contour at both variants
 - Characteristic for the standard camshaft from validated model w/ test rig data
- ➔ Very good agreement in the frequency characteristics
- ➔ Deviation results from the different stiffness's of the two camshafts



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Summary and next step

Summary

- Successful model build up of the DuoCam - (supported by Gamma Technologies)
- Integrated Features
 - Torsional and bending stiffness from structural analysis (ANSYS)
 - Robust solution for cylinder deactivation mechanism was found
 - Modifiable firing fraction control
- The simulation model provides the right drag torque signature to the camshaft for the different firing orders.

Next step

- Check of the torque characteristic of the DuoCam with data from the test rig

Thanks for the support to

- **Marcel Schmädicke,** Gamma Technologies
- **Pete Nguyen,** formerly Gamma Technologies

- **Jonathan Aspinall,** formerly Mechadyne (Rheinmetall / Sensors and Actuators)
- **Ian Methley,** formerly Mechadyne (Rheinmetall / Sensors and Actuators)
- **Haitham Korkis,** Rheinmetall / Sensors and Actuators

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