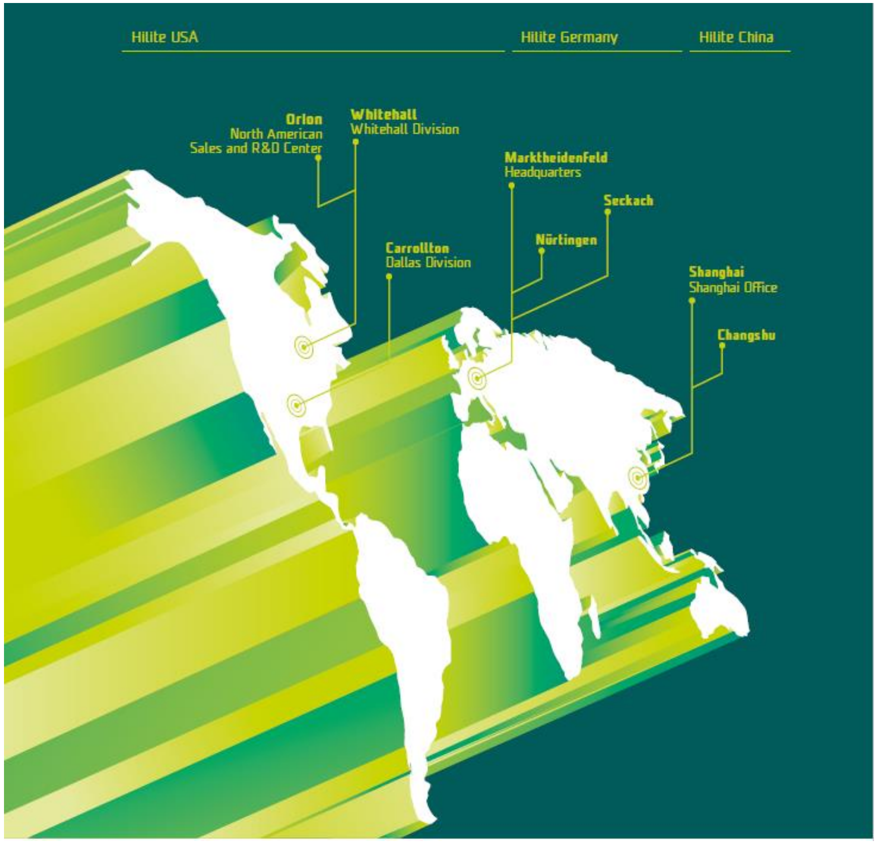
Robust Design:
CAE Driven Design Development

Dr. Oleksiy Kurenkov

Contents

Company Profile



- global supplier for the automotive industry
- focus on engine components
- 1600 employees
- 8 locations in Europe, North America and Asia

Product Portfolio

HILITE INTERNATIONAL

Engine Applications
(Cam Phasers)

Transmission Applications
(Valves)

Quo vadis, simulation world?

HILITE INTERNATIONAL

- Ansys "Digital Twin" (simulation describes the current status of running parts using real-time sensor data)
- More and more complex multiphysics (example: ultrasonic sensor simulation: electric->structural->acoustics)
- Increasing part of system simulation and coupled simulations (1D->3D)
- **CAE + optimization tools = Design optimization & Sensitivity & robustness analyses**

When we need design optimization

- Every product development process is an iterative design optimization process
- Optimization tools improves design faster and better then simple „what-if“ studies
- Numerical optimization is the next logical evolutional step in virtual prototyping
- Numerical optimization does not replace engineers -> it gives them more powerfull tools!

Examples of numerical optimization

- DOE in experiment ->reduced overall time of experiment due to the optimal scheme of design parameter variation (lower number of physical samples & experiments)

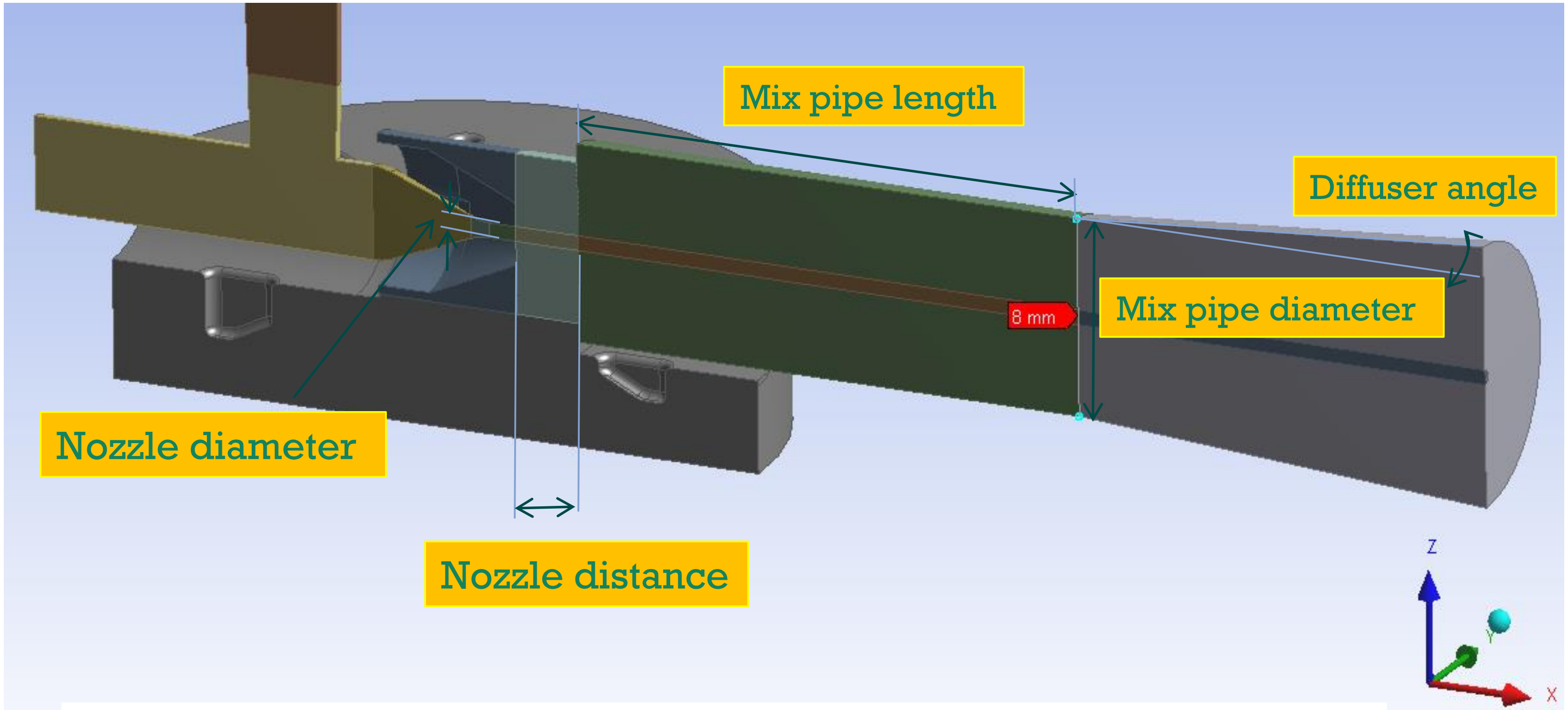
- Design optimization of the fluid pump ->optimal design

When we need robustness analysis

- An ultimative „***firefighting***“ tool for solving quality issues in real production world
  - Find out which design parameter is responsible for the failure and fix them
  - Let perform quckly the quality improvement studies -> saves money!

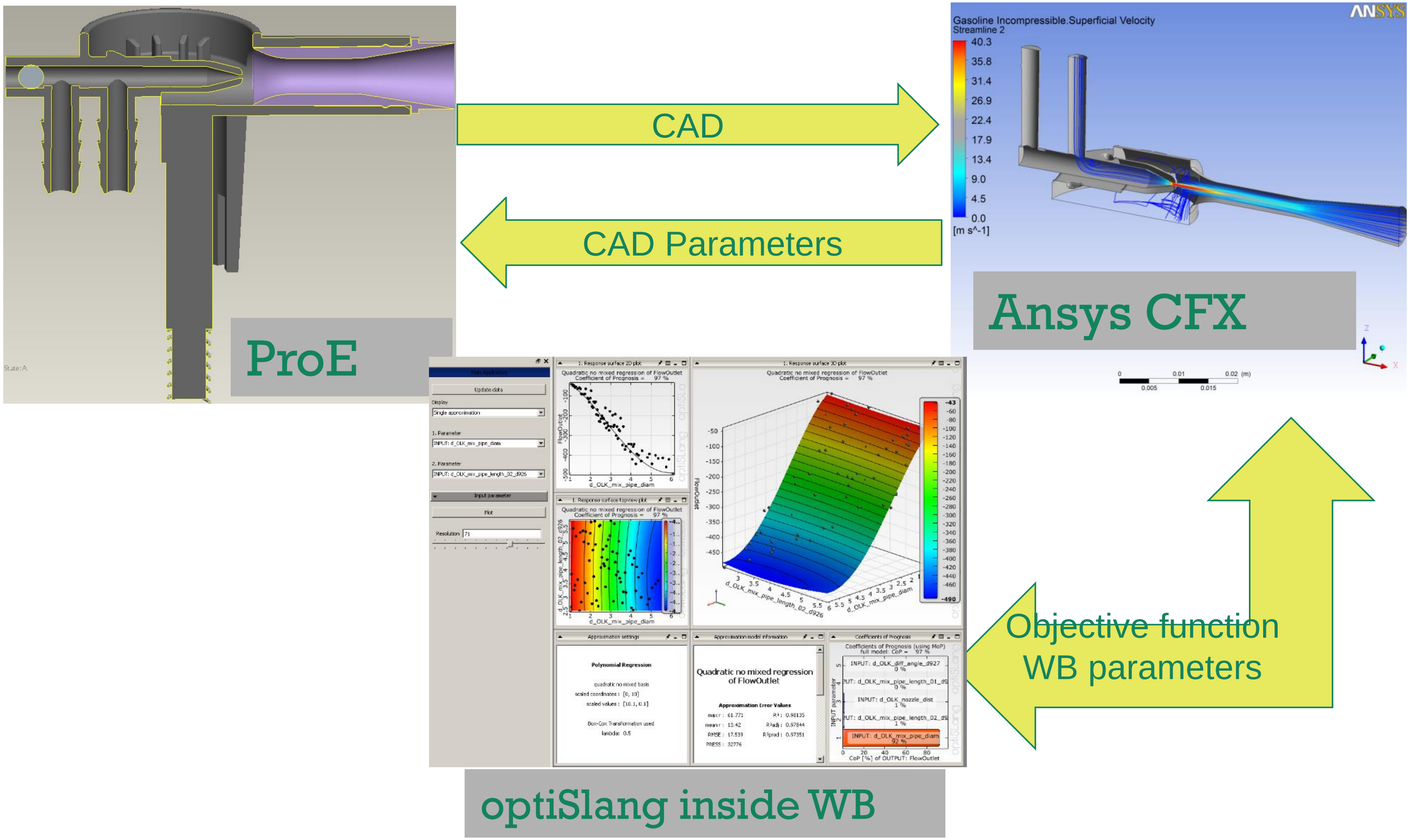
- Helps to **prevent** quality issues by identifying safe limits for design parameters

Example 1: Jet pump
Parametric optimization

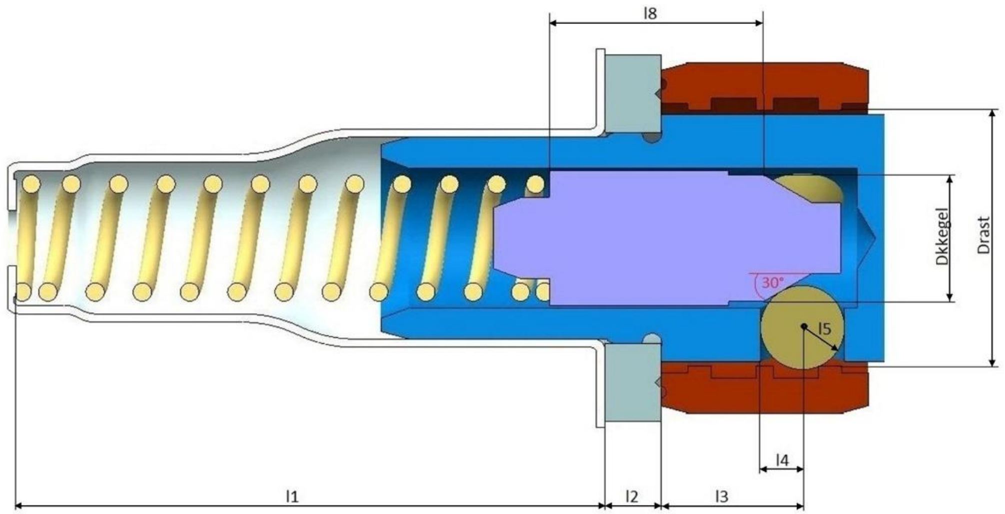


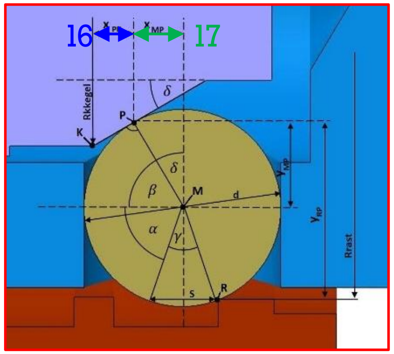
*O.Kurenkov, Ansys User Meeting, 2012

Example 1: CAD+CFX+Optislang



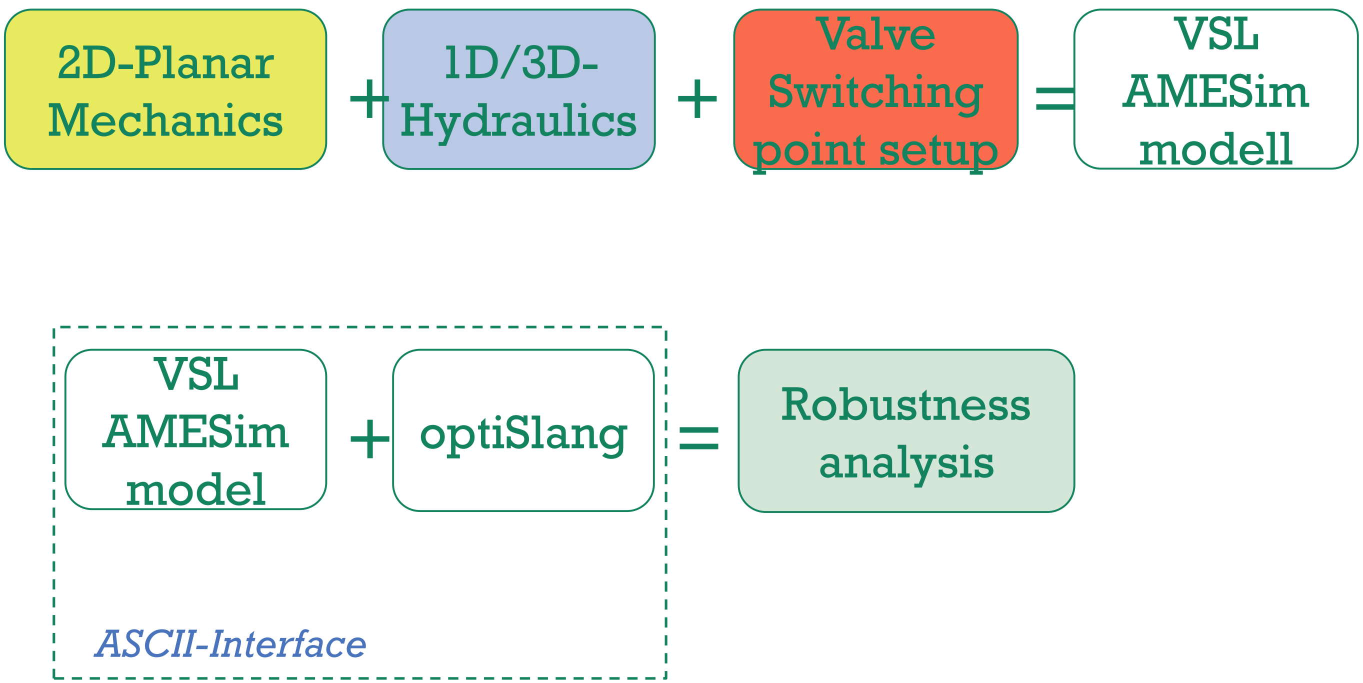
Example 2 : System simulation + robustness analysis



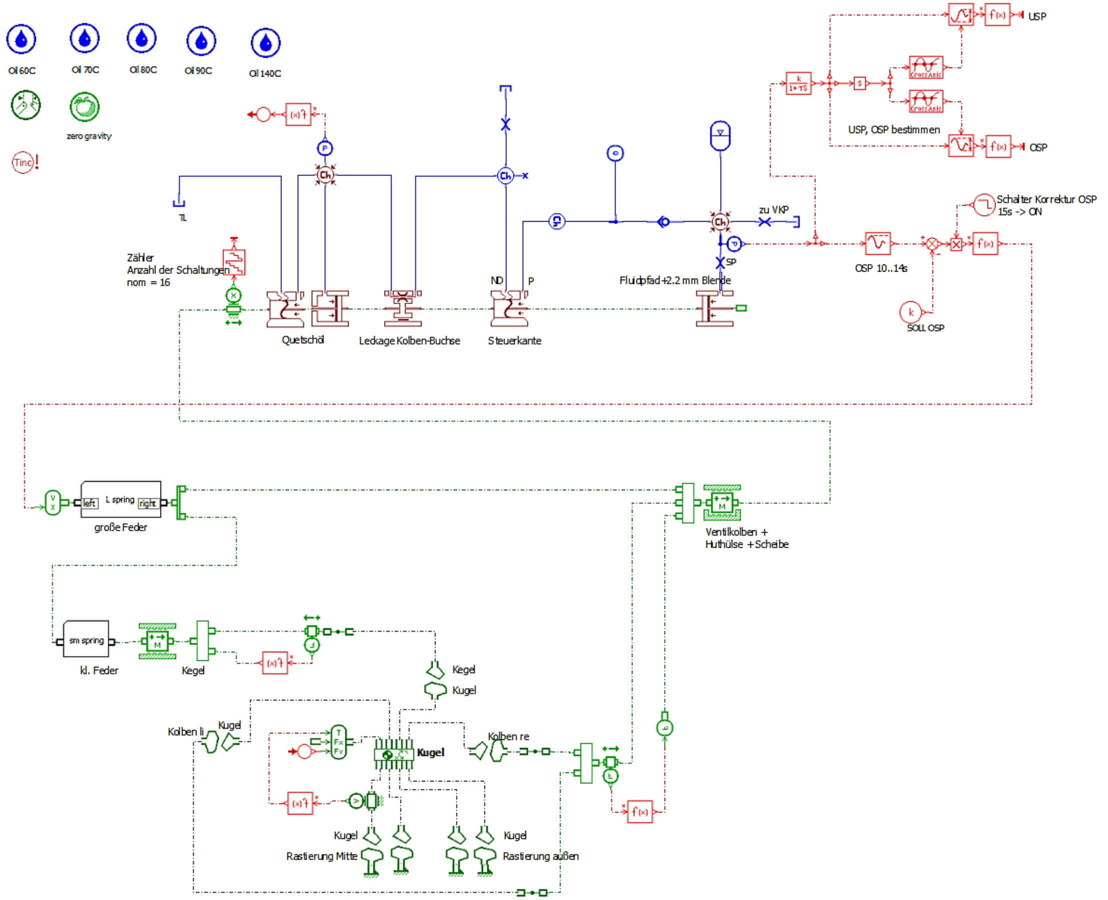


- VSL hydraulic valve used in automatic gear systems
- Problem statement 1: to decrease the variation of the pressure switching points due to the process tolerances
- Problem statement 2: to decrease the valve wear
- Solution: system simulation + robustness analysis using the real tolerances data

Modeling methods

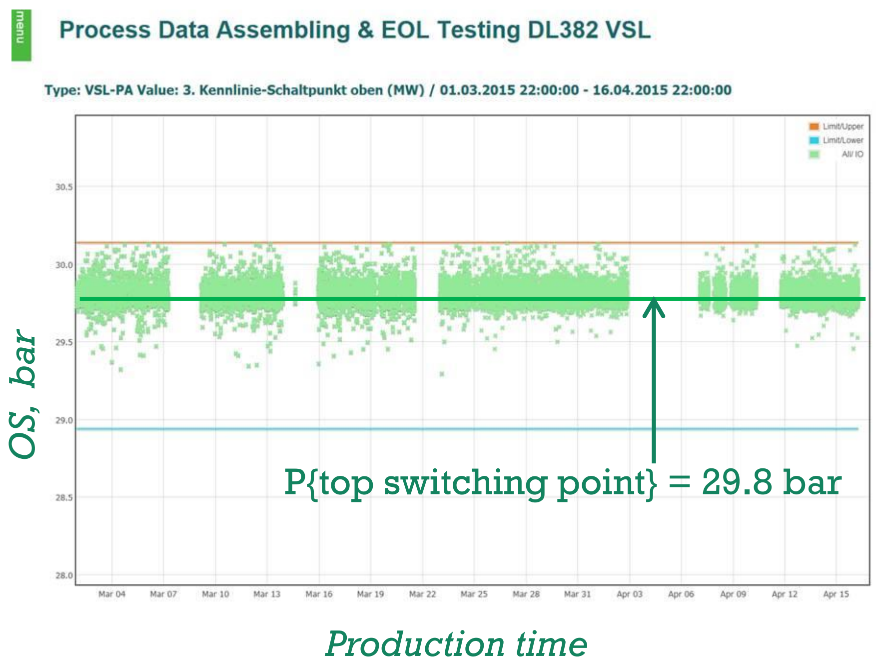


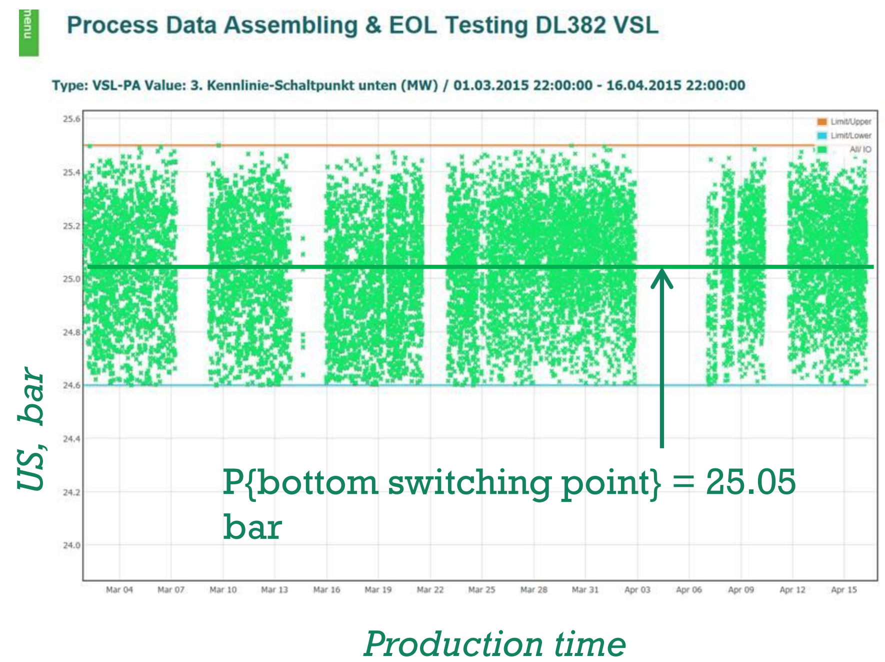
VSL system simulation model



- 1D System simulation with AMESim
- Contains 0D/1D hydraulics and 2D contact mechanics
- Key hydraulics is modeled in 3D CFD
- Model calibration is mandatory

VSL switching points

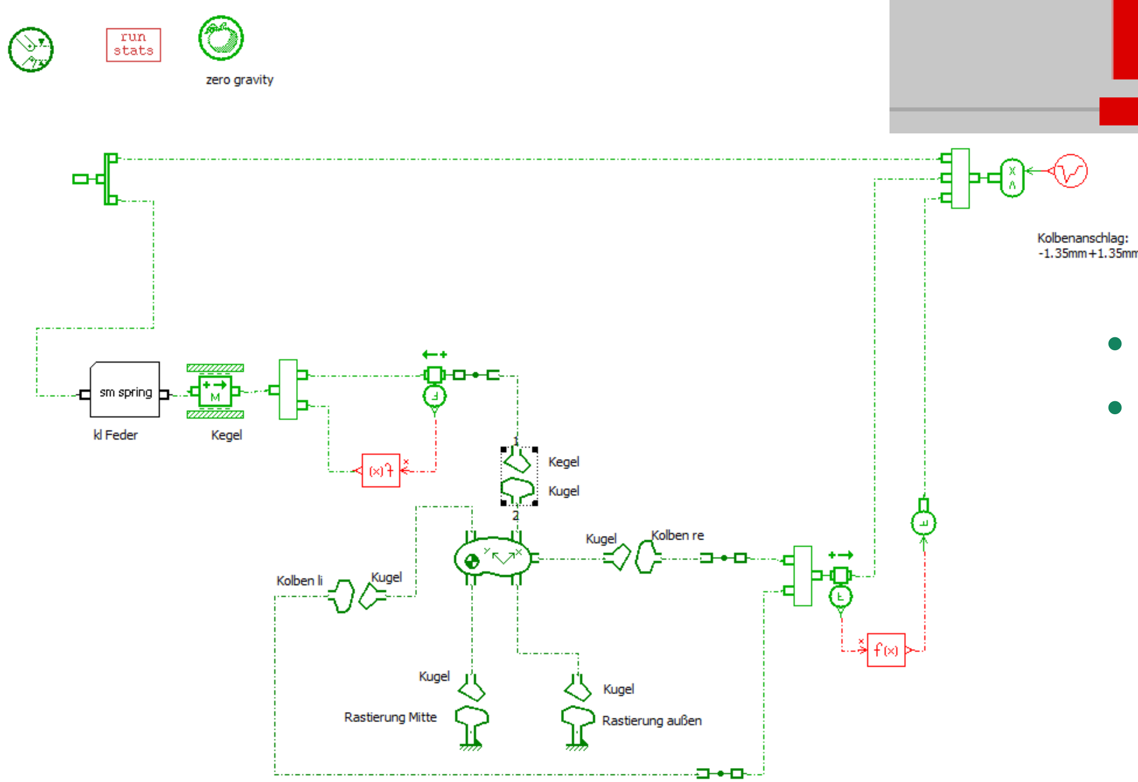




- Every model was calibrated in order to fit the pressure switching points of the valve to the production data

Model calibration static mechanics

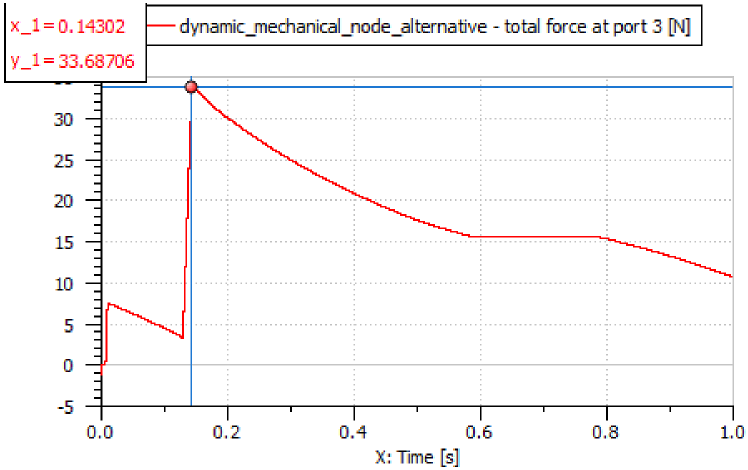
Spring force



- Simplified model
- Latching force validated

Madel validation latching force

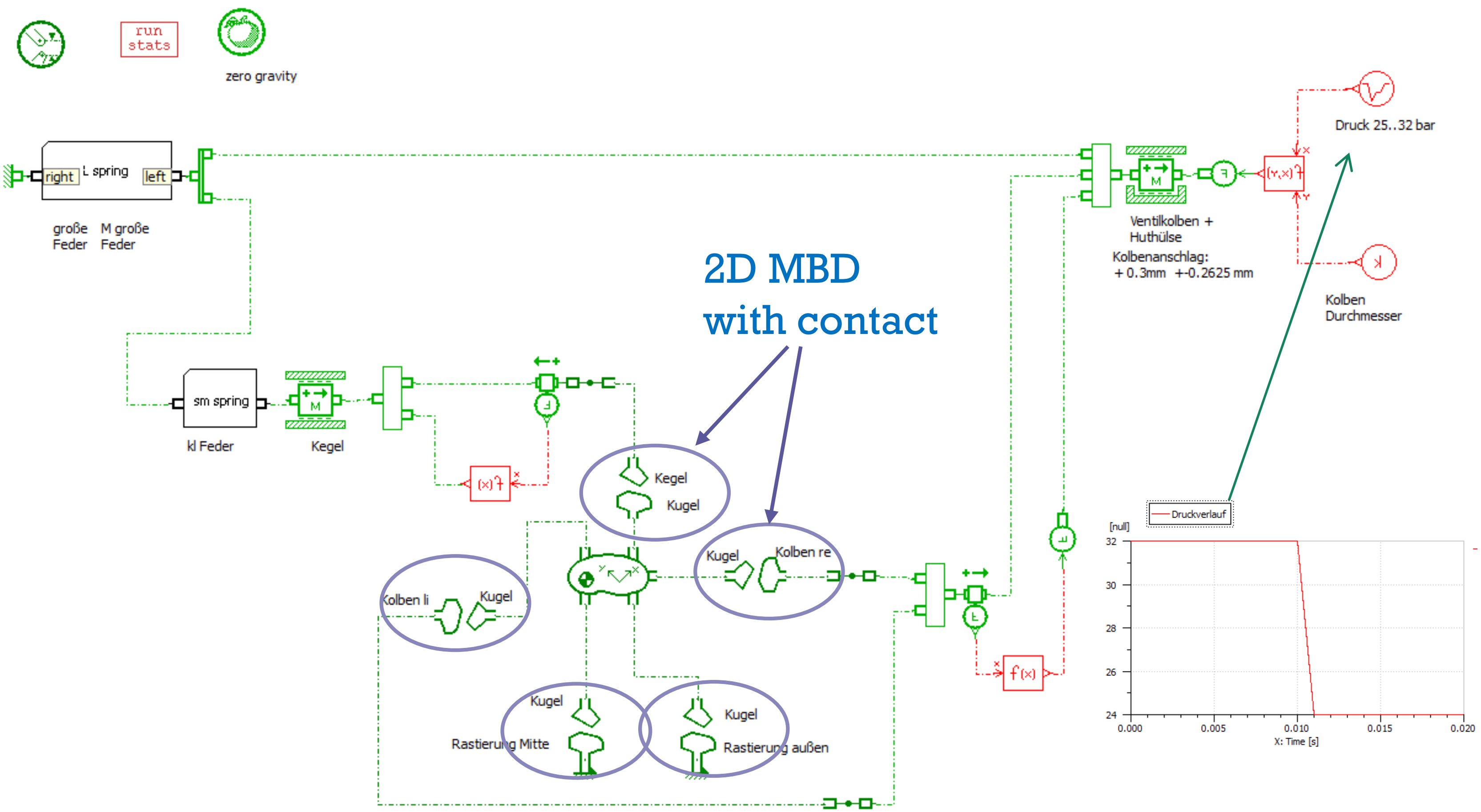
μ	Analytical solution, N	Amesim, N	Difference, %
0	28.91	28.87	0.1
0.08	33.86	33.75	0.3
0.15	39.73	39.50	0.6



Analytical solution for the latching force

$$F_R = F_0 \frac{\left[\sin\left(\delta + \arcsin\frac{s}{d}\right) - \mu_2 \cos\left(\delta + \arcsin\frac{s}{d}\right)\right]}{\left[\sqrt{1 - \frac{s^2}{d^2}} - \mu_1 \frac{s}{d}\right] [\sin\delta - \mu_2 \cos\delta]}$$

Model validation in the dynamics



Contact Modeling
Planar Mechanics Library

$$F_C = K_e p - H_c V_c \left(1 - e^{-p/dp}\right)$$

$$K_e = \left(K_c^{-1} + K_{max}^{-1}\right)^{-1}$$

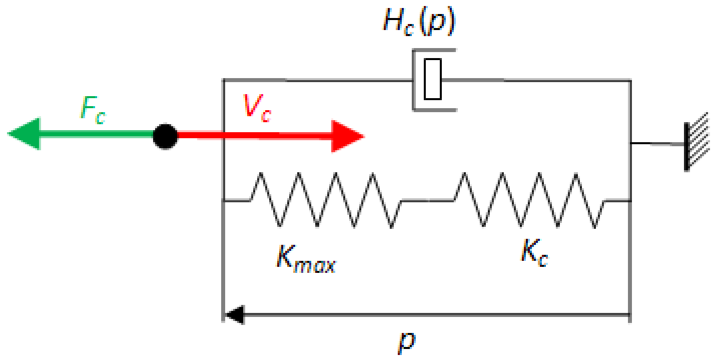
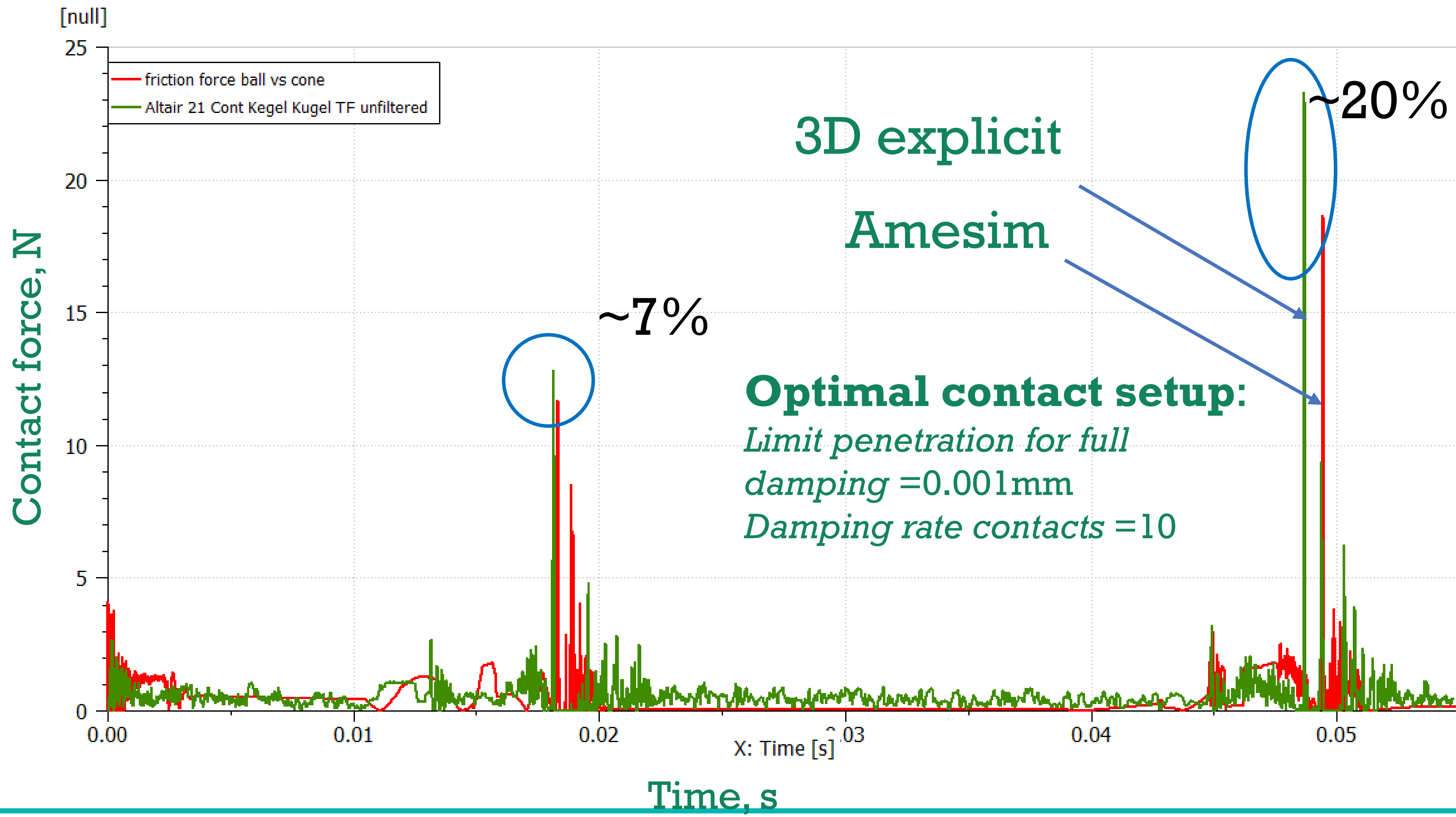


Figure 11: contact force model

Two contact parameters to calibrate:

Hc – damping coefficient
dp – limit of penetration for full damping

Model validation dynamics

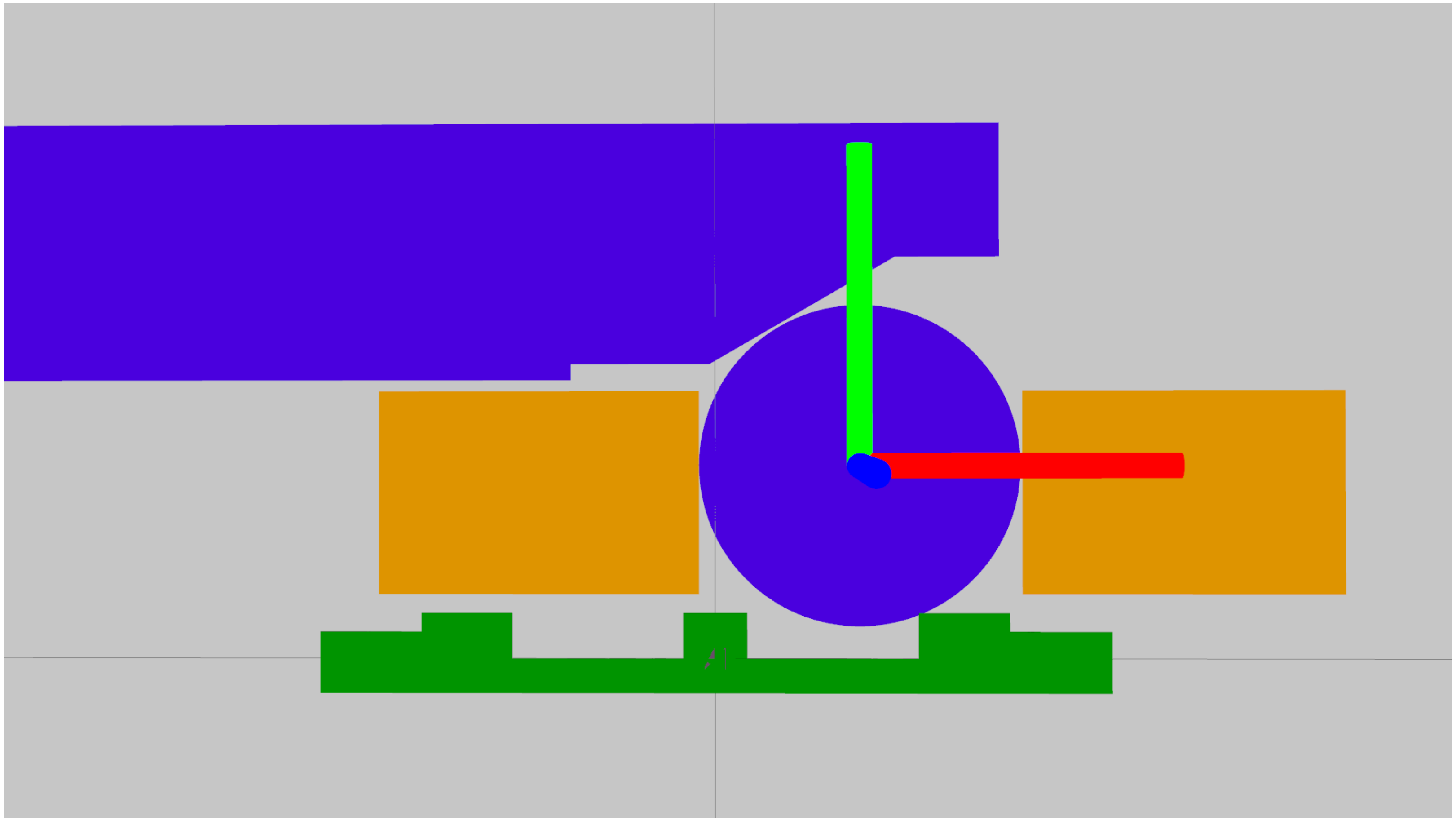


Optimal contact setup:

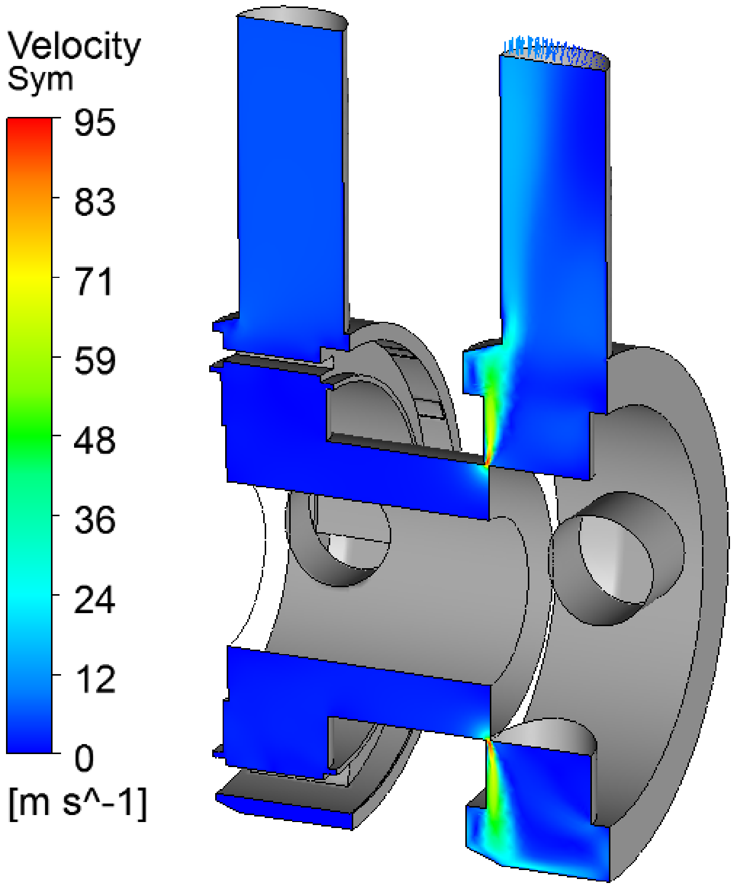
Limit penetration for full damping =0.001mm

Damping rate contacts =10

Animation of valve reaction on pressure drop

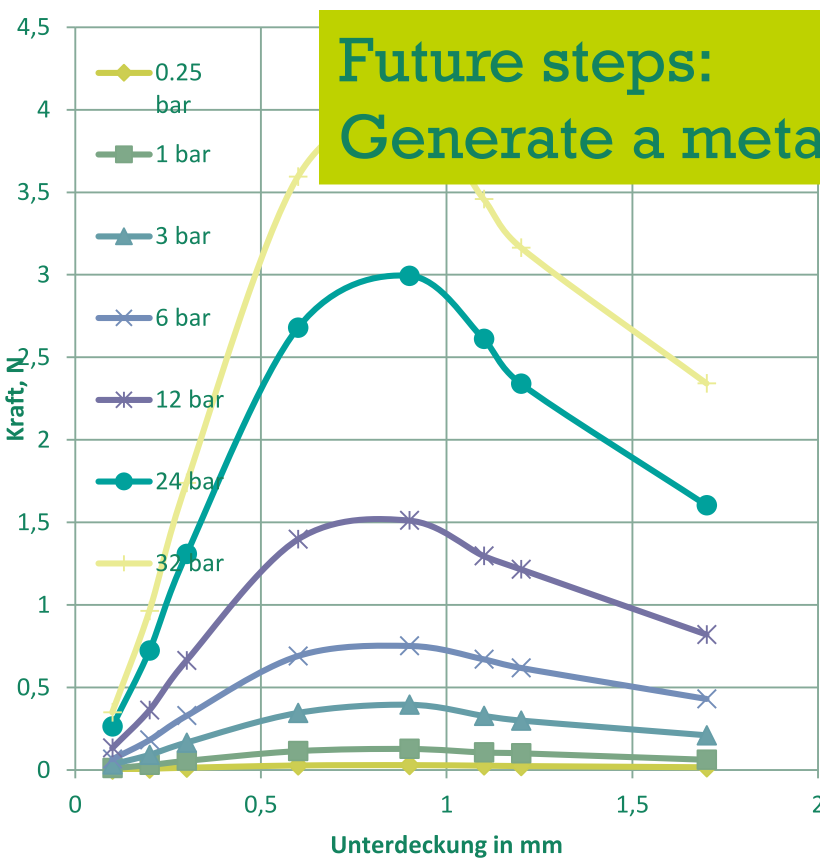


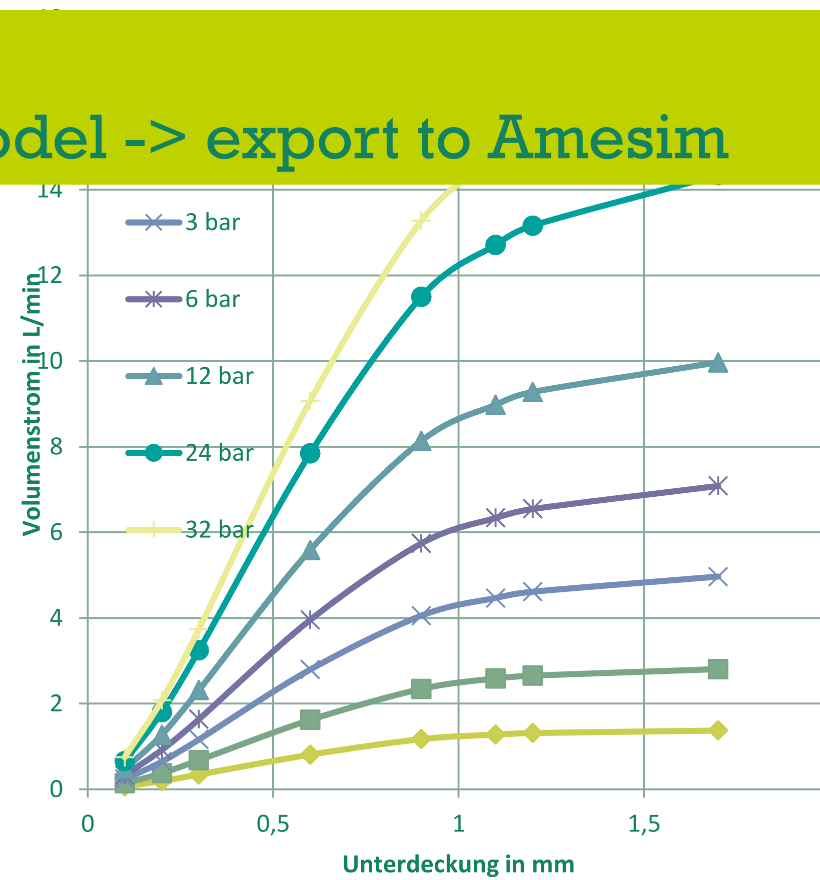
Hydraulik part:
3D CFD Modeling



Important leakages were modeled in 3D CFD and stored as p-Q tables

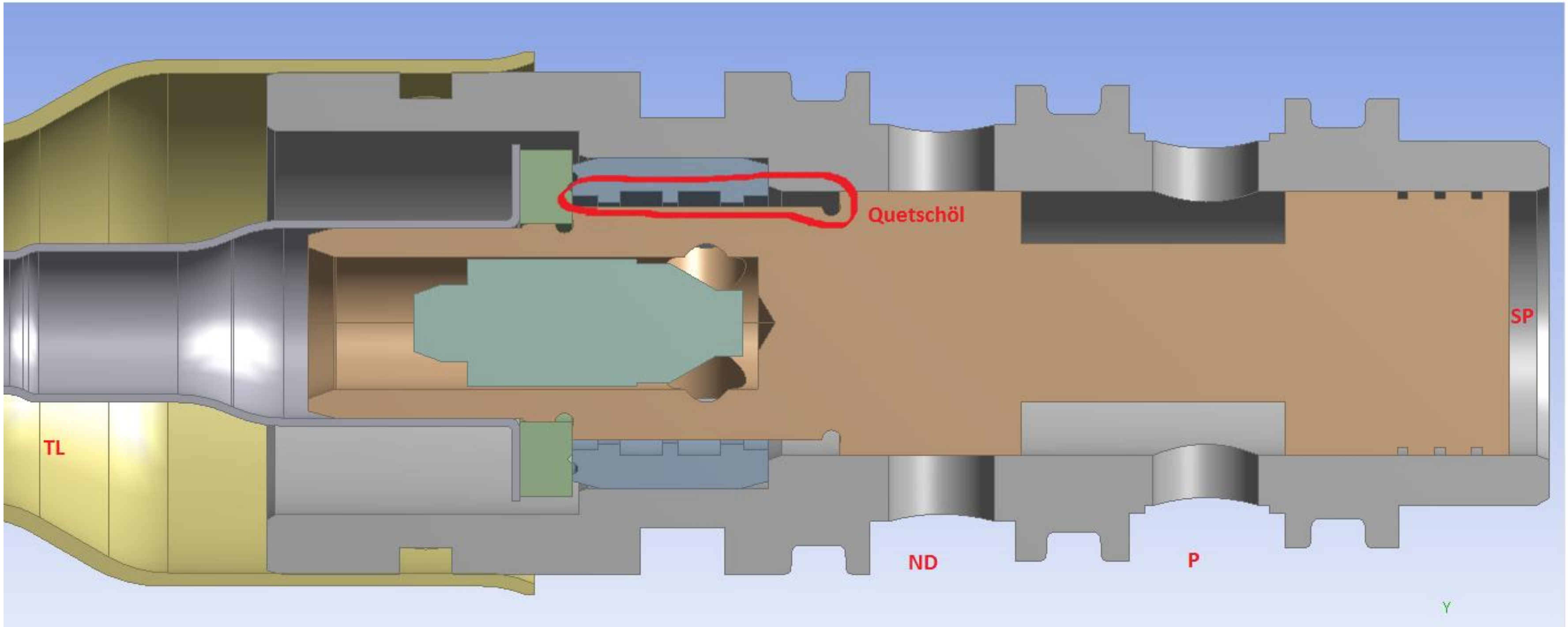
Flow/Force data for system simulation model





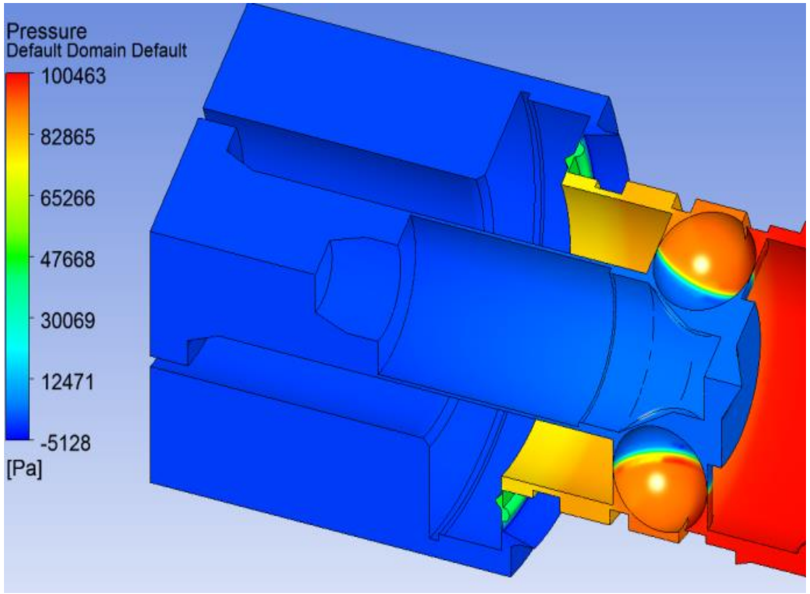
Future steps:
Generate a metamodel -> export to Amesim

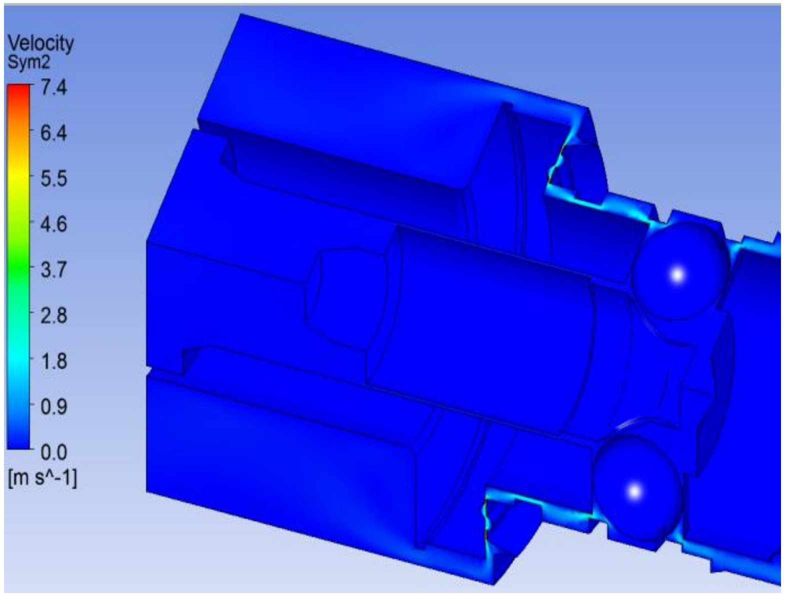
Squeeze oil simulation

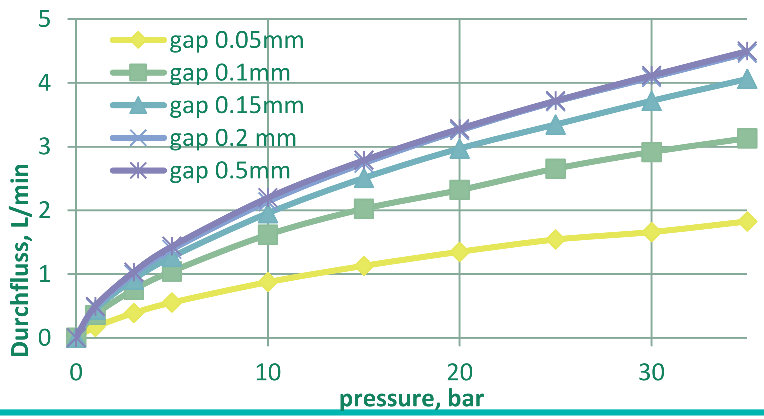


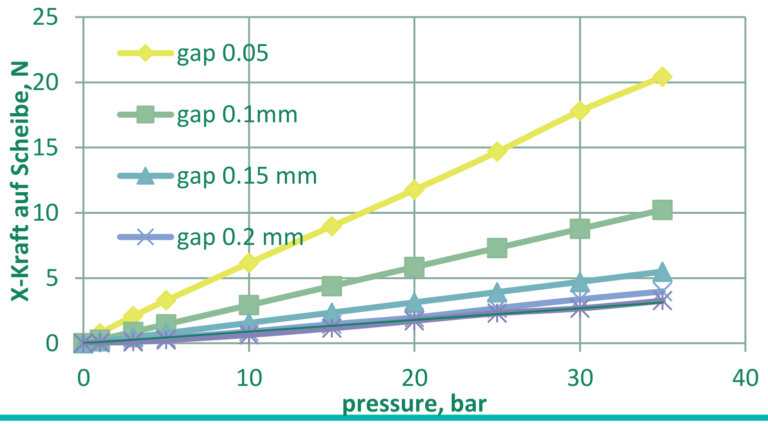
Oil trapped in a small volume has damping influence on valve dynamics

Squeeze oil simulation 2

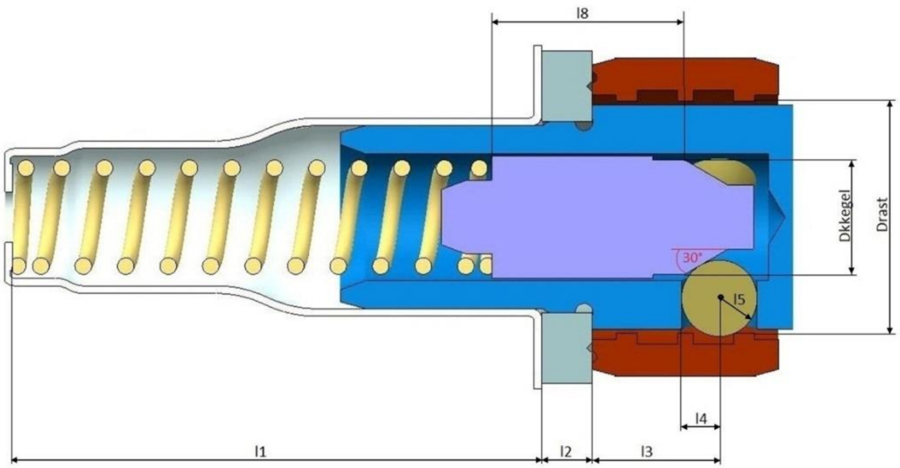


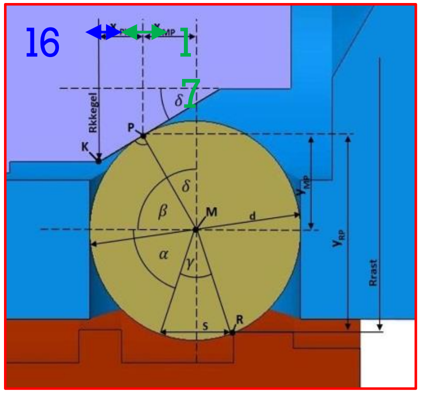




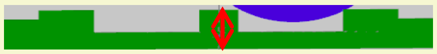
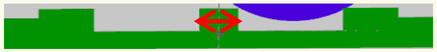
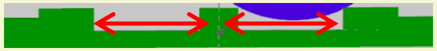
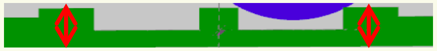


Robustness study: input parameters

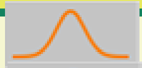
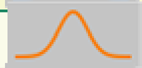
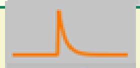
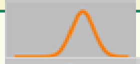
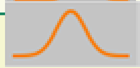
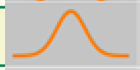
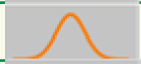
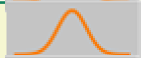
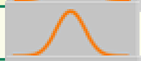
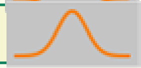
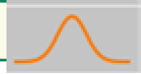




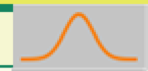
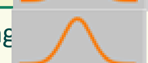
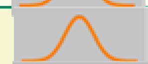
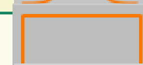
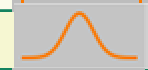
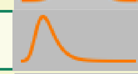
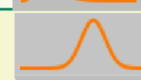
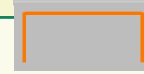
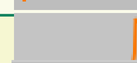
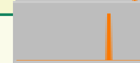
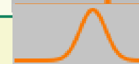
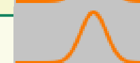
l6: distance sphere centrum to cone
l7: dsitance contact point cone/spere to fase of cone

Parameter of grate	Picture
Middle fillet height	
Middle fillet width	
Notch width	
Fillet height left/right	

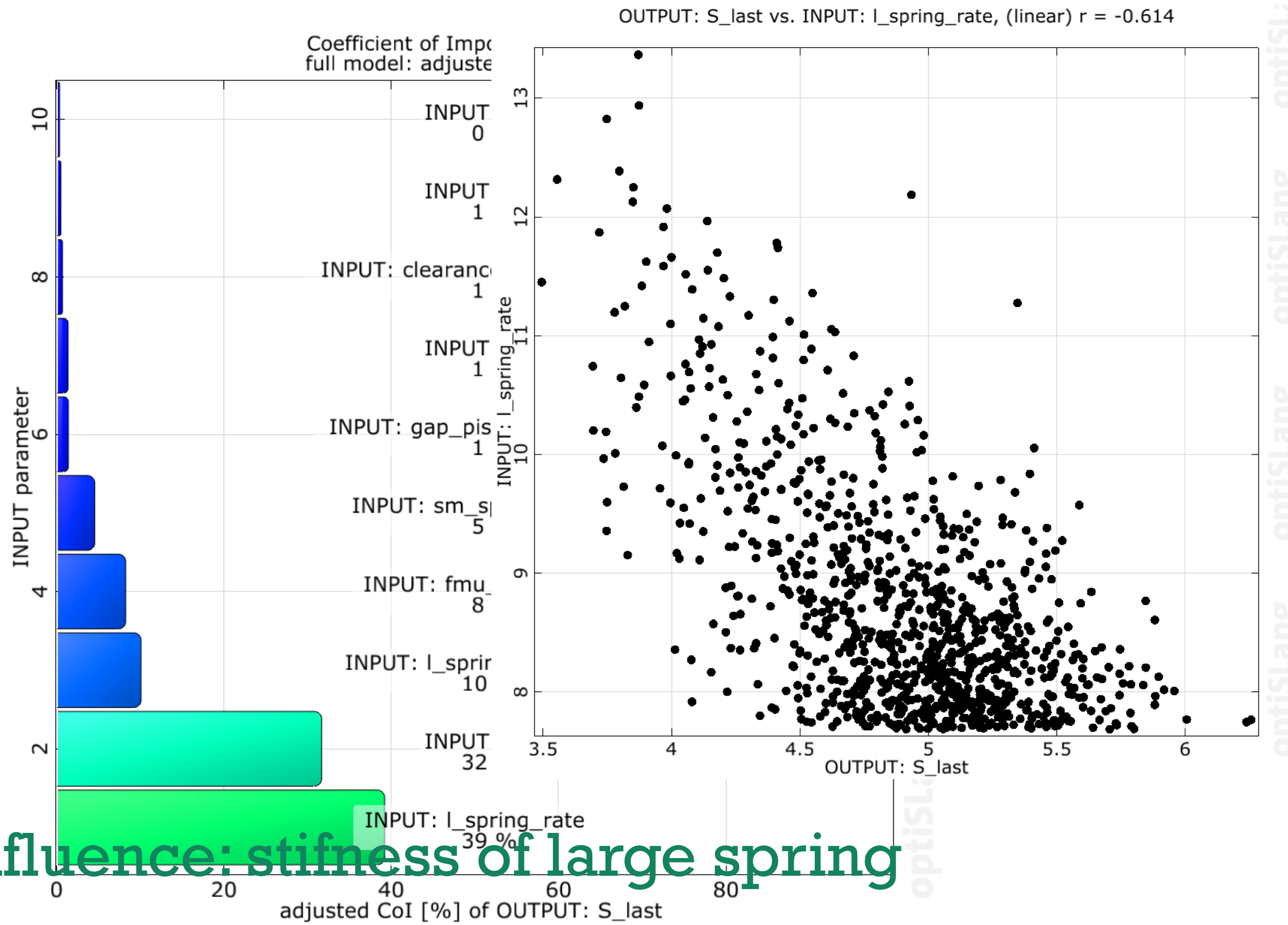
Robustness study: distribution of input parameters

Nr.	parameter	name in the model	PDF		Averaged value	RMS
1	Preload force of large spring	l_spring_f0		Normal	215	0.66
2	Friction force of large spring	l_spring_fr_force		Normal	12.75	1.5833
3	Stiffness of large spring	l_spring_rate		Exponent.	8.814	1.128
4	Stiffness of small spring	sm_spring_rate		Lognormal	3.26	0.03789
5	µ contacts (grating)	fmu_contacts		Normal	0.11	0.00367
6	Toler. of the middle fillet heights	middle_part_height		Normal	-0.005	0.00065
7	Toler. of the middle fillet heights	middle_part_width		Normal	0	0.01667
8	Toler. notch width left	notch_width_left		Normal	-0.0013	0.0057
9	Toler. notch width right	notch_width_right		Normal	-0.0013	0.0057
10	Toler. of left fillet height	outer_part_height_left		Normal	0	0.001375
11	Toler. of left fillet height	outer_part_height_right		Normal	0	0.001375
12	Clearance sphere/piston	clearance_piston_ball		Normal	0	0.005

Robustness study: distribution of input parameters (ext.)

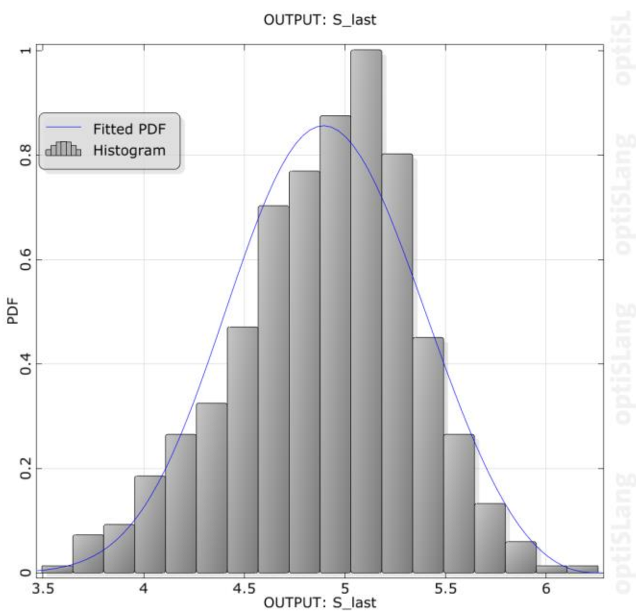
Nr.	Parameter	name in the model	PDF	Averaged value	RMS
13	Tol. of cone angle	cone_angle_tol	 Normal	0.55	0.04561
14	Clearance piston/sleeve	gap_piston_housing	 Normal	5.375e-6	9.583e-7
15	Notch width	s	 Normal	1.5987	0.0057
16	Sphere diameter	d	 Uniform	2.997	0.00086
17	Inner radius of grating	Rrast	 Normal	4.5786	0.001375
18	Fase on cone	Rkkegel	 Gumbel	2.241	0.003506
19	Free Length of small spring	l0	 Lognormal	23.698	0.13738
20	l1 small spring	l1	 Uniform	21.0	0.01998
21	l2 small spring	l2	 Weibull	2.037	0.0163
22	l3 small spring	l3	 Trunc. Normal	5.054	0.01041
23	l4 small spring	l4	 Lognormal	1.5105	0.0081
24	l8 small spring	l8	 Lognormal	7.714	0.03123

Results robustness analysis



Largest influence: stifness of large spring

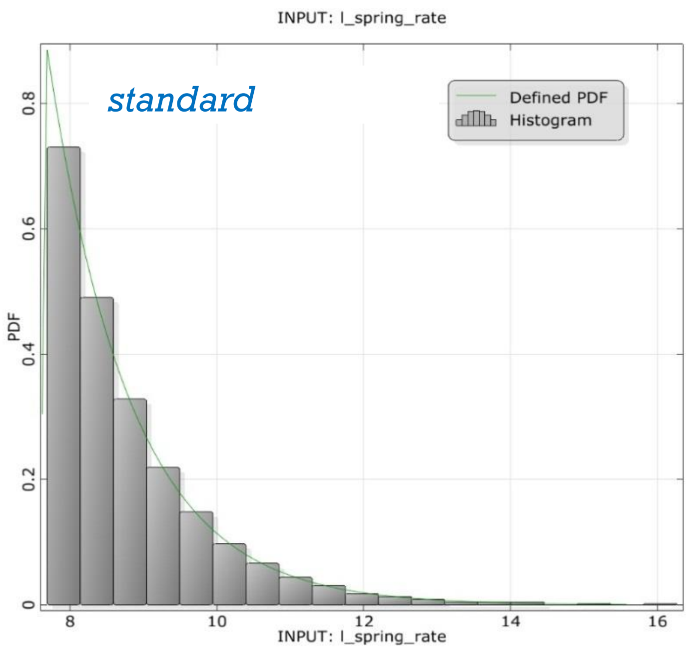
Statistical distribution of the pressure spread



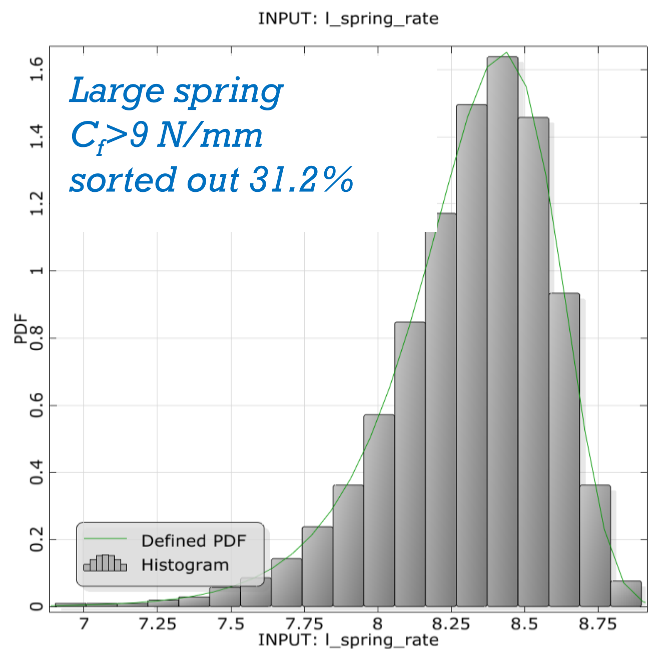
Statistic data			
Min:	3.495	Max:	6.257
Mean:	4.897	Sigma:	0.4469
CV:	0.09125		
Skewness:	-0.332	Kurtosis:	3.033
Fitted PDF: Weibull (Extreme Typ III Min)			
Mean:	4.897	Sigma:	0.4469
Upper cut:	6.257		

- Pressure spread (difference top switching point – bottom switching point) is a **result of tolerances variation**
- The distribution can even give directly **the estimation of the failure rate**
- Corrective actions and economic decisions can be made using the computed failure rate

Corrective action:
sorting out of „bad“ large springs



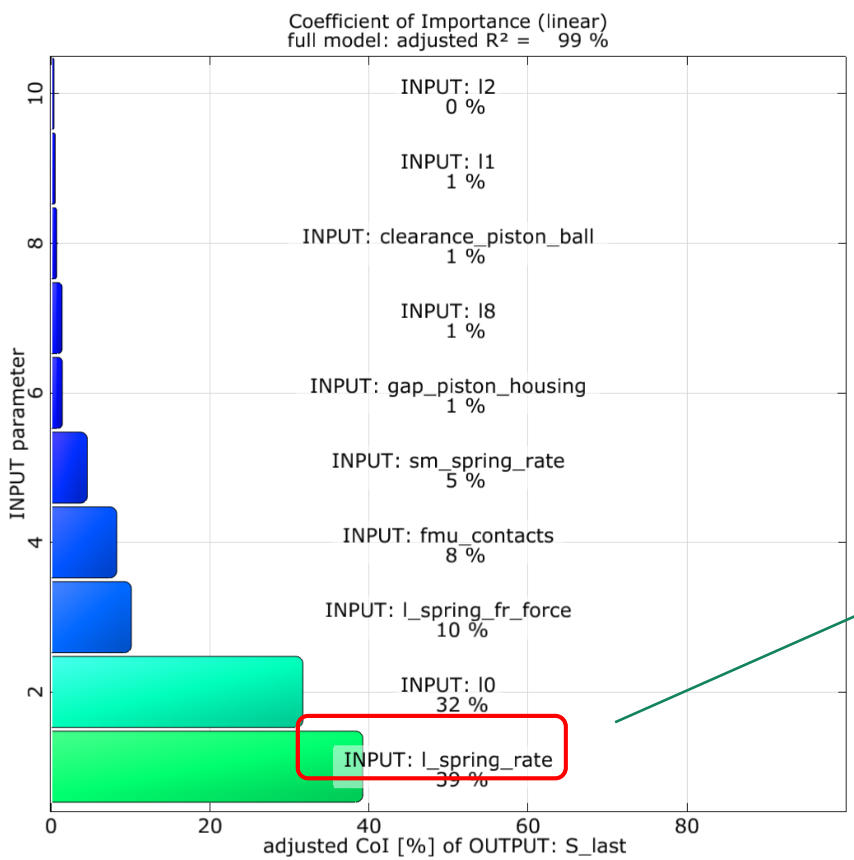
Statistic data			
Min:	7.687	Max:	16.26
Mean:	8.811	Sigma:	1.122
CV:	0.1274		
Skewness:	1.959	Kurtosis:	8.42
Defined PDF: Exponential			
Mean:	8.814	Sigma:	1.128



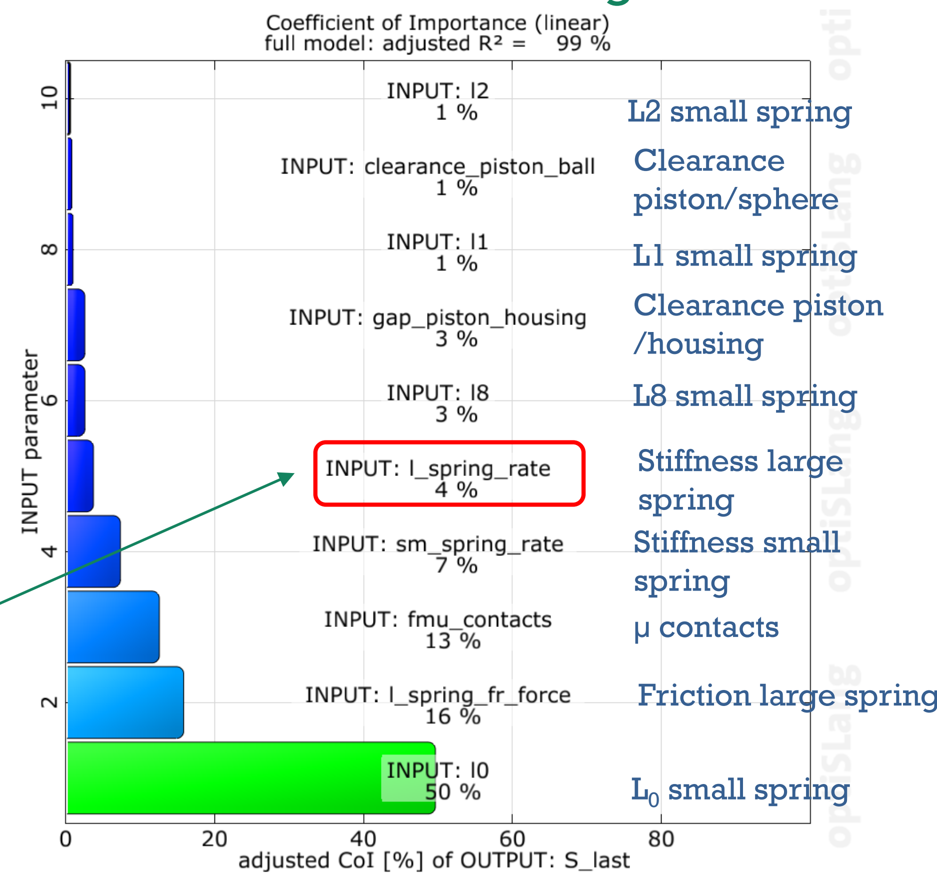
Statistic data			
Min:	6.903	Max:	8.898
Mean:	8.312	Sigma:	0.2756
CV:	0.03315		
Skewness:	-0.9763	Kurtosis:	4.577
Defined PDF: Weibull (2p)			
Mean:	8.312	Sigma:	0.276

Effect of outsorting of the large springs

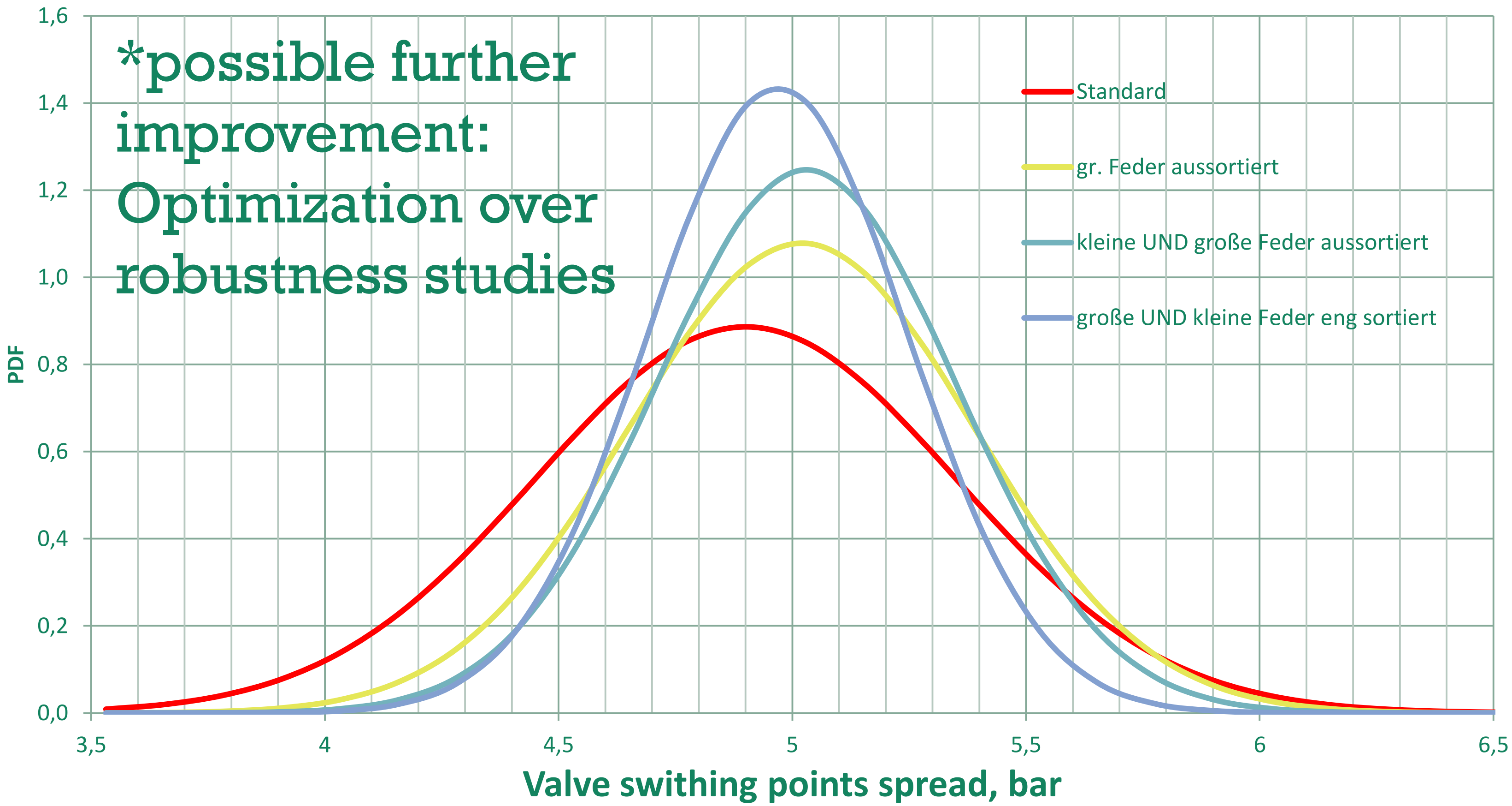
No outsorting



With outsorting



Quality improvement studies



Improvement of tolerance studies (Dynardo idea)

- How to: Create a optimization process over the number of robustness systems
- Variate the design parameters *limits* (***sorting out process***) or design parameters *distributions* (***manufacturing process***)
- Goal function: fulfill some design requirements (i.e.switching points spread)
- Find out the *allowed* tolerance ranges

Summary

- Coupling of CAE tools with optimization/ sensitivity/ robustness studies is one of the next evolutional steps in the CAE driven product development process

- It can be used for any CAE tool and even for experimental DOE

- DESIGN FOR A DESIRED QUALITY is possible!

Thank you very much for your kind attention!