WOST 2016
WEIMARER OPTIMIERUNGS- UND STOCHASTIKTAGE

HILITE® INTERNATIONAL

Optimization of a spool-geometry for jet force compensation in a pressure control valve

C. Hugel (M. Eng.) | Hilite Germany GmbH | 28.06.2016

Motoranwendungen

Getriebeanwendungen

Inhaltsübersicht

What is Hilite International GmbH?

Everything important about us

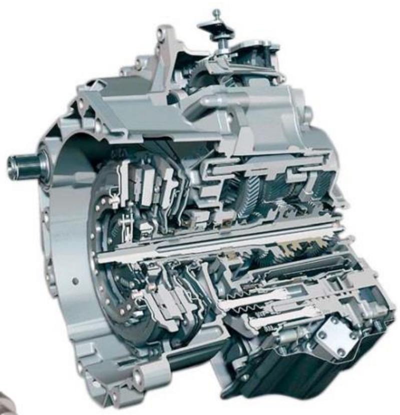
zurück

Information

Hilite International GmbH

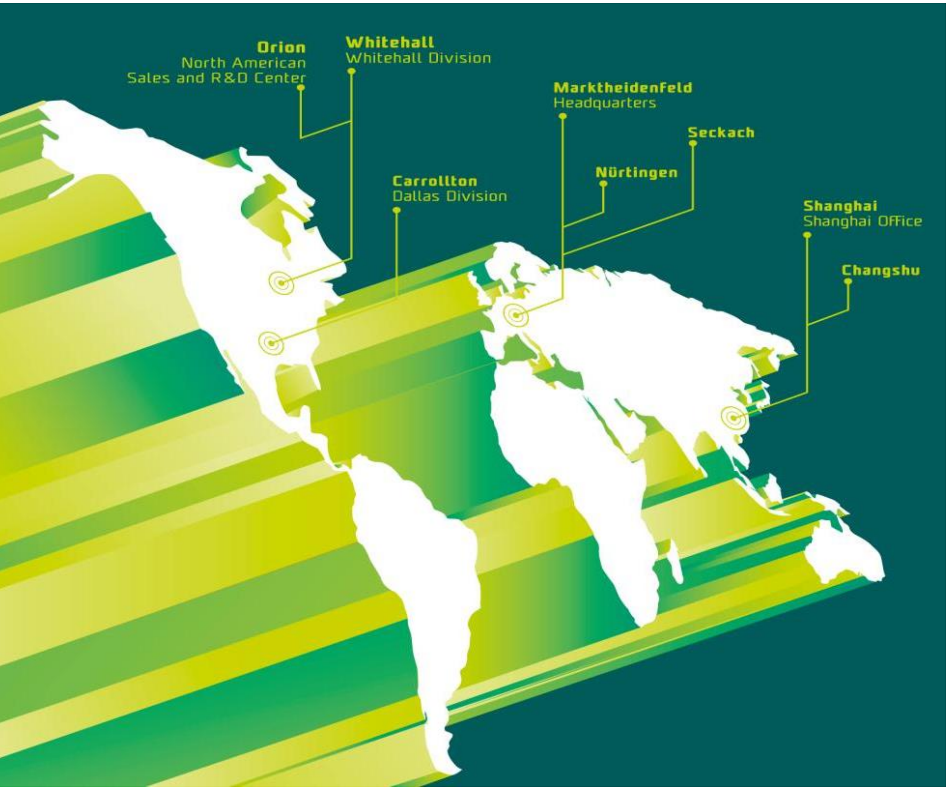
Key facts about Hilite

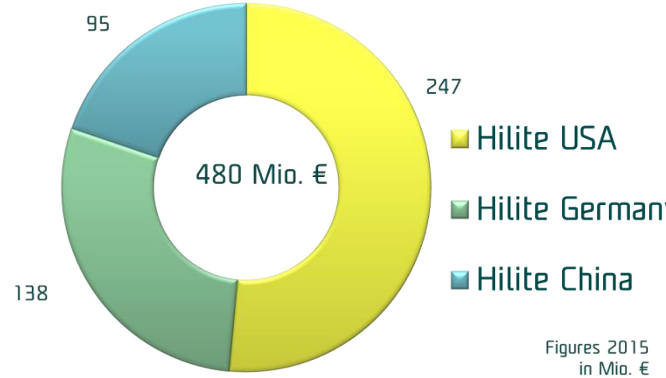
- Foundation of Hilite (Heller Hydraulik) in 1930
- Products for the automotive industry divided into two fields:
    - Transmission (AT valves, DCT valves,…)
    - Unit Engine (VVT, engine valves,…)
- Approx. 1500 employees

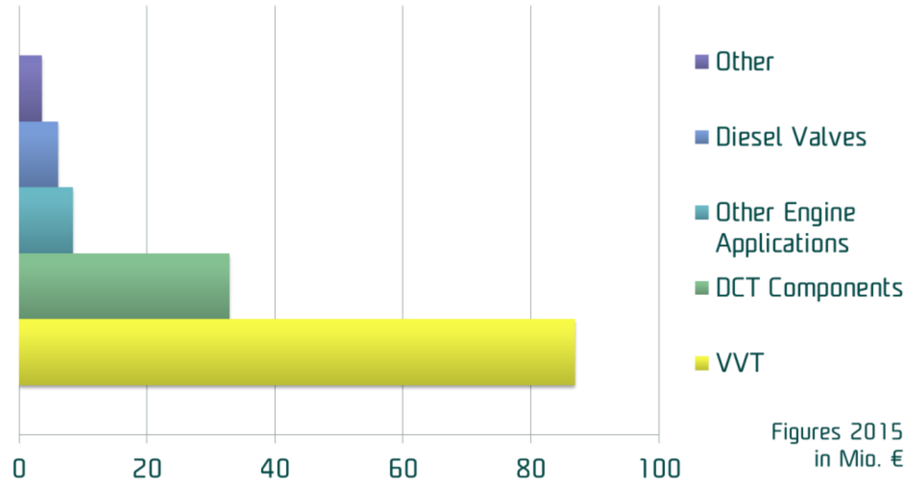


Information

Hilite International GmbH



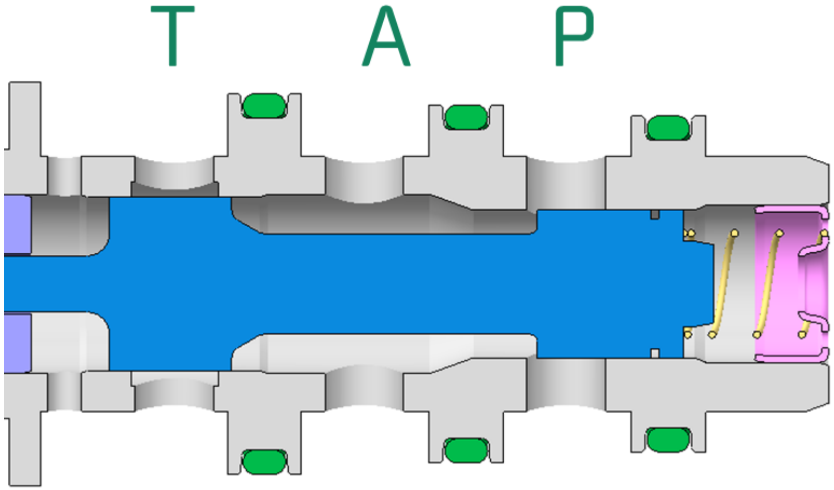




- Headquarters: Marktheidenfeld
- 8 Locations on 3 continents

What had to be solved?

Introduction to the product and its problem



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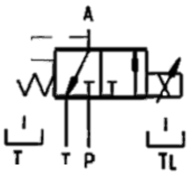
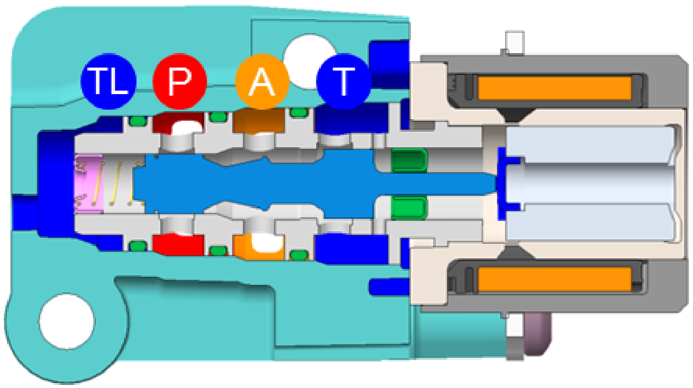
Introduction – response time

<u>**Pressure control valve for DCT**</u>

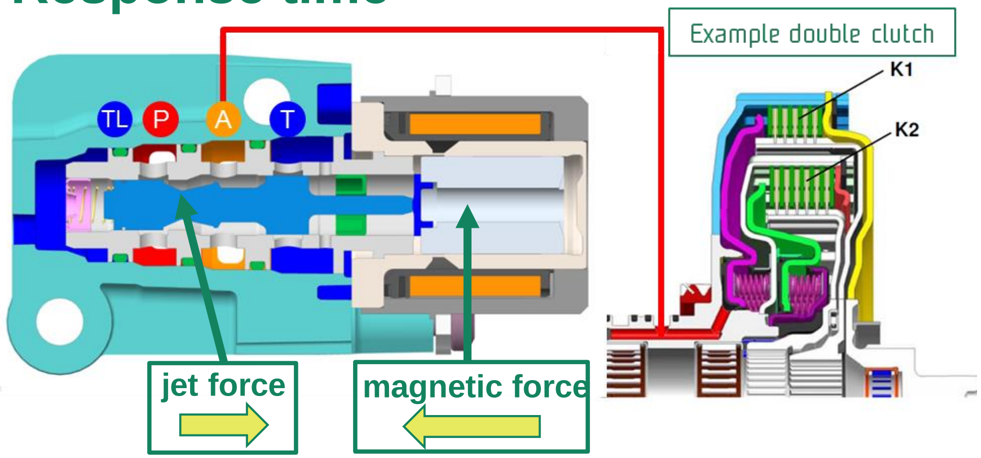
- 3/2 proportional valve
- Regulation of the inflation of the clutch
- Low hysteresis and leakage
- Control pressure: 0 – 15bar
- Supply pressure up to 20bar



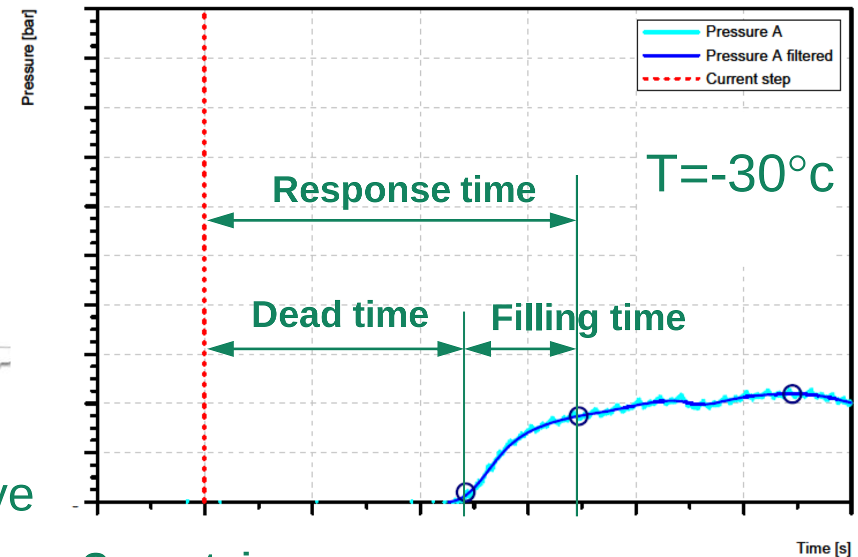


Introduction

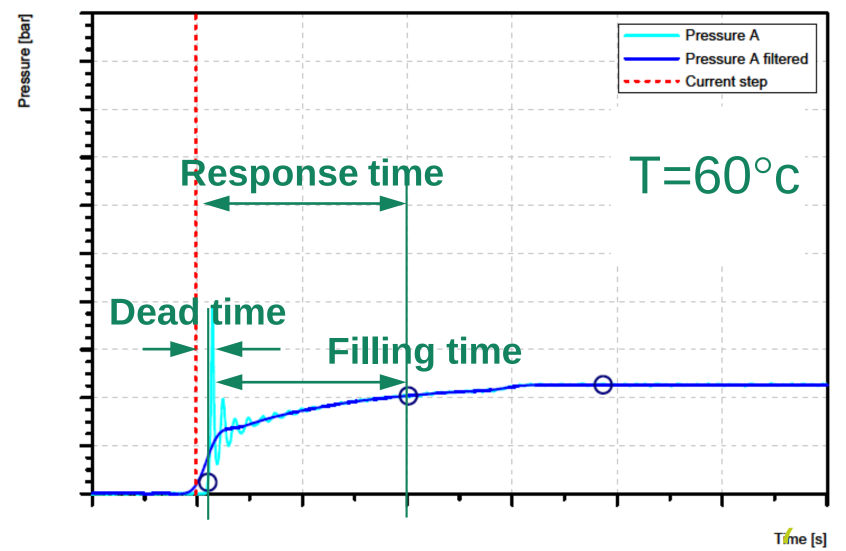
Response time



Current rise



Current rise



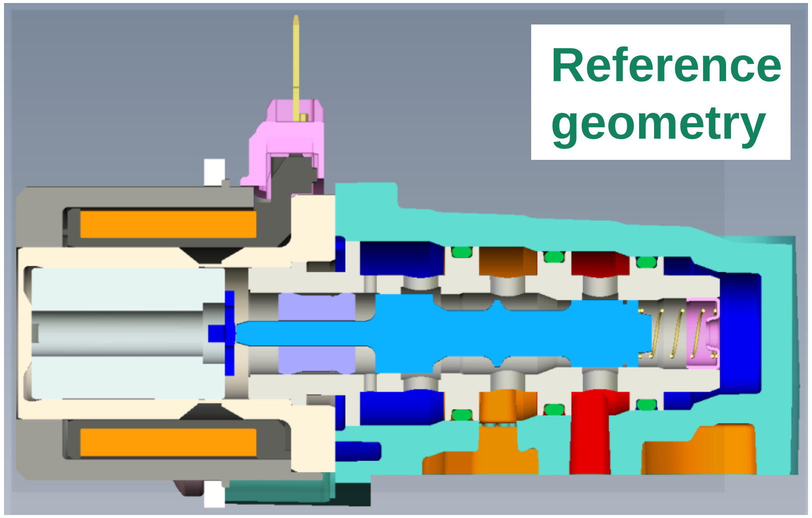
Actuation of the clutch with pressure control valve

- **Response time:** Time between current rise (actuation) and achieving the target pressure (till 90% of target pressure)
  - **Dead time:** Time between current rise (actuation and pressure rise (<10%)
  - **Filling time:** Time between pressure rise and achieving 90% of the target pressure

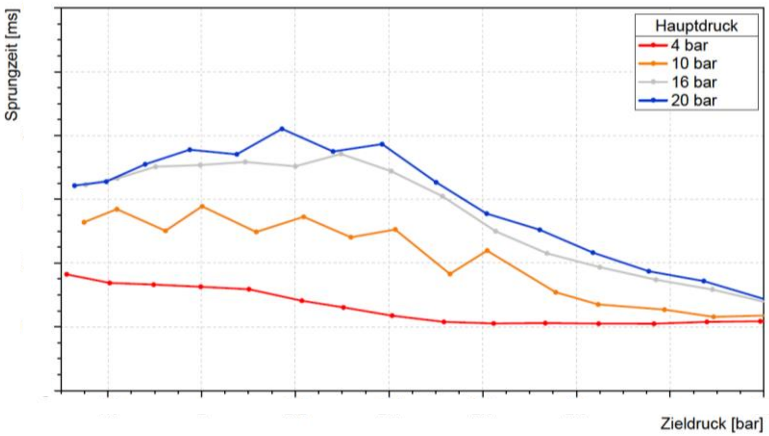
Introduction
Results reference system

- max. step response at 20bar supply pressure of 420ms
- pressure dependence within a band of 250-300ms

→ Slow response times lead to cogging during gear change



Reference step response



→ Reduction of the step response by optimizing jet force

Solving the problem!

Optimization with OptiSLang and ANSYS CFX

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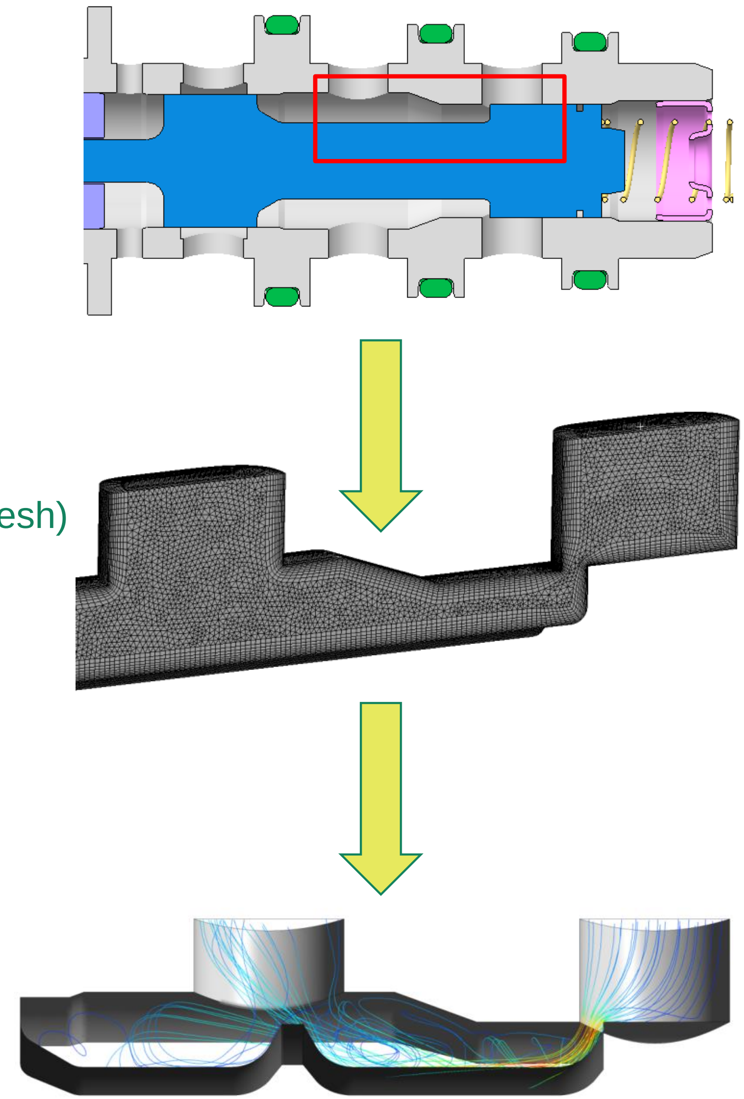
Solving the problem

Methods and tools

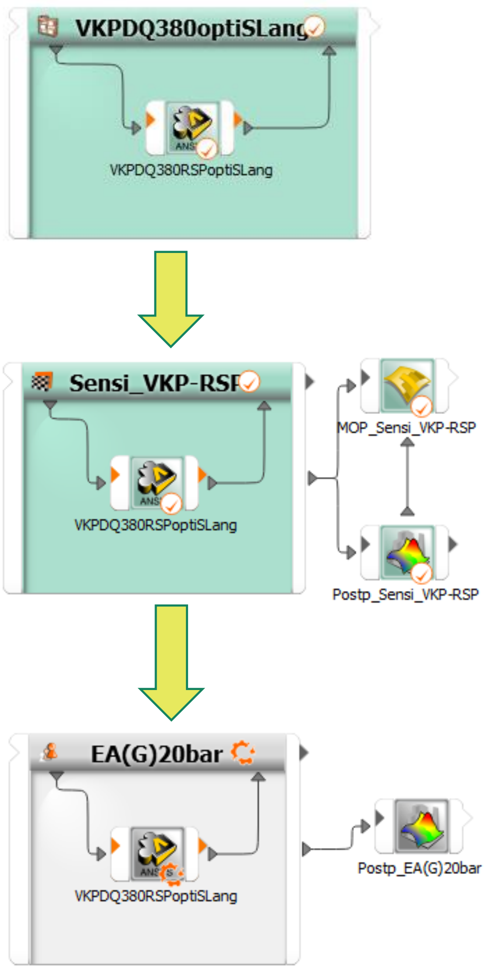
- **CFD:** Computational Fluid Dynamics (simplified)
  - Numerical approximation of fluid dynamic problem (Mainly used Navier-Stokes or Euler-equations)
  - <u>Method:</u> Finite Volume
    → Separate the area into discrete elements (mesh)
  - Solve the model equations for every element over all surfaces

➔ **Simulation of the oil flow through the valve with ANSYS CFX**



Solving the problem

Methods and tools



Parametric System

- Basic System to build sensitivity and optimization
- Connection with Workbench and ANSYS CFX

Sensitivity analysis

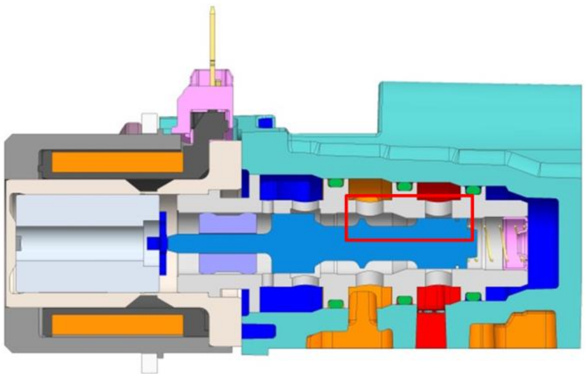
- Advanced Latin Hypercube Sampling (DoE) with 200 designs
- Analysis of the important parameters
- Start designs for optimization

Optimization

- Multidisciplinary optimization with two objectives
- Evolutionary algorithm with pareto ranking
  (start size 20, archive size 20, number of parents 10)

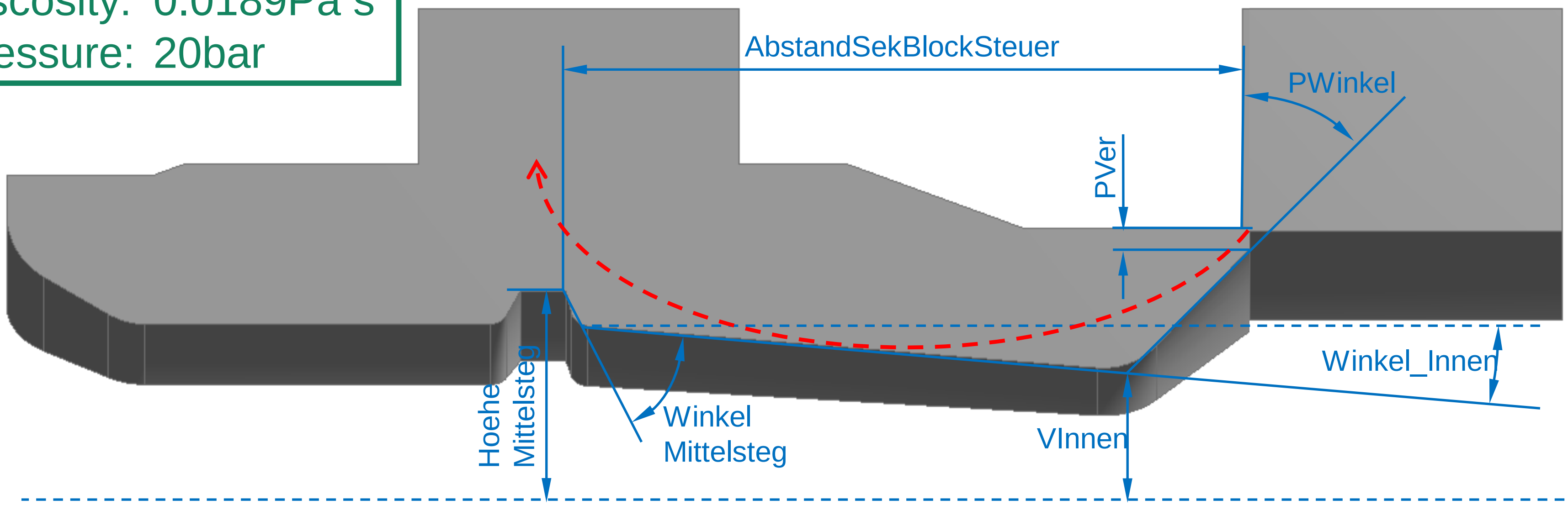
Solving the problem

Model information



- Edited CFD-Model to fit **jet force** calculation with optiSLang
- **7 adjustable spool geometry parameters** (see figure)
- **Different spool positions** (moving the lower part of the model to the right, with A- and P-Port staying in place; figure orifice 0.1mm)

Density: 816.5kg/m³
Viscosity: 0.0189Pa s
Pressure: 20bar



Solving the problem

Parameters, constraints and objectives

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- Variation of all important **geometry parameters** within a defined range
- **Input** pressure **20bar** at P-Port
- Different constraints to ensure correct geometries (not listed)
- Calculated spool positions (orifice at P-Port):
  0.025mm, **0.05mm**, **0.15mm**, **0.40mm**

Parameter | Start designs | Criteria | Initialization | Selection | Crossover | Mutation | Other | Result designs

	Name	Parameter type	Reference value	Constant	Value type	Resolution	Range		Range plot
1	VInnen	Optimization	2.25	☐	REAL	Continuous	1.5	3	
2	Winkel_innen	Optimization	0.1	☐	REAL	Continuous	0.01	15	
3	Winkel_Mittelsteg	Optimization	60	☐	REAL	Continuous	45	80	
4	AbstandSekBlockSteuer	Optimization	7	☐	REAL	Continuous	5.5	7.5	
5	HoeheMittelsteg	Optimization	3.25	☐	REAL	Continuous	2.5	3.85	
6	PressureP	Optimization	2e+06	☑	REAL	Continuous	450000	2e+06	
7	PWinkel	Optimization	30	☐	REAL	Continuous	25	85	
8	PVer	Optimization	0.3	☐	REAL	Continuous	0.1	0.5	

- Objectives (optimization targets):
  1. **Reduction** of the spools **jet force** (Obj_ForceMIN)
  2. **Increase** of the valves **flow rate** (Obj_FlowMAX)

Objectives

Name	Criterion	Expression	
Obj_ForceMIN	MIN	(-ForceSpoul0025)+(-ForceSpoul005)+(-ForceSpoul015)	3.52129
Obj_FlowMAX	MAX	(-FlowrateA0025*8e5)+(-FlowrateA005*3e5)+(-FlowrateA015*1.7e5)+(-FlowrateA04*1e5)	64.6387
new			

→ **Improve** of the **response time** to ensure, that the clutch is filled with an acceptable speed.

Results - Sensitivity

CoP

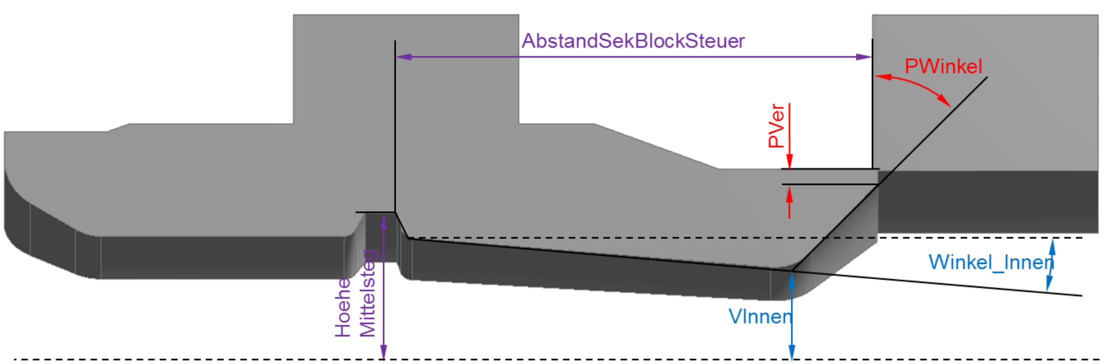
Important for jet force and flow rate:

- AbstandSBS
- HoeheMittelsteg

Important for jet force

- VInnen
- Winkel_Innen

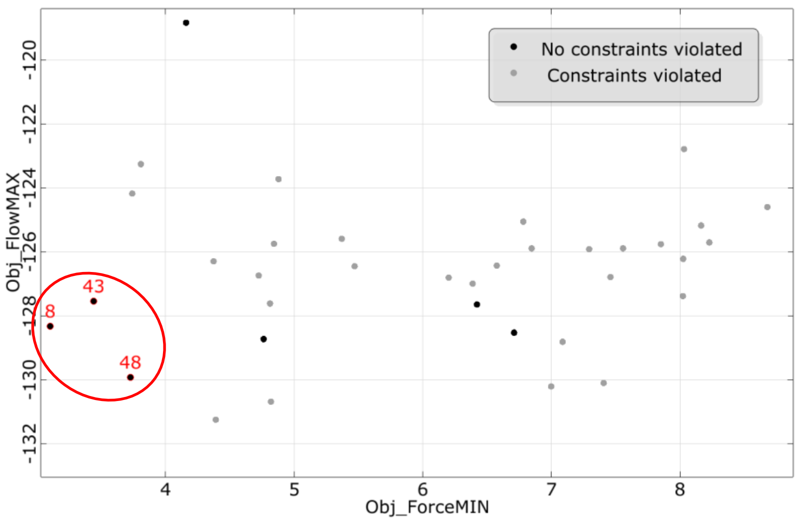
Models \ Parameter	VInnen	nkel_innen	Mittelsteg	AbstandSekBlockSteuer	HoeheMittelsteg	PWinkel	PVer	Total
FlowrateA06				22.5 %	32.7 %	30.5 %	14.7 %	93.0 %
FlowrateA03	0.0 %			18.1 %	19.6 %	38.2 %	32.6 %	91.0 %
FlowrateA015	3.7 %			6.8 %	8.3 %	36.0 %	44.8 %	86.7 %
FlowrateA005	11.6 %			3.0 %	4.0 %	32.4 %	59.6 %	91.6 %
ForceSpoul06	0.0 %			42.6 %	51.8 %			80.6 %
ForceSpoul03	10.2 %	12.7 %		40.2 %	42.5 %	8.0 %		77.9 %
ForceSpoul015	27.0 %	11.5 %		19.4 %	22.7 %	15.9 %		66.6 %
ForceSpoul005	24.0 %			14.5 %	16.4 %	19.2 %	8.1 %	64.4 %

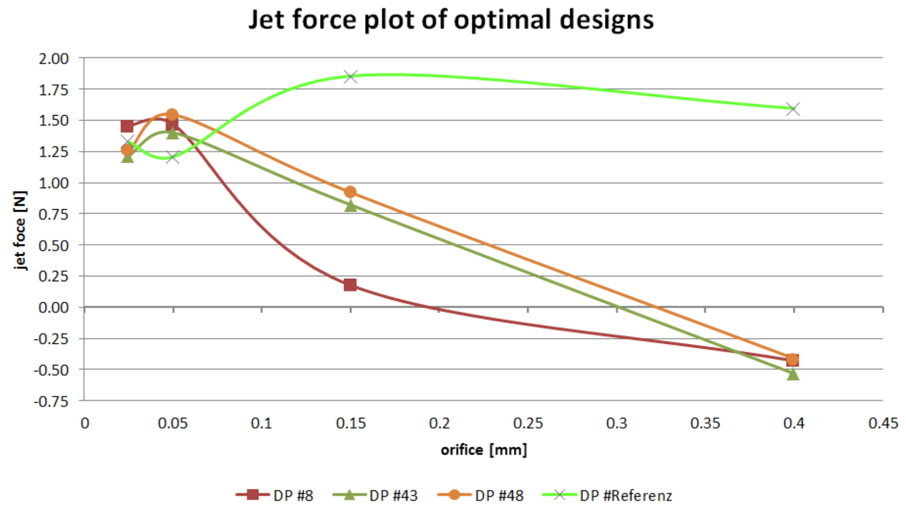


Important for flow rate

- PVer
- PWinkel

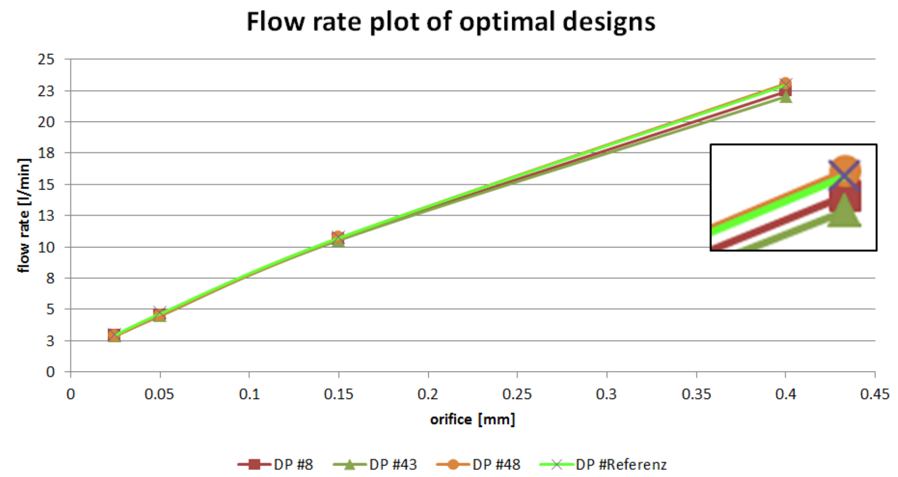
Results – Optimization
Calculation





Three designs with major reduction of jet force: #8, #43 and #48

- #08 lowest jet force
- #48 highest flow rate
- #43 lowest jet force at small orifice; good characteristics of the curve



Optimal design for the given requirements is #43

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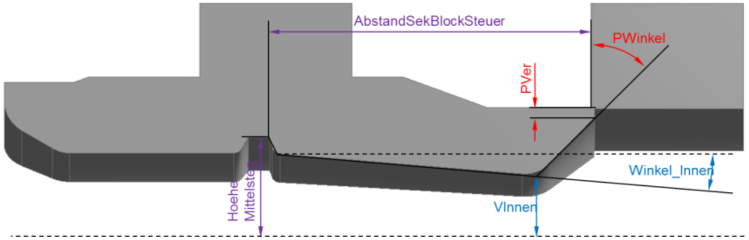
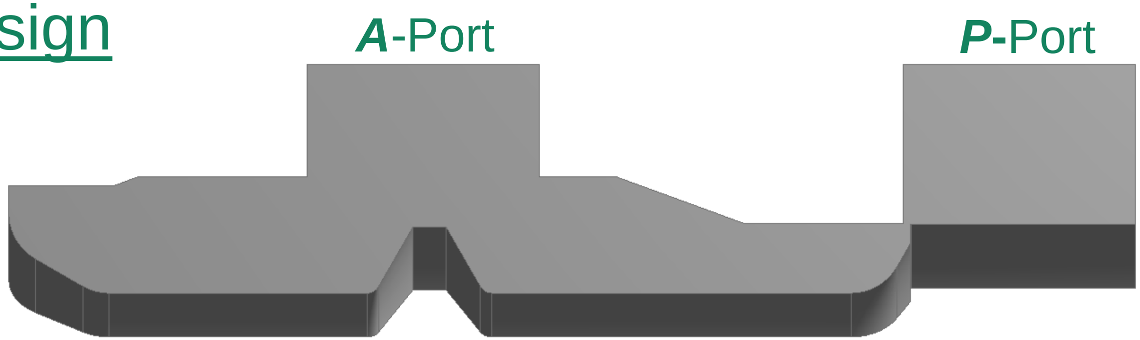
Results - Optimization

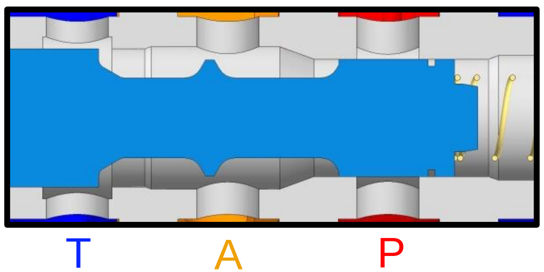
Geometry



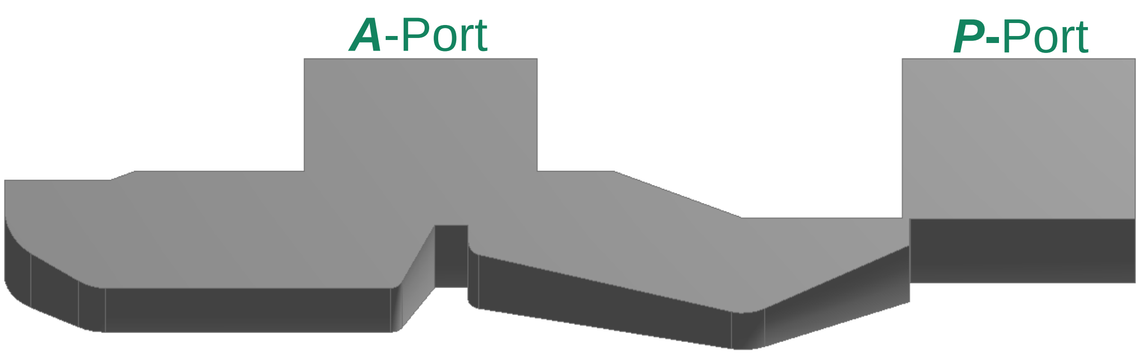
Reference Design



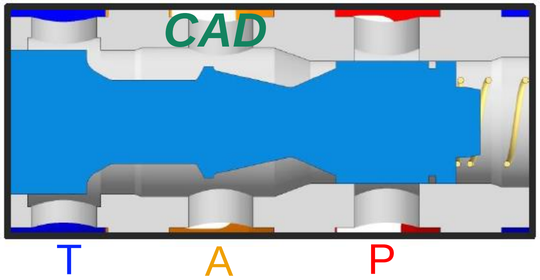
Ref. CAD



Optimized Design

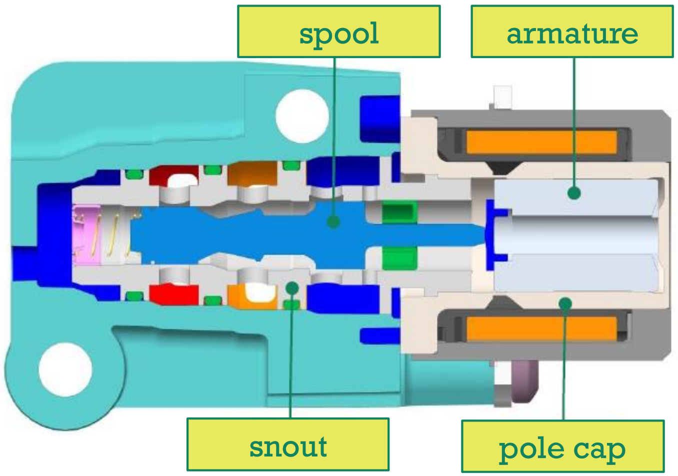


Opti. CAD

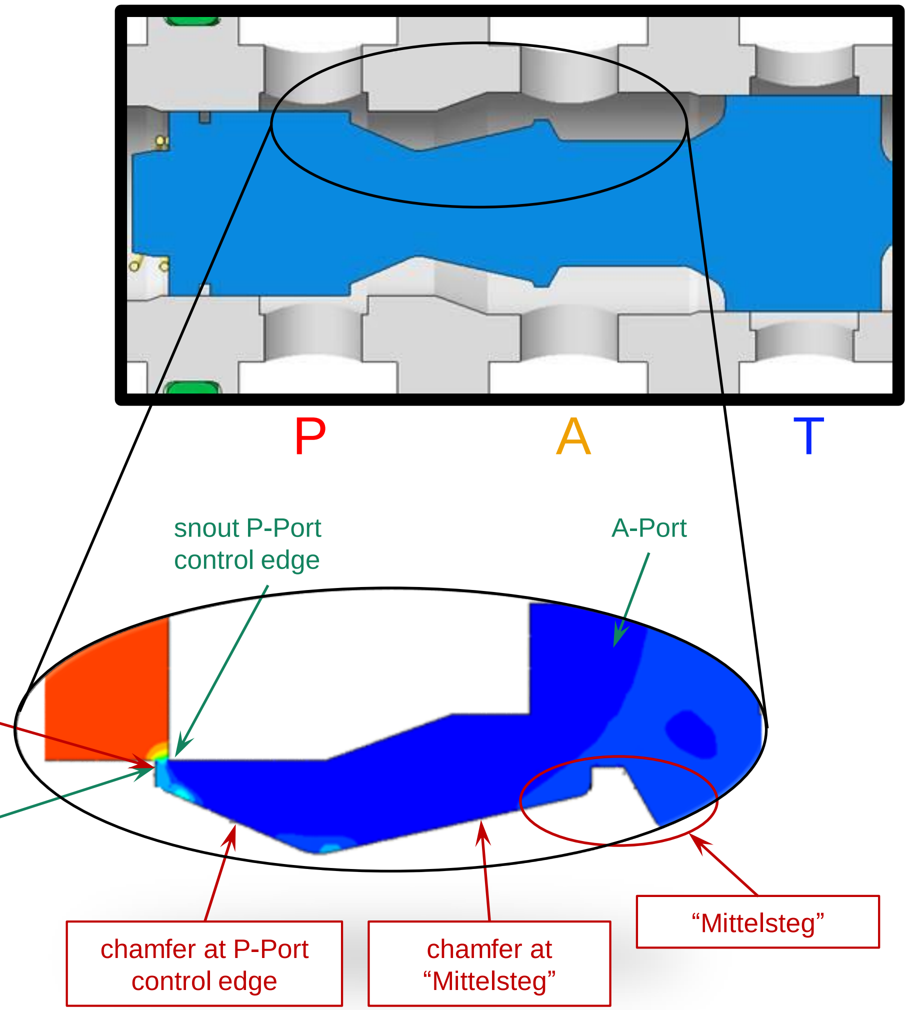


Results - Optimization

Changes of the spool



jet force compensation at

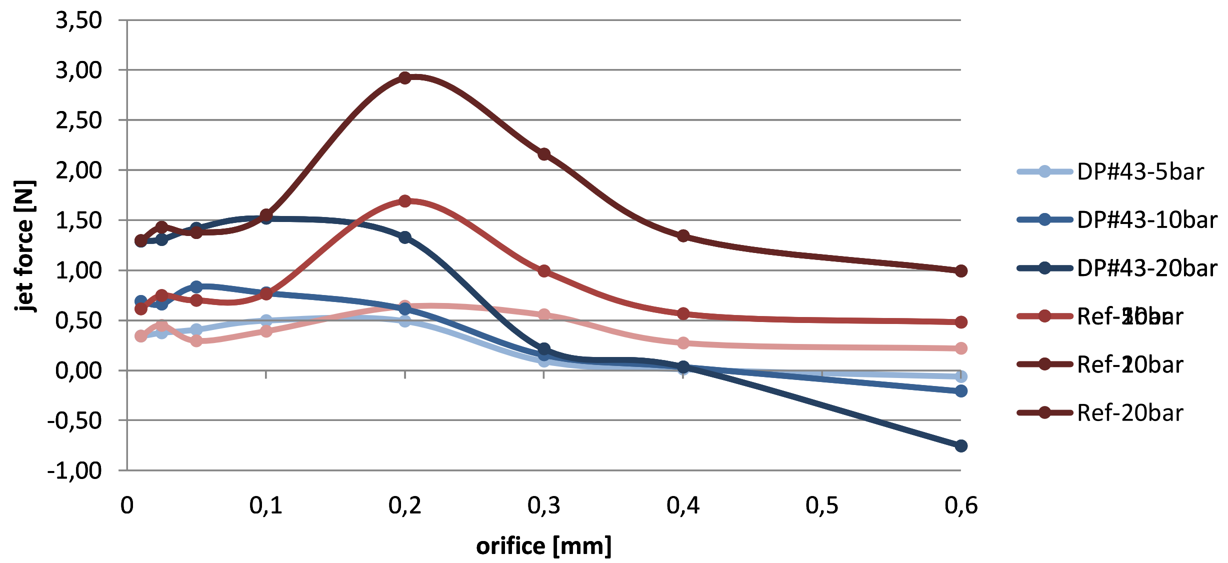


Jet Force reduction up to **50%** & **flow rate** decrease of only **7%**

Density: 816.5kg/m³;
Viscosity: 0.0189Pa s;
Pressure: 20bar;
gap: 0.2mm

Results - Optimization

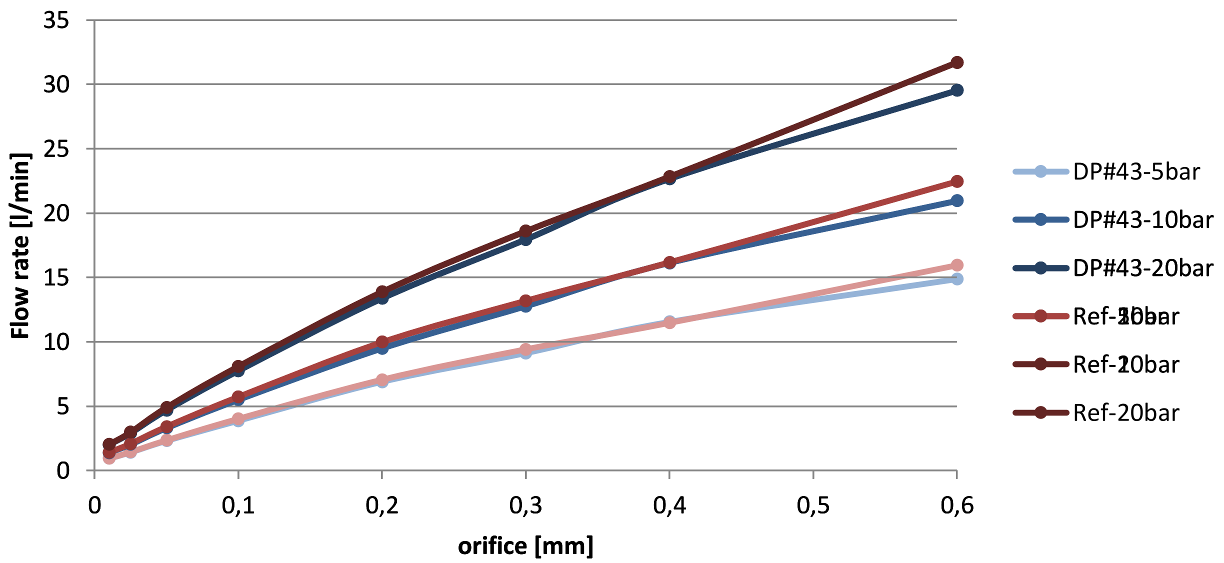
Jet force



- Detailed verification computation to show the behavior of the **jet force vs. spool position** (P-Port gap) for a pressure jump of 5bar, 10bar and 20bar
- **Comparison** of the optimized design and the reference design of the spool
- **Reduction** of the **jet force of 50%** around the peak value
- **Shift** of the **maximum position** to a smaller gap

Results - Optimization

Flow rate

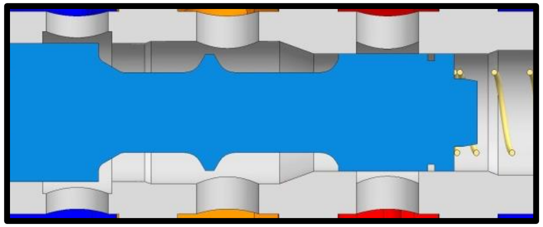


- Detailed verification computation to show the behavior of the **flow rate vs. spool position** (P-Port gap) for a pressure jump of 5bar, 10bar and 20bar
- **Comparison** of the valve between the optimized and the reference spool
- **No increase** of the **flow rate** with a reduced jet force **possible**
- **Low decrease** of the flow rate (maximum at **7%**) with a significant reduction of the jet force (50%)

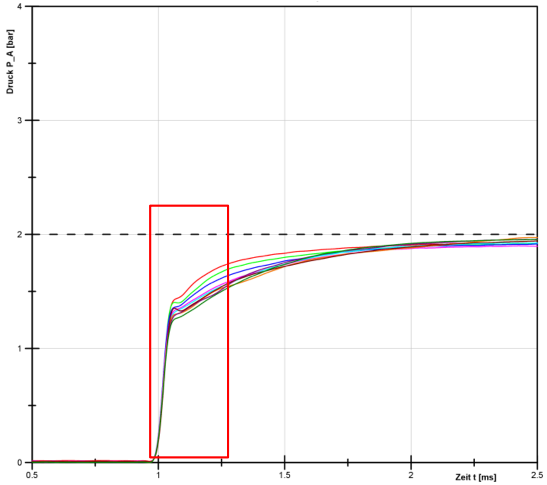
Results - Optimization

Response time

p-t-curve without jet force compensated spool (reference)

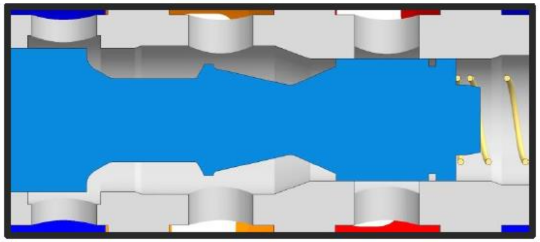


Max. response time at 20bar (90% pressure target):
550 ms

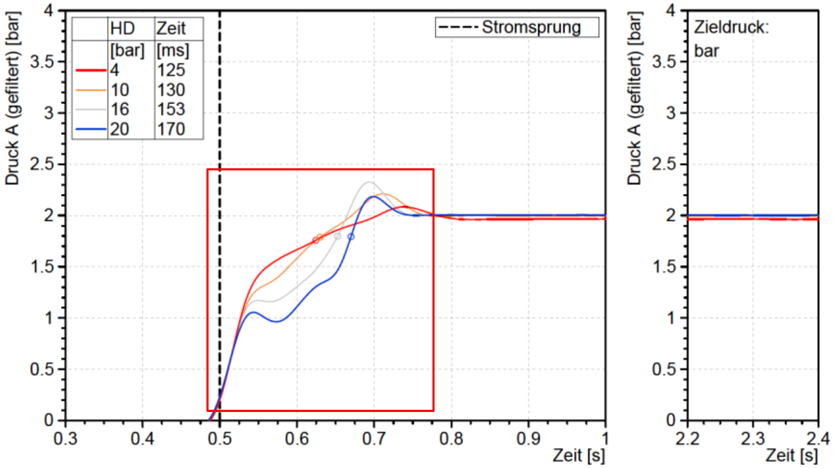


	Betriebsdruck	Schaltzeit	Totzeit	Überschwinger
(red)	4 bar	279 ms	26 ms	0 bar
(light green)	6 bar	339 ms	21 ms	0 bar
(blue)	8 bar	432 ms	23 ms	0 bar
(magenta)	10 bar	468 ms	23 ms	0 bar
(cyan)	12 bar	507 ms	22 ms	0 bar
(orange)	14 bar	501 ms	22 ms	0.07 bar
(purple)	16 bar	655 ms	21 ms	0 bar
(brown)	18 bar	588 ms	22 ms	0 bar
(dark green)	20 bar	555 ms	21 ms	0 bar

p-t-curve with jet force compensated spool (optimized)



Max. response time at 20bar (90% pressure target):
170 ms

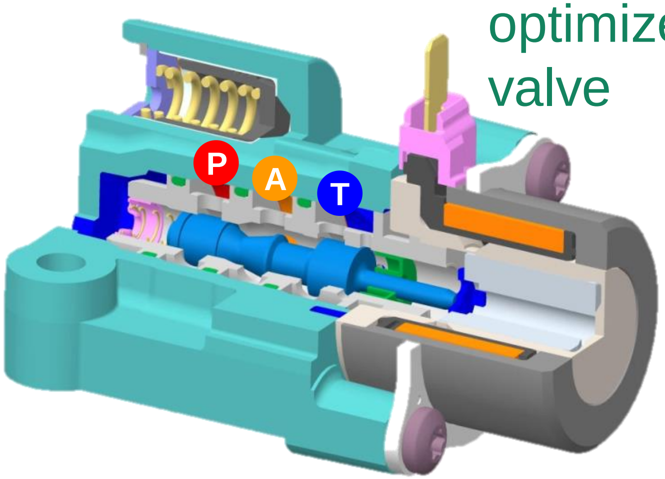


Results - Optimization

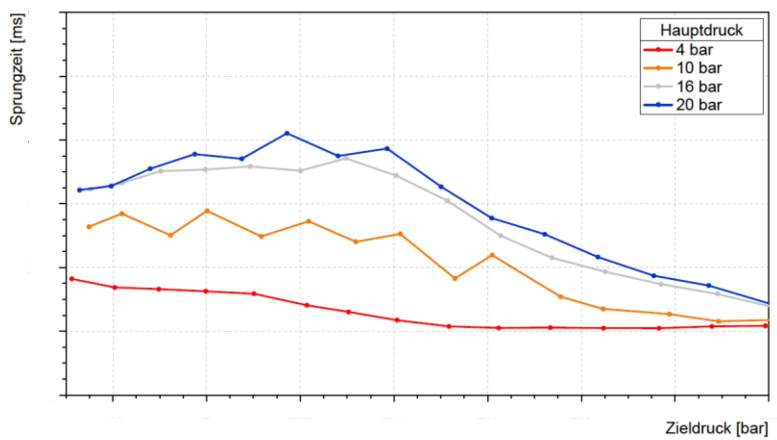
Step response

- max. step response at 20bar supply pressure of 280ms (reference 420ms)
- pressure dependence within a band of <200ms (reference 250-300ms)

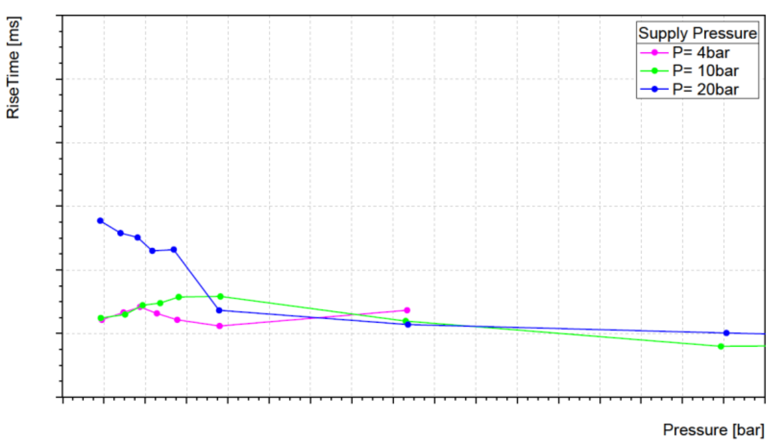
optimized valve



Reference valve



Optimized valve



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Summary

- Using the given parameters, a reduction of the jet force at small gaps is very difficult
- Due to the optimized spool the maximum jet force decreased by 50%
- The critical peak of the jet force (reference design) was removed
- Reduction of the flow rate decreased by 7% at maximum gap
- Tests with the real optimized design show the improvement of the valve`s response time
- No cogging during gear change with the optimized valve

➔ Optimization target of a faster valve fulfilled

Danke für Ihre Aufmerksamkeit.

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