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

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What is Hilite International GmbH?

Everything important about us
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
Introduction – response time

Pressure control valve for DCT

- 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

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

→ Reduction of the step response by optimizing jet force
Solving the problem!

Optimization with OptiSLang and ANSYS CFX
Solving the problem
Methods and tools

- **CFD**: Computational Fluid Dynamics (simplified)
- Numerical approximation of fluid dynamic problem (Mainly used Navier-Stokes or Euler-equations)
- **Method**: 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: 816.5 kg/m³
Viscosity: 0.0189 Pa s
Pressure: 20 bar
Solving the problem
Parameters, constraints and objectives

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

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Results - Sensitivity
CoP

Important for jet force and flow rate:
- AbstandSBS
- HoeheMittelsteg

Important for jet force
- VInnen
- Winkel_Innen

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
Results - Optimization

Geometry

Reference Design

A-Port

P-Port

Optimized Design

A-Port

P-Port

Ref. CAD

Opti.CAD
Results - Optimization
Changes of the spool

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

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)
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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