FLUID DYNAMIC OPTIMIZATION OF HYDRAULIC PROPORTIONAL VALVES BY MEANS OF MODEFRONTIER COUPLED WITH CFD

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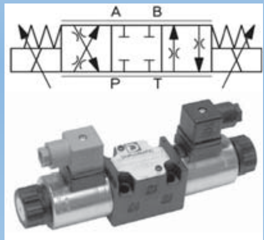
INTRODUCTION

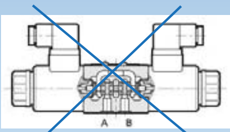
Single stage directional proportional valves are widely and effectively used to enhance the performance of hydraulic circuits. They allow adjusting the flow rate with high precision so as to control the velocity and the position of the actuator (hydraulic cylinder or hydraulic motor) as well as its acceleration and deceleration.



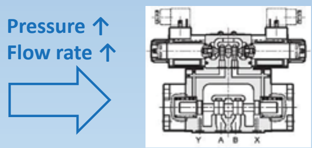
4/3 single stage proportional valve

ADVANTAGES:
- these valves are cheap and are characterized by a very simple architecture;
- they are accurate and guarantee good frequency responses.

LIMITATIONS: these types of valves cannot be used for high values of pressure and/or flow rate because, in this case, the flow forces acting on the spool are too high to be counteracted by the actuation forces generated by commercially available solenoids. In such cases, the two stage configuration must be used, which is more complicated to construct and hence more expensive.


Single stage configuration

Pressure ↑
Flow rate ↑

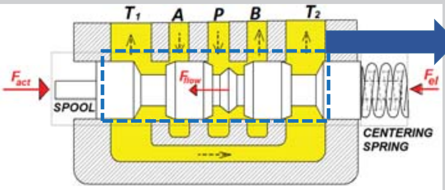

Two stage configuration

Costs ↑
Manufacturing Times ↑

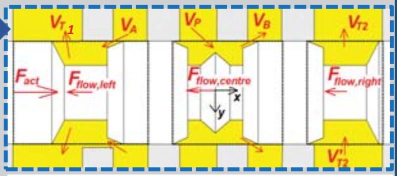
OBJECTIVE OF THE RESEARCH ACTIVITY

Is to propose a valid methodology that allows the spool geometry of single stage proportional directional valves to be improved, thus reducing the required actuation forces in order to extend their application range towards higher values of pressure and flow rate. The methodology is designed to have general validity and be reliable.

METHODOLOGY: SELECTION OF THE DESIGN PARAMETERS



typical architecture of a 4/3 single stage valve



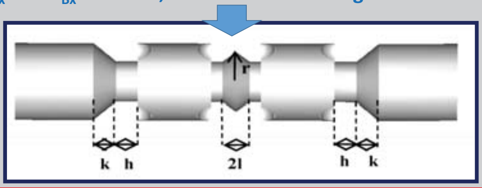
Enlargement on the spool

The actuation force F_{act} must counteract the flow force F_{flow}, namely the resistance force due to the fluid motion. The flow force F_{flow} can be calculated as follows:

$$F_{flow} = F_{flow,\,left} + F_{flow,\,centre} + F_{flow,\,right} = \dot{m}\,[\,V_{Bx} - V_{Px} + V_{Ax} - V_{T1x}\,]$$

The proposed strategy is to reduce the flow force by increasing V_{Px} and V_{T1x}, while manteining V_{Ax} and V_{Bx} constant, in order not to change the metering characteristics

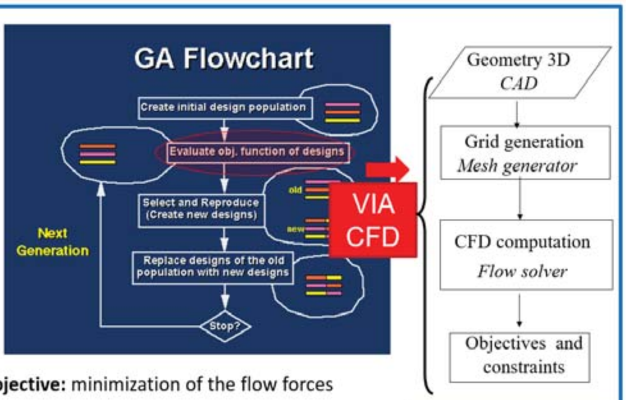
DESIGN PARAMETERS



These parameters do not affect the flow rate characteristics

NOMENCLATURE:
P= inlet port; A, B= ports connected with the actuator; T1, T2= discharge ports
V= fluid velocity; ṁ= mass flow rate; F_{flow} = flow force; F_{act} = actuation force

METHODOLOGY: OPTIMIZATION PROCESS BY MEANS OF MODEFRONTIER



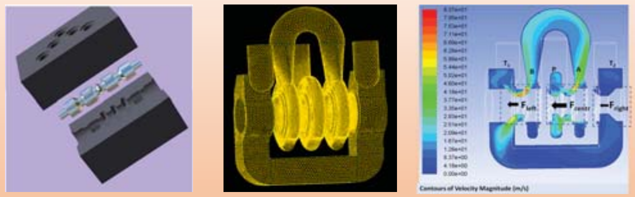
Objective: minimization of the flow forces

Constraint: constant mass flow rate

The single objective optimization process is based on the coupling between a genetic algorithm (MOGAII) and the fully 3D CFD model of the fluid flow within the valve

APPLICATION OF THE FLUID DYNAMIC OPTIMIZATION TO A COMMERCIALLY AVAILABLE VALVE

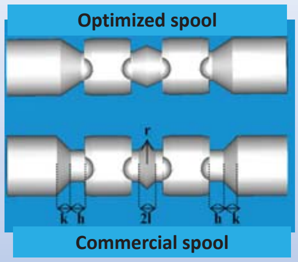
The optimization procedure has been tested on an existing valve


CAD model **mesh** **flow solution**

The CAD models of both the spool and the valve body were built so as to generate the 3D mesh (1.4 million cells)

RESULTS OF THE OPTIMIZATION PROCESS

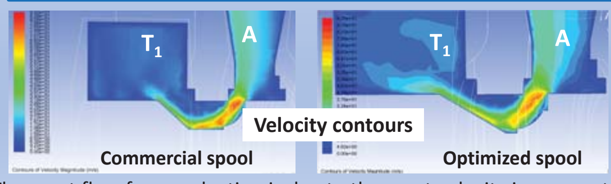
Individuals explored	1000
Computational time	20 days
Hardware	Intel core i7, 3.2 GHz and 32 GByte of ram



Parameter (mm)	Reference (commercial)	Optimized
h	4.1	0.9
k	3.8	5.8
r	6.2	6.0
l	2.0	4.0

Values of the design parameters

THE OPTIMIZED SPOOL ALLOWS A FOW FORCE REDUCTION OF ABOUT 15% AT THE MAXIMUM OPENING



Velocity contours

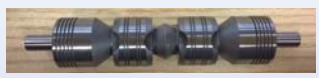
The great flow force reduction is due to the great velocity increase at the outlet of the valve (section T_1).

EXPERIMENTAL VALIDATION

To validate the procedure, the optimized sliding spool was constructed and then experimentally compared with the commercial one.

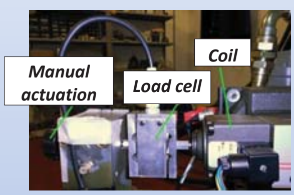

Commercial spool

VS


Optimized spool

An experimental test rig was assembled to compare the two spools. A manual actuation system was also designed to accurately measure the actuation forces.


Hydraulic test rig



Actuation force measurement system

The experimental results confirm that the actuation force is reduced by 15% at the maximum opening degree, while the flow rate is not changed.