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.

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.

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:

$$ F_{flow} = F_{flow, left} + F_{flow, centre} + F_{flow, right} = \dot{m} \left[ V_{BA} - V_{PX} + V_{AX} - V_{TX} \right] $$

The proposed strategy is to reduce the flow force by increasing $V_{BA}$ and $V_{TX}$, while maintaining $V_{PX}$ and $V_{AX}$ 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; $T_1$, $T_2$: discharge ports
- $V$: fluid velocity; $\dot{m}$: mass flow rate; $F_{flow}$: flow force; $F_{act}$: actuation force

METHODOLOGY: OPTIMIZATION PROCESS BY MEANS OF MODEFRONTIER

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.

RESULTS OF THE OPTIMIZATION PROCESS

<table>
<thead>
<tr>
<th>Parameter (mm)</th>
<th>Reference (commercial)</th>
<th>Optimized</th>
</tr>
</thead>
<tbody>
<tr>
<td>$h$</td>
<td>4.1</td>
<td>0.9</td>
</tr>
<tr>
<td>$k$</td>
<td>3.8</td>
<td>5.8</td>
</tr>
<tr>
<td>$r$</td>
<td>6.2</td>
<td>6.0</td>
</tr>
<tr>
<td>$l$</td>
<td>2.0</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Values of the design parameters

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

EXPERIMENTAL VALIDATION

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

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