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Experimental and numerical investigation of flow forces in a seat valve using a damping sleeve with orifices

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Introduction

Current vehicle drive system:
Low efficiency, heavy pollution.

Hydraulic hybrid system:
Low installed power, Energy saving, but complicated.

Hydraulic free piston engine system:
Energy saving, Highly integrated.

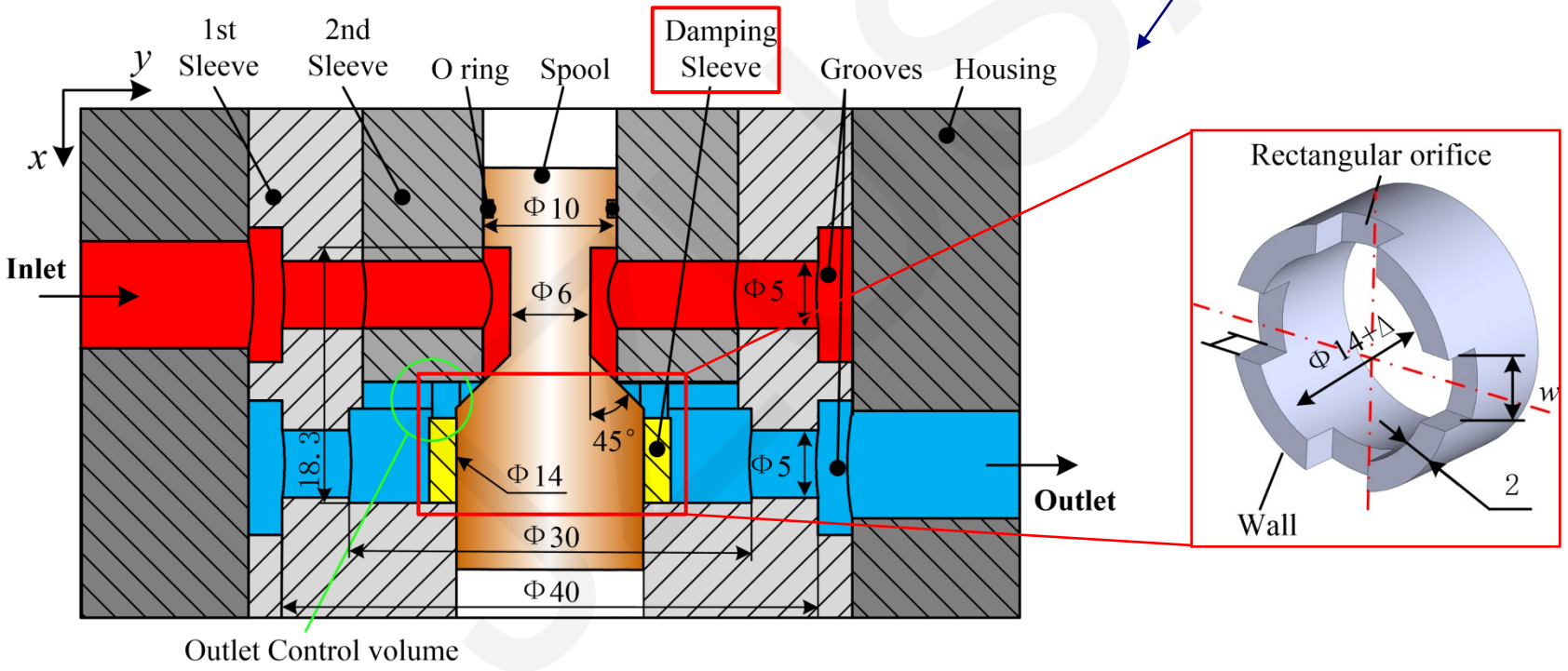
Requirement for the valve:
High response and fast switch.

Method:
Increasing the driving force & Decreasing the flow force.

Flow force reduction method

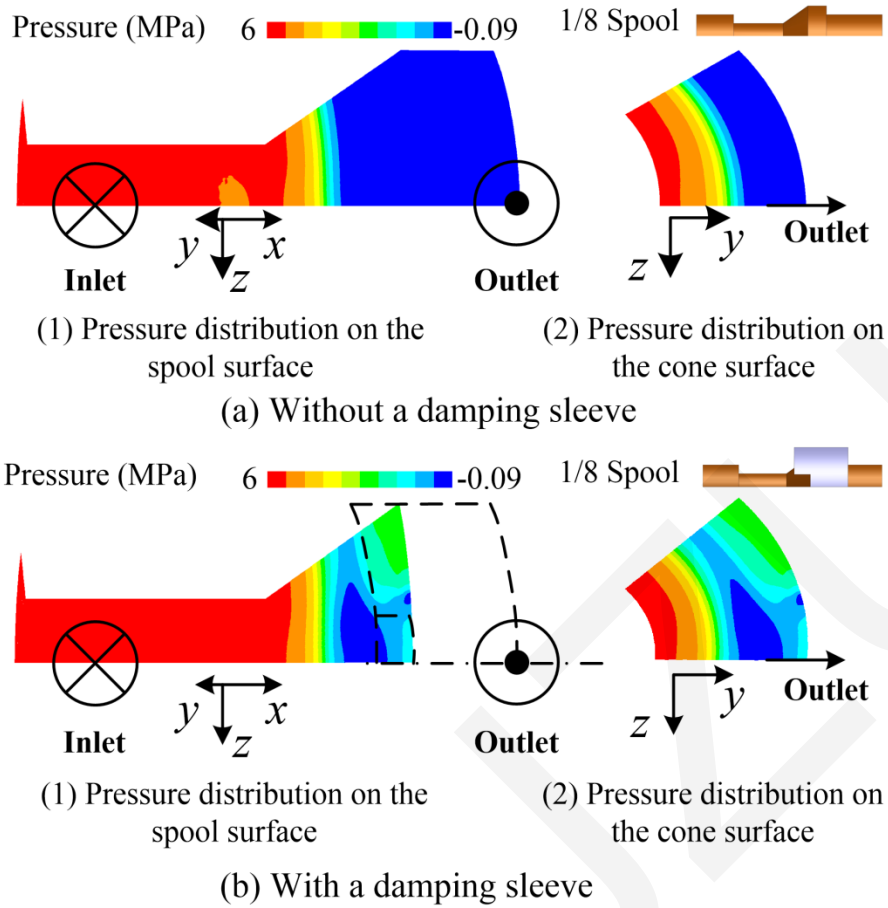
Reduction method	:	Radial flow compensation	Pressure drop compensation	Jet guiding compensation

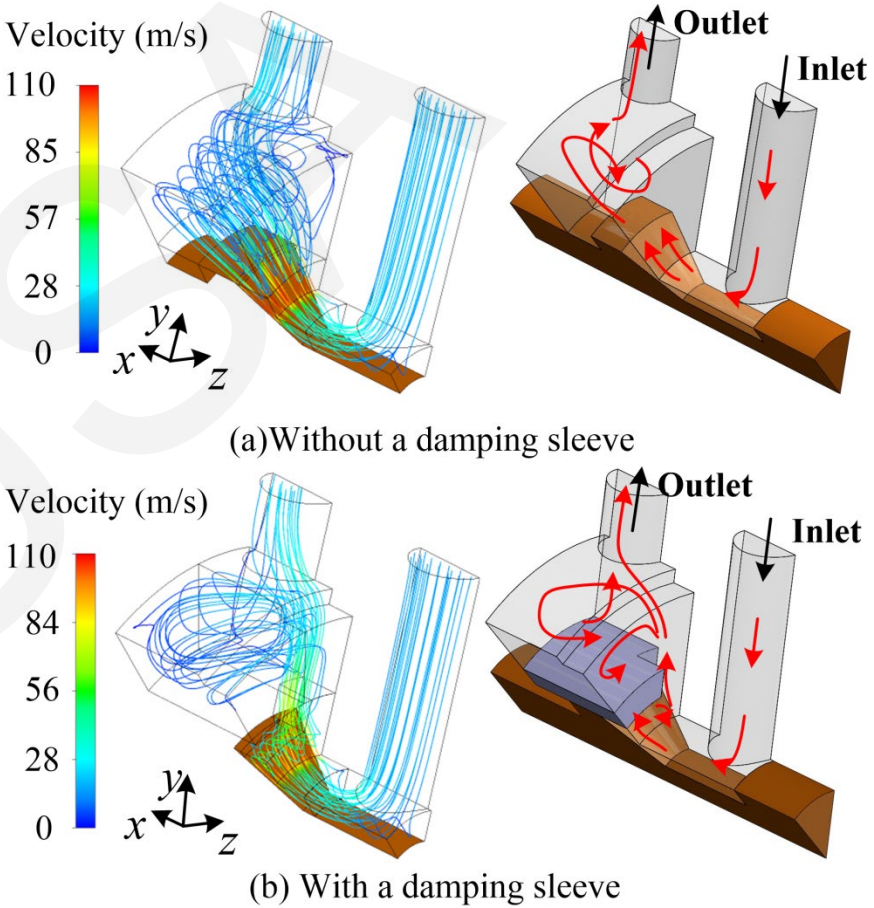
Proposed damping slave



The effect is simulated by CFD approach and tested by experiment.

Simulated & experimental results

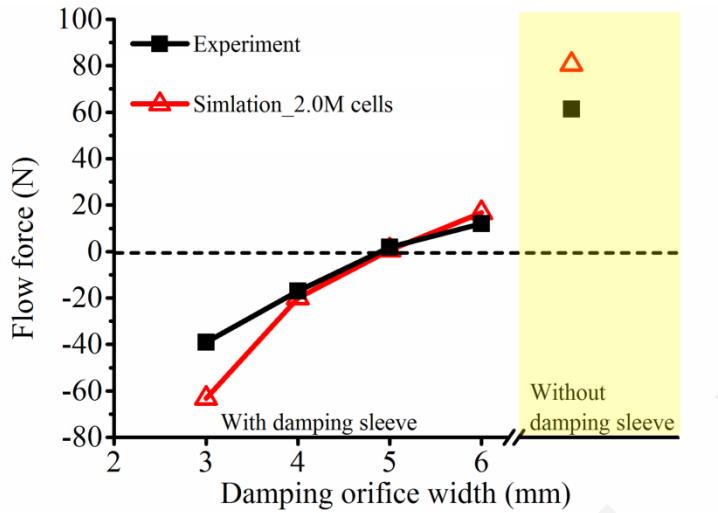




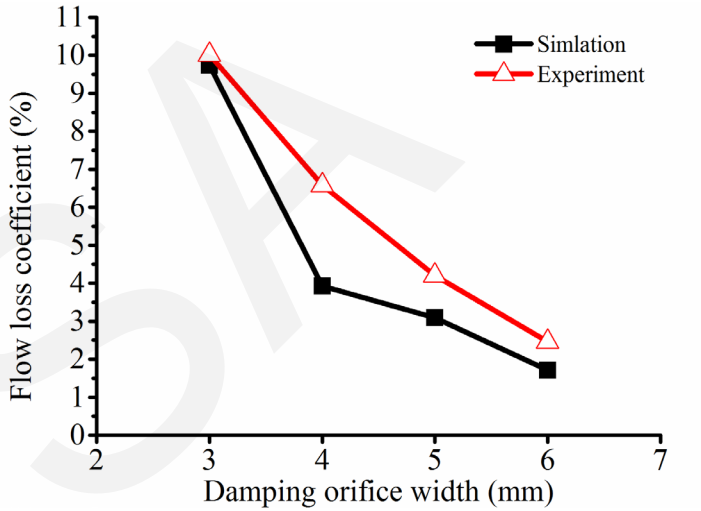
Comparison of the pressure distribution on the spool

Comparison of the of the flow structure

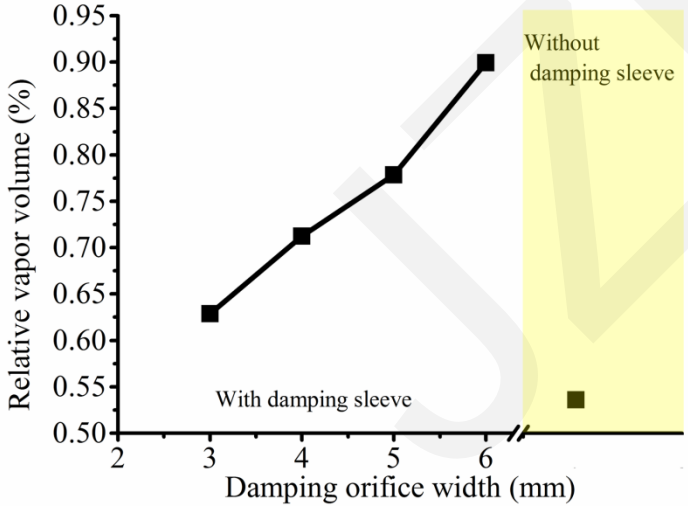
Simulated & experimental results



Flow force comparison



Flow loss comparison

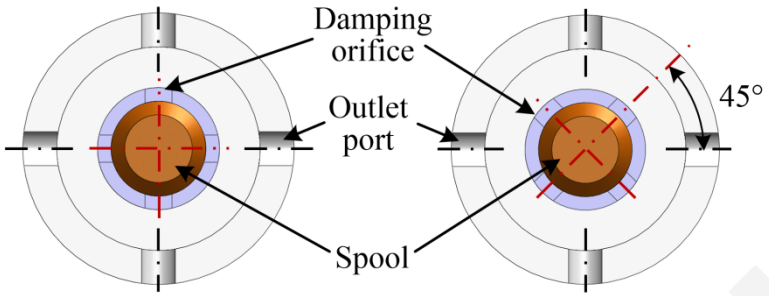


Relative vapor volume comparison

- The damping sleeve changes the pressure distribution and flow direction at the spool;
- The damping sleeve can significantly reduce the flow force with rather low flow loss and cavitation change.

Simulated results

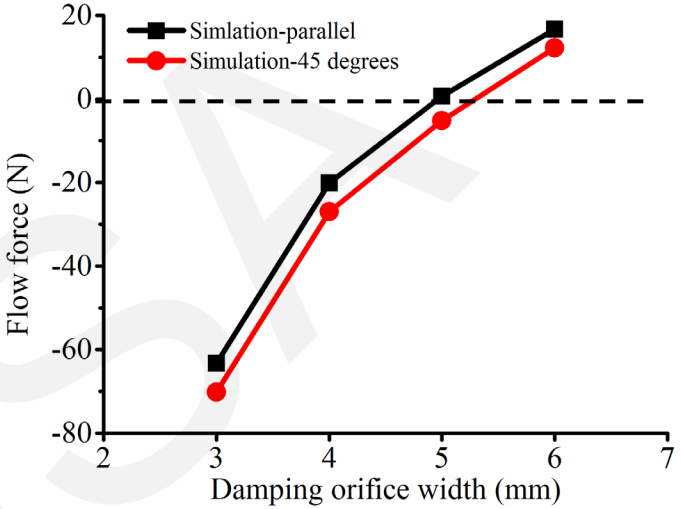
Relative installation position change



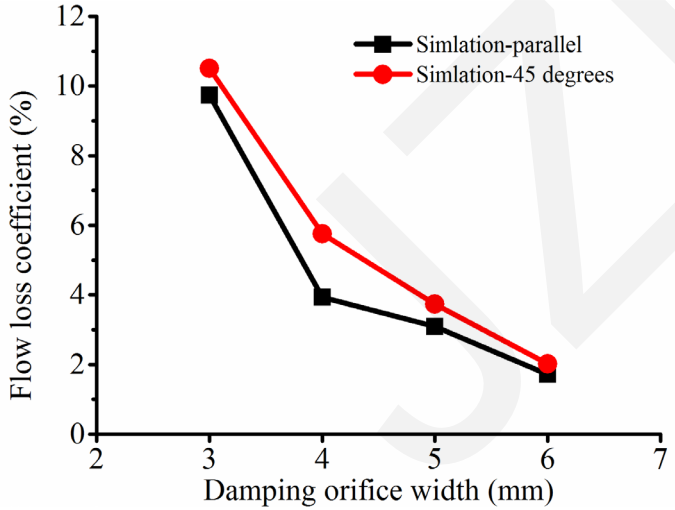
(a) Damping orifices are parallel with outlet ports

(b) Damping orifices are at the angle of 45° to the outlet ports

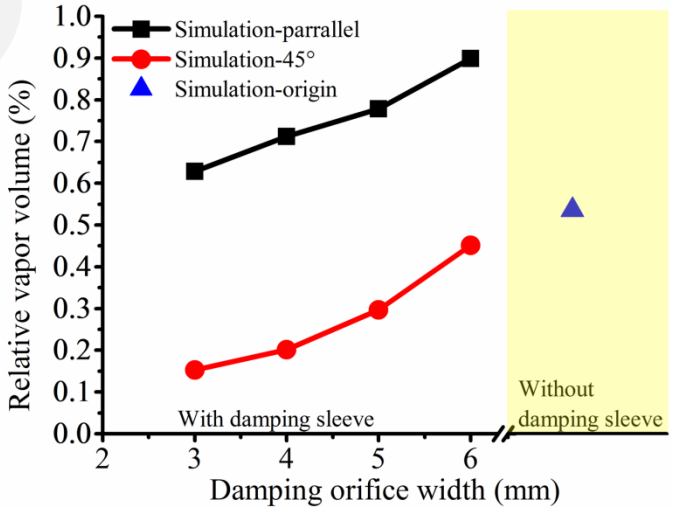
Installation angle : 0° → 45°



Flow force comparison

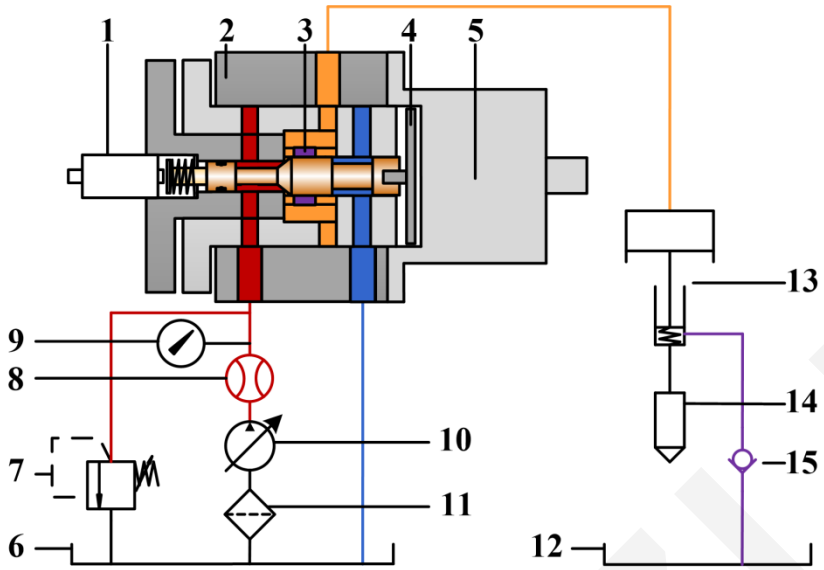


Flow loss comparison



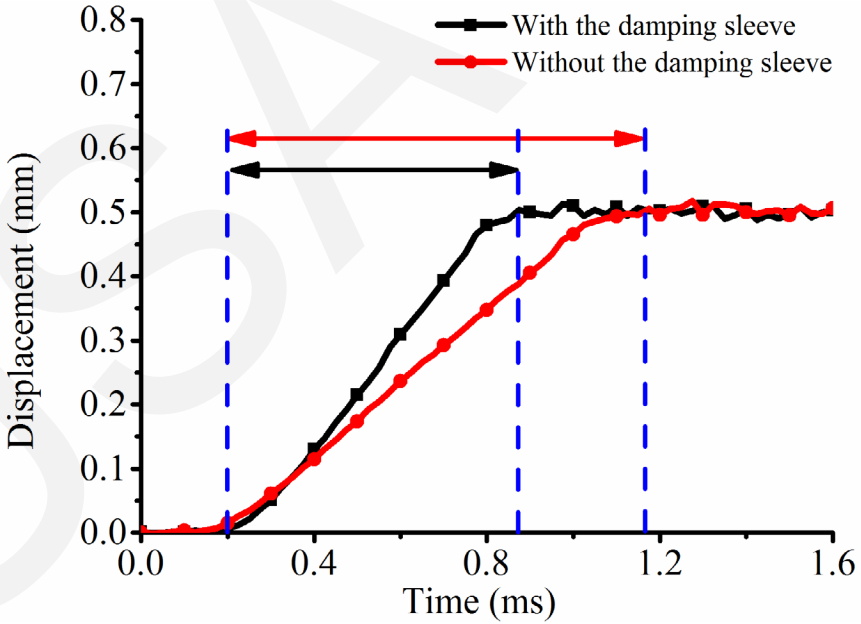
Relative vapor volume comparison

Experimental tests of valve response



1-Displacement sensor; 2-Teseted valve; 3-Damping sleeve;
4-Armature; 5-Electromagnet; 6-Hydraulic oil tank;
7-Relief valve; 8-Flow sensor; 9-Pressure sensor; 10-Pump;
11-Filter; 12-Fuel tank; 13-Pressure transformer;
14-Injector; 15-Check valve

Fuel injection system test rig



Comparison of spool displacement when given step signal

- The opening time of the valve is reduced by 31% from 0.97 ms to 0.67 ms.

Conclusion and future work

Conclusion

- A 3D CFD analysis using RNG k-ε model for turbulent flow and the Schnerr and Sauer model for cavitation is carried out to look into the seat valve flow field. The simulated results are validated by experiment;
- A damping sleeve with orifices is proposed to reduce the axial flow forces;
- The flow force can be reduced by the damping sleeve from 61.29 N to 1.88 N with 4% flow loss;
- The cavitation effect is observed and compared with different structures.

Future work

- Further research will be focused on cavitation optimization by geometrical modifications and injection system improvements. The electromagnet capability should also be improved.