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Flow analysis of asymmetric clearance and optimization of pressure equalization grooves to mitigate hydraulic spool valve sticking

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Key words: Spool valve, Flow characteristics; Multi-objective optimization; Solid-liquid two phase flow; Aerospace hydraulic systems; Valve sticking

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1 Research model

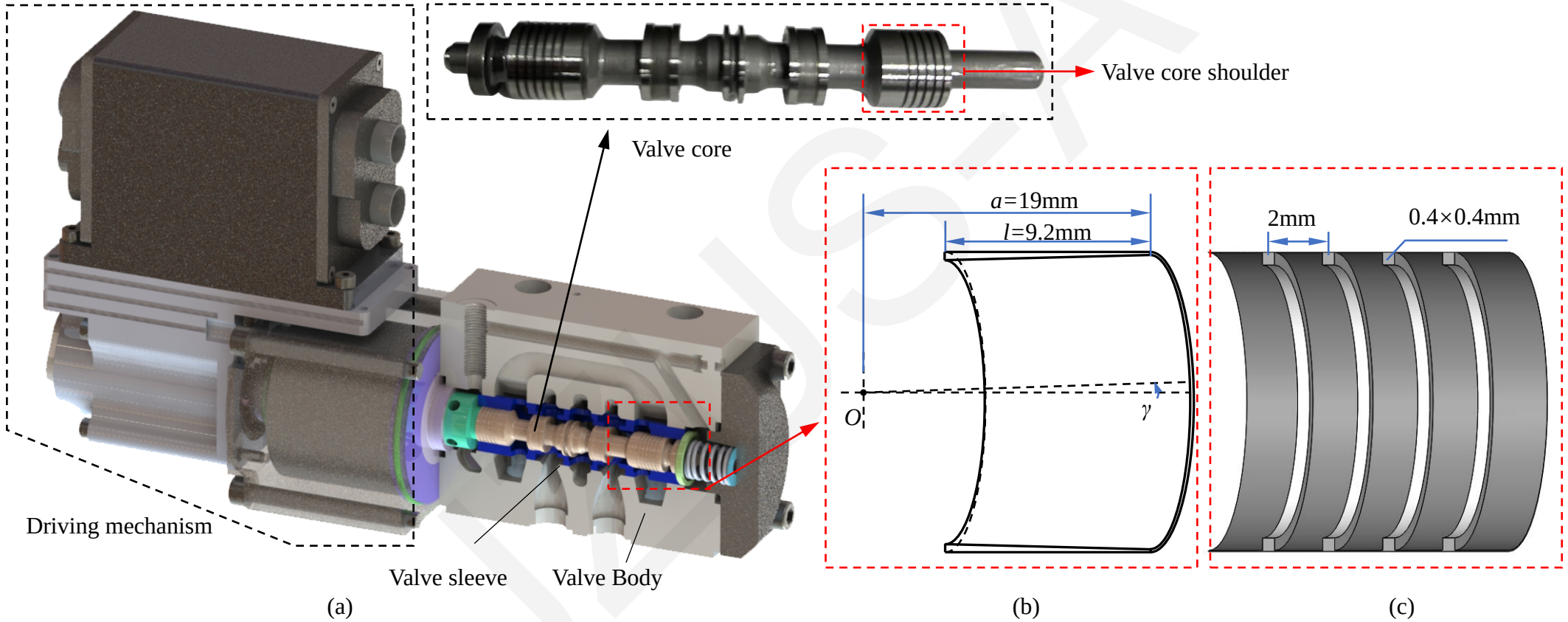


Fig. 1 Hydraulic spool valve and flow channel of the fit clearance

2 Fluid force analysis of the valve core

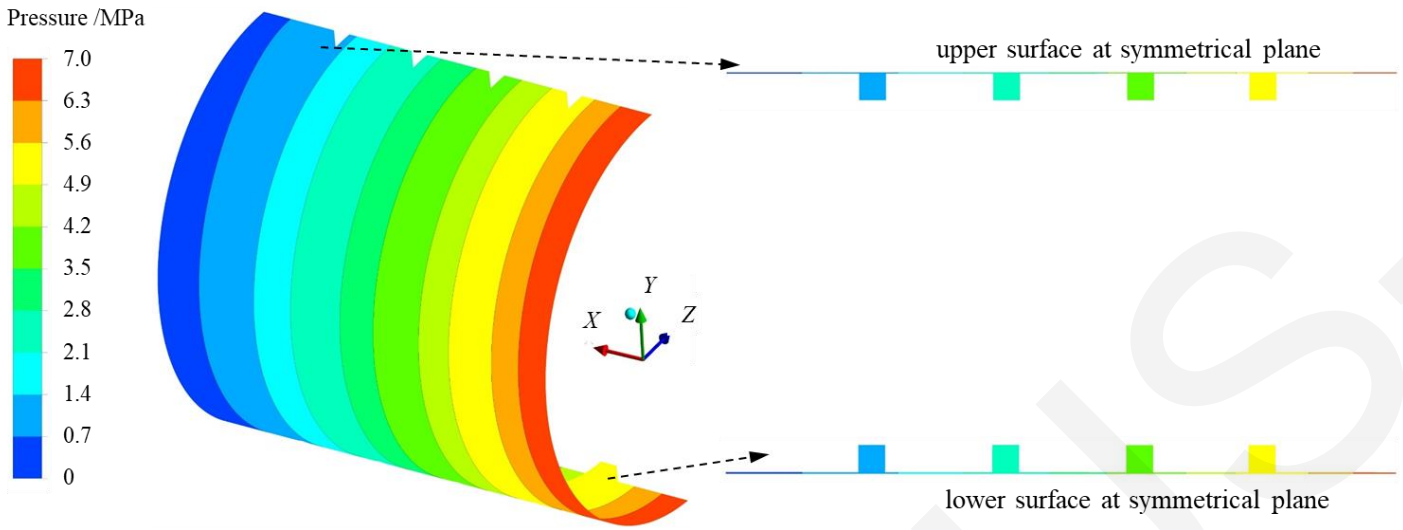


Fig. 2 Pressure distribution of the valve core shoulder surface with PEG

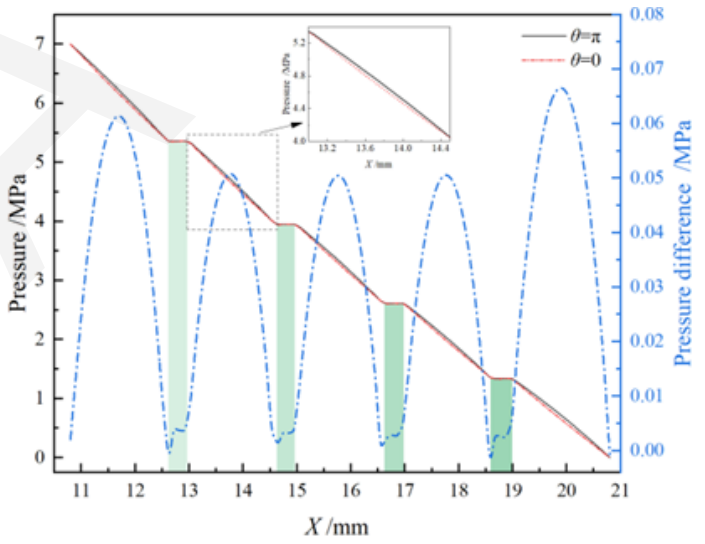


Fig. 3 Pressure curve of the valve core shoulder surface with PEG

- The PEG divides the uneven pressure distribution within the clearance into multiple segments.
- The pressure distribution on the upper and lower surfaces of the valve core shoulder with PEC along the circumferential direction is more uniform.

3 The distribution of solid particles

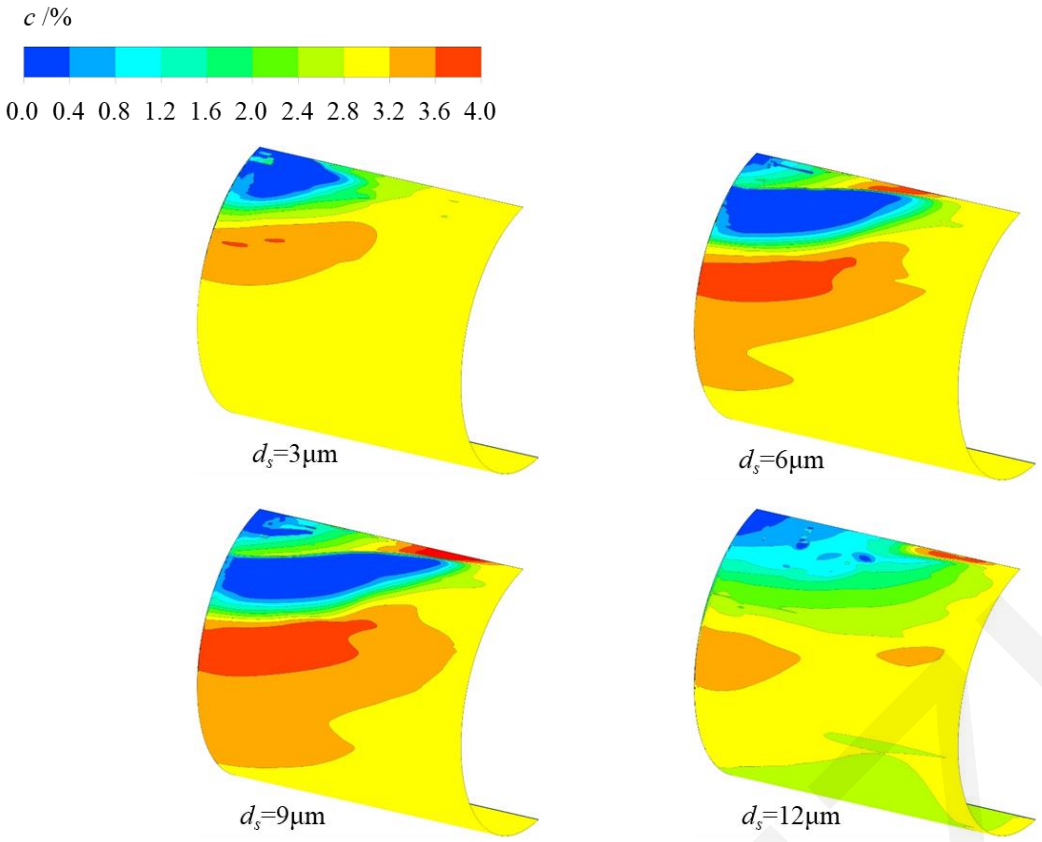


Fig. 4 The distribution of the particle volume fraction

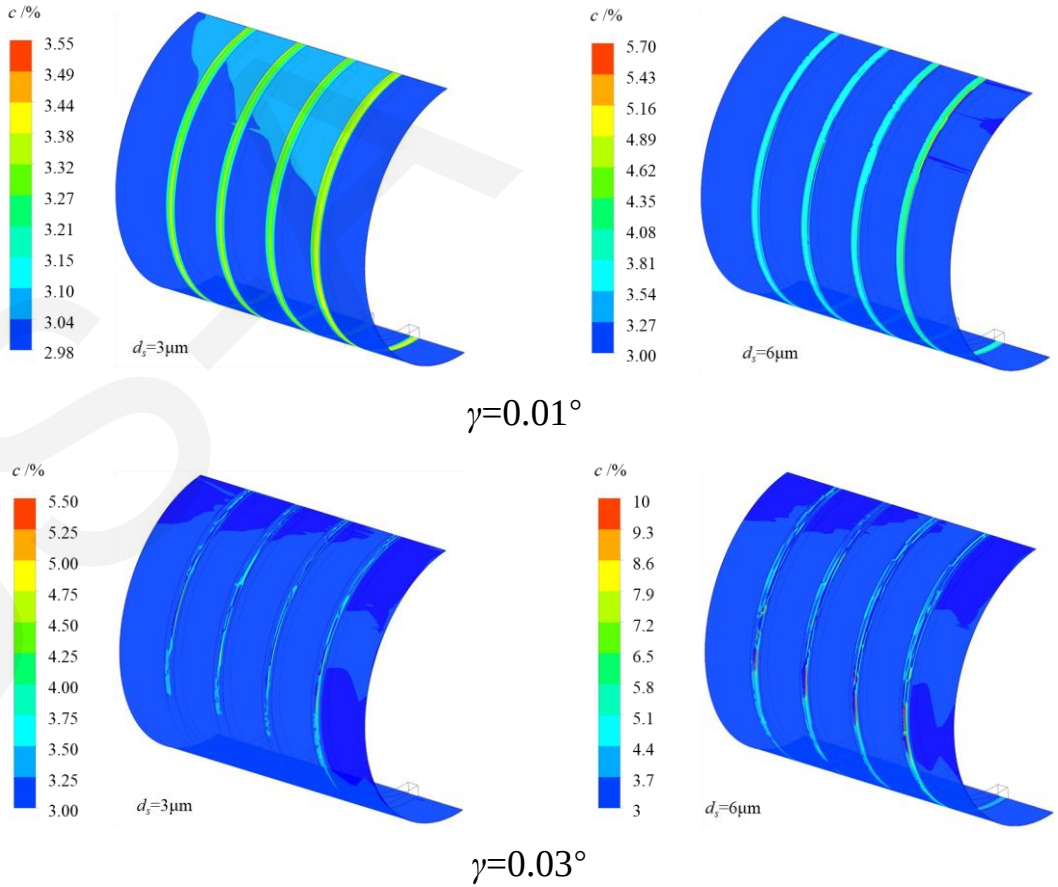


Fig. 5 The distribution of the particle volume fraction with PEG

- The solid particles are mainly located at the position of the PEG, and the particle accumulation slows down in the sensitive sticking area.

4 Optimization design of the PEG

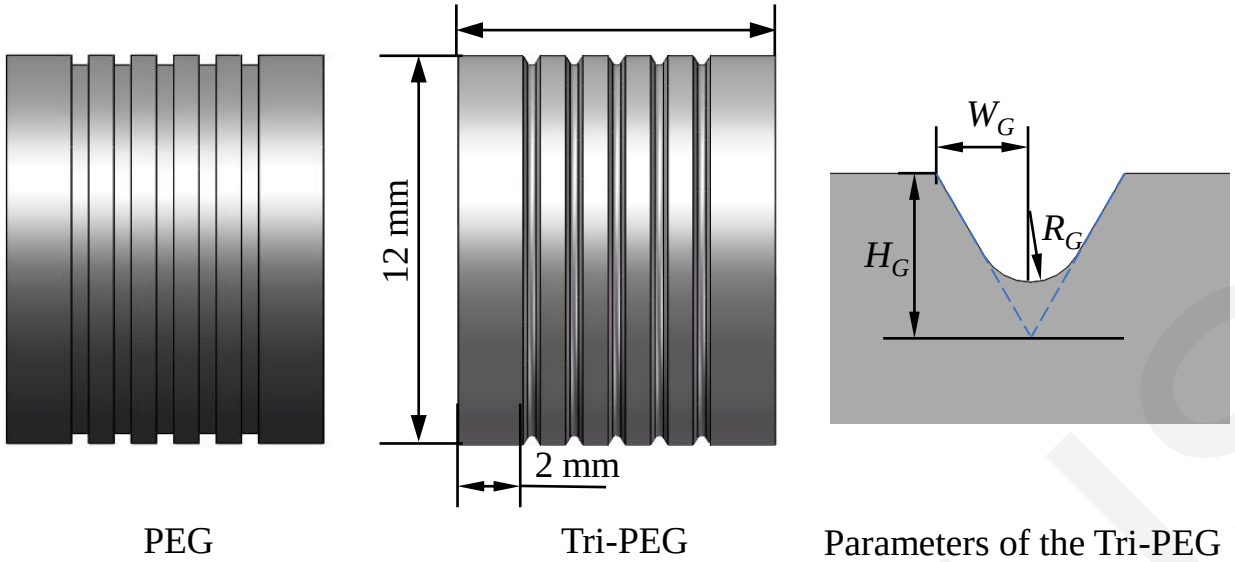


Fig. 6 Structural diagram of Tri-PEG

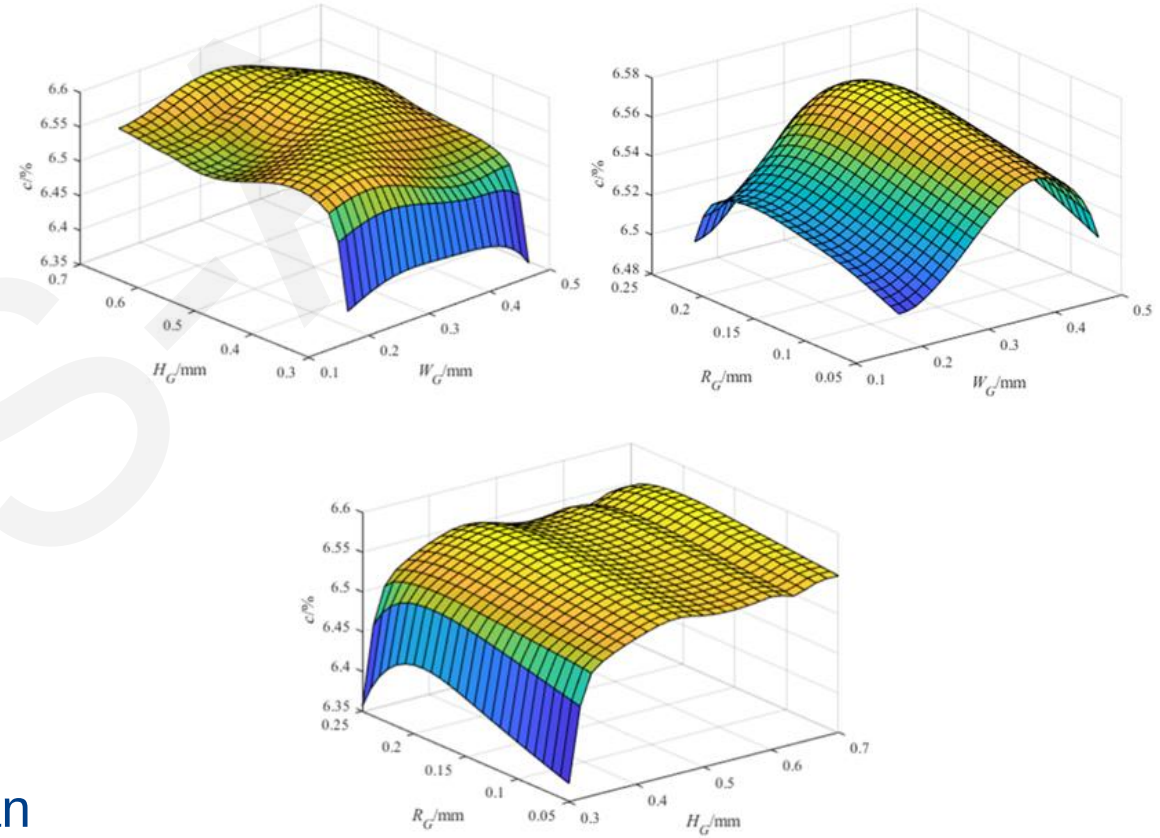


Fig. 7 Variation of particle volume fraction with H_G , W_G and R_G

- A triangular pressure equalization groove with an arc-shaped bottom (Tri-PEG) was proposed.
- After optimization, the problems of spool valve sticking can be effectively alleviated.

5 Conclusions

- The radial fluid force is positively correlated with the inclination angle, and negatively correlated with the clearance. The introduction of a PEG into the valve core is beneficial for reducing the uneven distribution of pressure in the fit clearance, and can slow down the aggregation of particles in the sensitive sticking area. The particles are mainly concentrated in the PEG, which helps to reduce the occurrence of valve core sticking.

- The groove width of the triangular PEG with an arc-shaped bottom (Tri-PEG) was revealed to be the main factor affecting the leakage at the fit clearance. The groove depth and arc-shaped radius have positive and negative effects on the leakage rate, respectively. Compared with the rectangular PEG structure, the optimal Tri-PEG structure reduces the leakage by 12% and increases the volume fraction of particles in the groove by 6%. It can therefore control the leakage at the valve core clearance and the degree of particle concentration at the bottom of the groove.

- The Tri-PEG structure effectively reduces the unbalanced radial force by homogenizing the pressure distribution in the fit clearance, while simultaneously acting as an efficient particle trap to mitigate sticking risk. However, it should be noted that the optimization results and conclusions of this study were obtained under specific simulation operating conditions. If there are significant changes in the working fluid and operating conditions, then the optimal structural parameters of the Tri-PEG structure may change.