## Electronic supplementary materials

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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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**Section S1: The radial fluid force and the solid particle flow of the valve core**

Figure S1 shows the radial force diagram of valve core. The fluid flows from the left to the right, and the uneven pressure difference on the surface of the valve core causes an upward radial clamping force on the valve core. This exacerbates the inclination or skewness of the valve core, causing it to contact the valve body or sleeve. This can lead to sticking. If the fluid flows from the right side to the left side, the uneven pressure difference will cause a downward radial clamping force, making the valve core to move downward, thereby reducing the degree of inclination and deflection of the valve core.

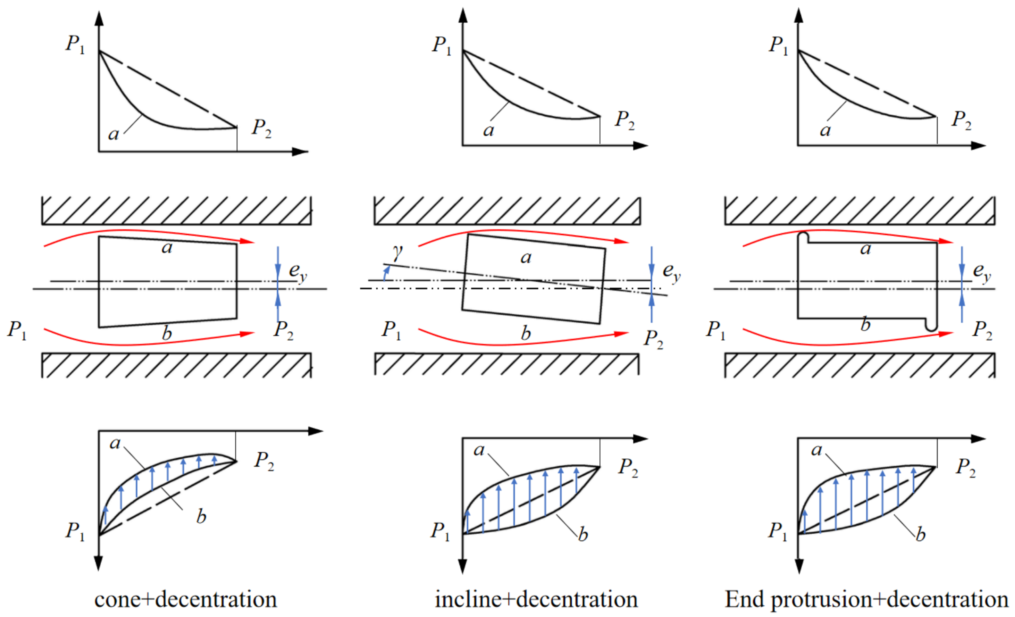


**Fig. S1 Radial force diagram of the valve core**

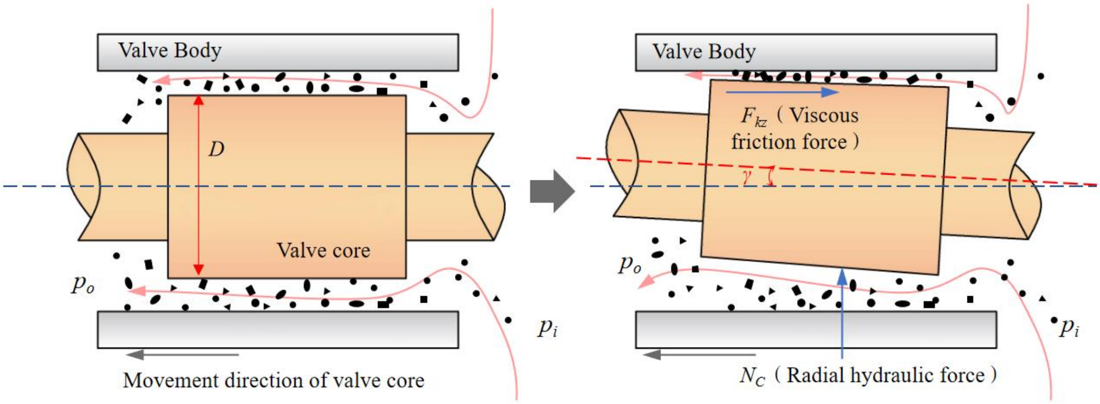


**Fig. S2  Solid particle flow within the asymmetric clearance of the valve core**

**Section S2: Structural design parameters and results of parameter optimization**

Take the arc-shaped radius ($R_G$), the groove depth ($H_G$), and the groove width ($W_G$) as the design parameters. The range of values for Tri-PEG design parameters are mainly determined by the structural continuity. Table S1 is the value range of design parameters. Considering the leakage and cleaning capacity changes caused by the structural parameters of the Tri-PEG. The leakage volume ($Q_s$) of the fit clearance and particle volume fraction ($c_s$) at the bottom of Tri-PEG were taken as the optimization objective. The objective function is as follows:

$$f_{ob} = \{\text{Min}\ (Q_s),\ \ \text{Max}\ (c_s)\} \tag{S1}$$

**Table S1  The value range of design parameters**

| Design parameter | $W_G$ (mm) | $H_G$ (mm) | $R_G$ (mm) |
|---|---|---|---|
| Value range | 0.165~0.565 | 0.3~0.9 | 0.05~0.25 |

**Table S2  Sample data points and results**

| Number | $W_G$ (mm) | $H_G$ (mm) | $R_G$ (mm) | $Q_s$ (mL/min) | $c_s$ (%) |
|---|---|---|---|---|---|
| 1 | 0.392 | 0.76 | 0.163 | 5.133 | 4.041 |
| 2 | 0.472 | 0.6 | 0.177 | 5.933 | 4.211 |
| 3 | 0.178 | 0.64 | 0.083 | 3.772 | 3.864 |
| 4 | 0.445 | 0.32 | 0.23 | 5.62 | 4.433 |
| 5 | 0.205 | 0.4 | 0.097 | 3.9 | 3.719 |
| 6 | 0.552 | 0.36 | 0.07 | 7.008 | 4.22 |
| 7 | 0.418 | 0.84 | 0.217 | 5.374 | 3.695 |
| 8 | 0.525 | 0.72 | 0.203 | 6.613 | 3.984 |
| 9 | 0.285 | 0.44 | 0.15 | 4.345 | 3.81 |
| 10 | 0.258 | 0.68 | 0.243 | 4.189 | 3.98 |
| 11 | 0.338 | 0.52 | 0.123 | 4.707 | 4.114 |
| 12 | 0.232 | 0.8 | 0.11 | 4.039 | 3.113 |
| 13 | 0.365 | 0.56 | 0.137 | 4.904 | 3.774 |
| 14 | 0.498 | 0.88 | 0.057 | 6.256 | 3.674 |
| 15 | 0.312 | 0.48 | 0.19 | 4.52 | 3.977 |

Table S2 displays the sample data points and results. The test data of the sample were obtained through numerical simulation. The particles diameter of the inlet is 3 μm and the particle volume fraction is 6%. The numerical models and boundary conditions were consistent with those of the numerical calculation as described in Section 3.2.