Study on motion characteristics of check valve in reciprocating liquid hydrogen pumps

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Abstract

In this paper, based on the fluid continuity equation and the mechanical equilibrium equation, a mathematical model of valve motion is established, where the density change due to compressibility of liquid hydrogen is considered in the continuity equation and the cylinder pressure is incorporated into the differential equations as a variable. The impacts of spring stiffness and frequency on valve motion are investigated. The results demonstrate that the spring stiffness mainly affects the valve after opening. In contrast, the frequency directly affects the initial speed of the valve and then has a greater impact on the valve movement. This work would contribute to understanding the valve motion mechanism of reciprocating liquid hydrogen pumps.

Modelling check valve dynamics

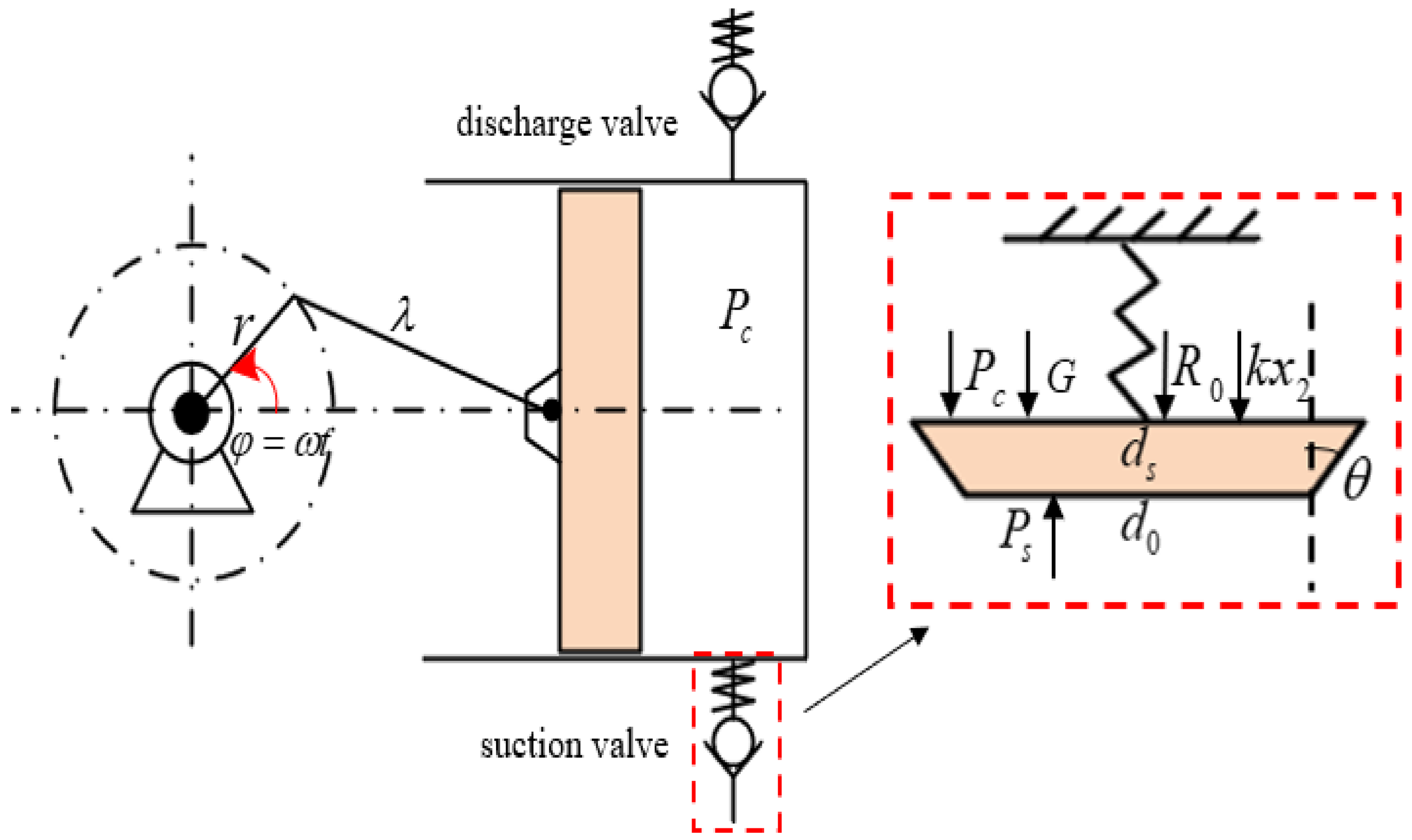


Table 1. Parameters of the pump and suction valve.

Parameters	Symbol	value
Suction pressure (Pa)	P_s	300000
Crank radius (m)	r	0.04
Link ratio (m)	λ	0.2
Angular velocity of crank (rad/s)	ω	10π
The cross-sectional area of piston (m^2)	A	0.0095
Clearance volume (cm^3)	V_0	0.95
Diameter of the suction valve seat hole (m)	d_0	0.049
Diameter of suction valve disc (m)	d_s	0.059
Spool-head angle (°)	θ	45
Mass (kg)	m	0.275
Spring stiffness (N/m)	K	550
Preload force (N)	R_0	1.58

- Mass conservation equation

$$\left[Ax_p+V_0-V_s\right]d\rho-\rho dV_s+A\rho dx_p=\mu f_{xs}\varepsilon_s\sqrt{\frac{2\left|P_s-P_c\right|}{\rho_{xs}}}\rho_{xs}dt$$

- Force equilibrium equation

$$m\frac{d^2h}{dt^2}=\left(P_s-P_c\right)f_s-mg-\left(R_0+Kh\right)$$

- The correlation between the density and pressure of liquid hydrogen during the suction process under the isentropic assumption

$$\rho=2.7491*10^{-6}*P+66.94$$

- The opening pressure of the suction valve

$$P_{os}=P_s-\frac{12\left(G+R_0\right)}{\pi\left(d_0^{\,2}+d_0d_s+d_s^{\,2}\right)}$$

- The first-order differential equation

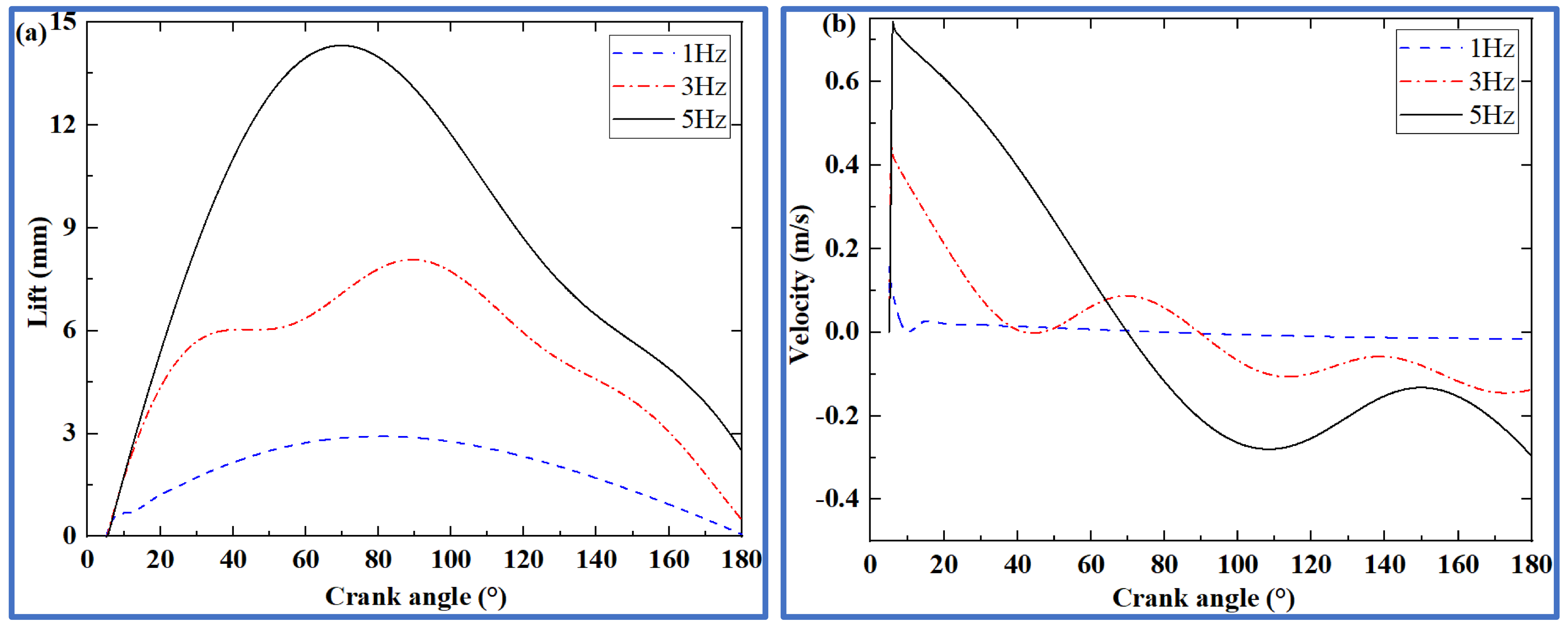
$$\begin{cases}\dfrac{dx_1}{dt}=\dfrac{\left[\mu\varepsilon_s\pi d_s x_2\sin\theta\sqrt{\dfrac{2\left|P_s-x_1\right|}{\rho_{xs}}}\rho_{xs}+\rho f_s x_3-A\rho\dfrac{dx_p}{dt}\right]}{\left[Ax_p+V_0-f_s x_2\right]\dfrac{d\rho}{dx_1}}\\[2ex] \dfrac{dx_2}{dt}=x_3\\[2ex] \dfrac{dx_3}{dt}=\dfrac{1}{m}\left[\left(P_s-x_1\right)f_s-mg-\left(R_0+Kx_2\right)\right]\end{cases}$$

Conclusion

- The spring stiffness mainly affects the valve after opening. Larger spring stiffness can decrease the valve's maximum lift and constrain the valve's closing speed.
- The frequency directly impacts the initial velocity of the valve and significantly influences the movement of the valve.

Results and discussion

- When the frequency decreases from 5 Hz to 1 Hz, the initial speed and the maximum lift are reduced by nearly 80%. At the same time, the hysteresis height is also reduced by 97%, which is beneficial to volumetric efficiency.



- In the closing stage of the valve, the large spring stiffness limits the speed of valve movement. The speed of the suction valve during the closing stage reaches 0.4 m/s when the spring stiffness is 800 N/m, which is 0.2 m/s with the spring stiffness of 300 N/m.