Effects of Double Damper System's Floating Characteristic on Percussion Performance of Hydraulic Rock Drill

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Abstract. The double damper system played an important role in shock absorption and noise reduction of the heavy hydraulic rock drill. However, its floating characteristic had negative effects on rock drills' percussion performance. Based on the operation principle, damping piston's statics equations were established by law of orifice flow. The key indicator parameters of damper system's floating characteristic were ascertained, which were damper flow rate and feed force. Their effects on the percussion performance were researched by experiment. The results indicated that the rock drill had the best percussion performance under a certain impact position, which was uncertain because of the damper system's floating characteristic. There was a greatly effect on the percussion performance of the damper flow rate and feed force. The greatest impact power discrepancy was 5.98 kW with different combinations of them. The negative influence would be amplified with impact power's rising, which should be given attention.

1. Introduction

Hydraulic rock drills are widely used in mining, coal mine roadway excavation, railway tunnel, highway tunnel and rock excavation projects with the advantages of high efficiency, clean, safety and so on. Heavy hydraulic rock drills with high-frequency and high-power become the first choice facing the large-scale mining and larger-sized tunneling [1]. Meanwhile, the performance of damper system is required higher and higher with the development of impact power. As the technological innovation of single damper system, the double damper system has better performance in shock absorption and noise reduction and is able to improve the efficiency and service life significantly [2].However, the impact position is uncertain because of the floating characteristic of double damper system, which has effect on the percussion performance. And the influence would be amplified with impact power's rising, which should be given attention.

At present, the research on double damper system is mainly focused on its performance of shock absorption and noise reduction. For example, Zhi Liu et al. [3] built the dynamic model of double damper system, simulated and obtained the moving law curves of the damper piston and housing. Zhixin Lu et al. [4] designed the annular clearance which was one of the most important parameters for double damper system. Yelin Li et al. [5, 6, 7] analyzed the dynamic characteristic of the double damper system and the annular clearance's effect on it. On this basis, performance parameters of the double damper system were optimized. Oh et al. [8] built an overall model including percussion
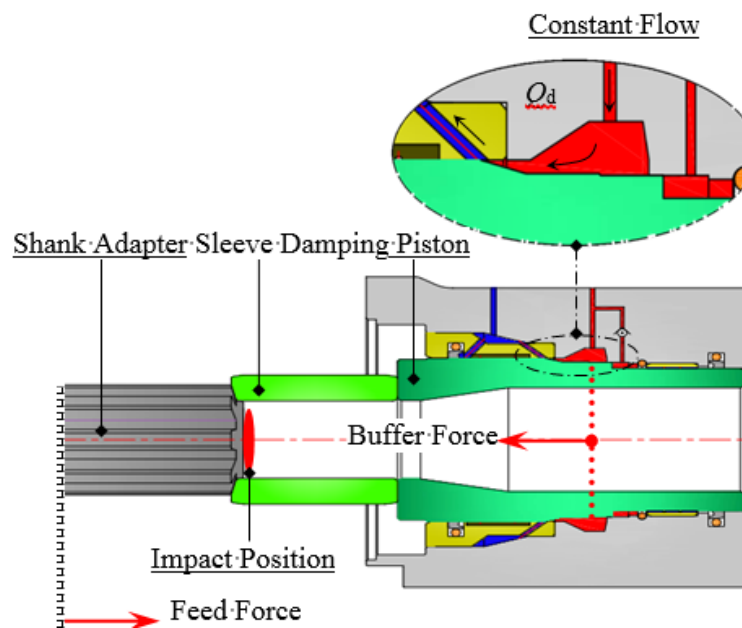
system, damper system and rock with AMESim and obtained the damper piston's displacement curve through simulation. Daniel [9] made a comparative analysis of three damper systems for hydraulic rock drill through experiment and Hopsan simulation. But there is few research of double damper system especially its floating characteristic's influence on percussion performance can be seen.

Based on the operation principle of double damper system, the statics equation was established using the law of orifice flow. The indicator parameters of damper system's floating characteristic was ascertained. The influence of double damper system's floating characteristic on rock drills' percussion performance was explored by experiment.

2. Floating characteristic of double damper system

As shown in Figure 1, the double damper system uses constant flow rate. The motion units such as damper piston, sleeve and shank adapter float during drilling process. They will move forward and backward under external force. So the double damper system is called "floating damper", too. The rock drills' percussion performance could be affected by the floating characteristic, because the impact position was determined by the shank adapter's position. In order to reduce the negative effect, it is necessary to research the floating characteristic, influencing factors and change law.

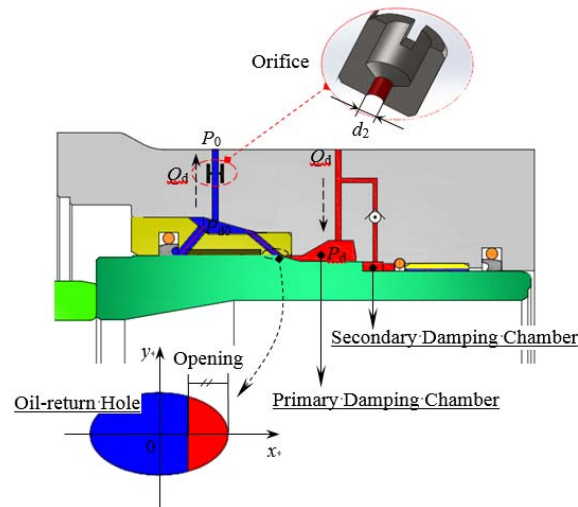**Figure 1.** Schematic diagram of double damper system's floating characteristic

3. Theoretical analysis

The double damper system was in equilibrium before strike. The pressures in primary and secondary damping chambers were equal. Damping piston's statics equation was as follows:

$$F_0 = P_d \cdot (A_{d1} + A_{d2}) \tag{1}$$

Where F0 is the feed force. Pd is the damping chamber pressure. Ad1, Ad2 were action areas of primary and secondary damping chambers respectively.

Formula (2) was the relation equations of pressure differentials and flow rate established using the law of orifice flow and constant flow supply referring to Figure 2.

Figure 2. Fuel circuit of the double damper system

$$\begin{cases} Q_d = C_d \cdot A_{t2} \cdot \sqrt{\dfrac{2}{\rho} \cdot (P_{d0} - P_0)} \\[3mm] \dfrac{Q_d}{2} = C_d \cdot A_{t1} \cdot \sqrt{\dfrac{2}{\rho} \cdot (P_d - P_{d0})} \end{cases} \tag{2}$$

Among them

$$A_{t2} = \frac{\pi}{4} \cdot d_2^{\,2} \tag{3}$$

Where Qd is the damper flow rate. Cd is the flow coefficient, Cd=0.8. At1, At2 were flow areas of oil-return hole and orifice. ρ is the density of hydraulic oil.

Formula (4) was the expression of At1 derived by simultaneous equations of (1), (2) and (3). It could be seen that the flow area of oil-return hole was determined by feed force and damper flow rate.

$$A_{t1} = \frac{Q_d}{2 \cdot C_d \cdot \sqrt{\dfrac{2}{\rho} \cdot (\dfrac{F_0}{A_{d1} + A_{d2}} - P_0) - (\dfrac{4Q_d}{C_d \cdot \pi \cdot d_2^{\,2}})^2}} \tag{4}$$

Formula (5) was the ellipse equation of oil-return hole's cross section. Formula (6) was the relation equation of At1 and x. Among them, x represents the damping piston's equilibrium position.

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1 \tag{5}$$

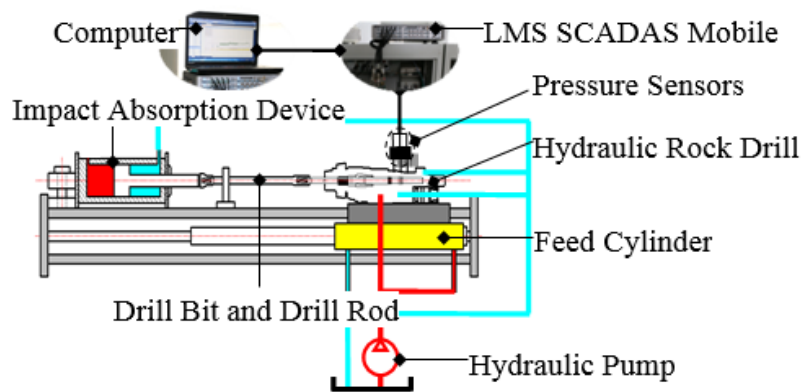$$A_{t1} = 2 \cdot \int_t^a b \cdot \sqrt{1 - \frac{x^2}{a^2}} \, dx \tag{6}$$

The two key indicator parameters of damper system's floating characteristic were ascertained, which were damper flow rate and feed force. Then the influence of double damper system's floating characteristic on rock drills' percussion performance would be explored by experiment of changing the two parameters.

4. Percussion performance experiments
The rock drill percussion performance was tested by chamber pressure testing method which had good reproducibility and high reliability according to rock drills' high-frequency and great energy [10, 11].
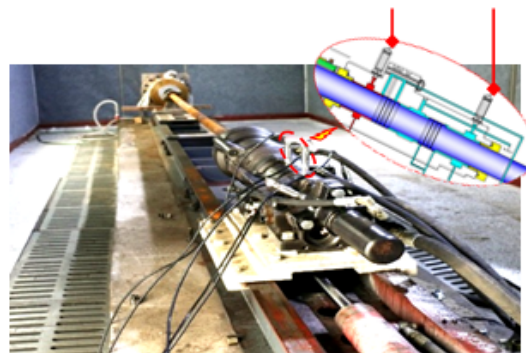
4.1. Experimental system
As shown in the Figure 3, experimental system are mainly composed of hydraulic pump station, feed cylinder, hydraulic rock drill, drill rod, drill bit, impact absorption device, pressure sensor, LMS SCADAS Mobile and computer. Pressure sensors were installed on the body of rock drill and tested its front-chamber and rear-chamber pressures directly whose response frequency could be up to 20 kHz.

(a) Experimental system

Pressure Sensors for Front-chamber, Rear-chamber

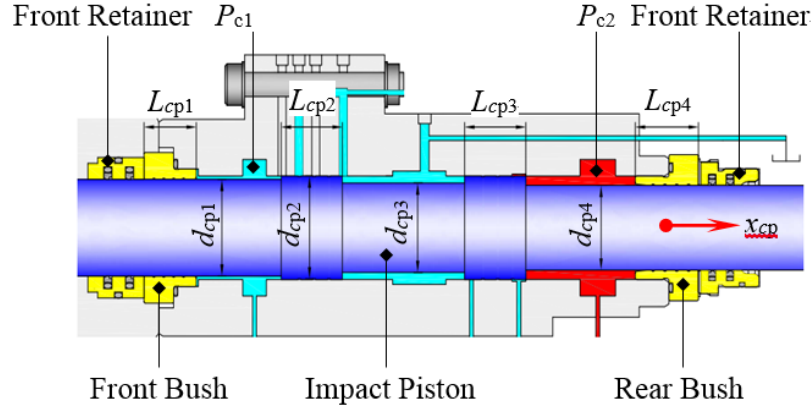（b）Scene graph

Figure 3. Experimental system and scene graph

4.2. Acquisition of percussive performance
The impact piston's kinematics equation and kinetic equation were established referring to Figure 4. The strike point was judged through the characteristic of rear-chamber's pressure spike because of the

impact piston springback. Then, impact piston's displacement and velocity curves could be obtained by putting test data of front-chamber and rear-chamber into equations.

Figure 4. Structure chart of impact system

$$m_{cp}\ddot{x}_{cp} + K_{cp}\dot{x}_{cp} + F_{cf}\frac{|\dot{x}_{cp}|}{\dot{x}_{cp}} = A_{cp1}P_{c1} - A_{cp2}P_{c2} \tag{7}$$

$$\begin{cases} \dot{x}_{cp} = v_{cp0} + \int\limits_0^t \ddot{x}_{cp} dt \\[2mm] x_{cp} = x_{cp0} + \int\limits_0^t \dot{x}_{cp} dt \\[2mm] \int\limits_0^T \dot{x}_{cp} dt = 0 \end{cases} \tag{8}$$

Among them

$$K_{cp} = \sum_{i=1}^{4} \frac{\mu\pi L_{cpi} d_{cpi}}{\sqrt{1-\varepsilon_{cp}^2} \cdot h_{ci}} \tag{9}$$

$$F_{cf} = \pi \cdot d_{cp1} \cdot b \cdot f \cdot P_{c1} + \pi \cdot d_{cp4} \cdot b \cdot f \cdot P_{c2} + 2\pi\left(d_{cp1}+d_{cp4}\right)\zeta \tag{10}$$

$$A_{cp1} = \frac{\pi}{4}(d_{cp2}^2 - d_{cp1}^2) \tag{11}$$

$$A_{cp2} = \frac{\pi}{4}(d_{cp2}^2 - d_{cp4}^2) \tag{12}$$

Where mcp is the mass of impact piston. Kcp is the coefficient of viscous resistance. Fcf is the friction force of seal. εcp is the eccentricity ratio, εcp=0.5. b is seal width. f is the friction coefficient between seal and piston, f=0.05. ζ is the compressibility correlation coefficient of O-ring, ζ = 1.
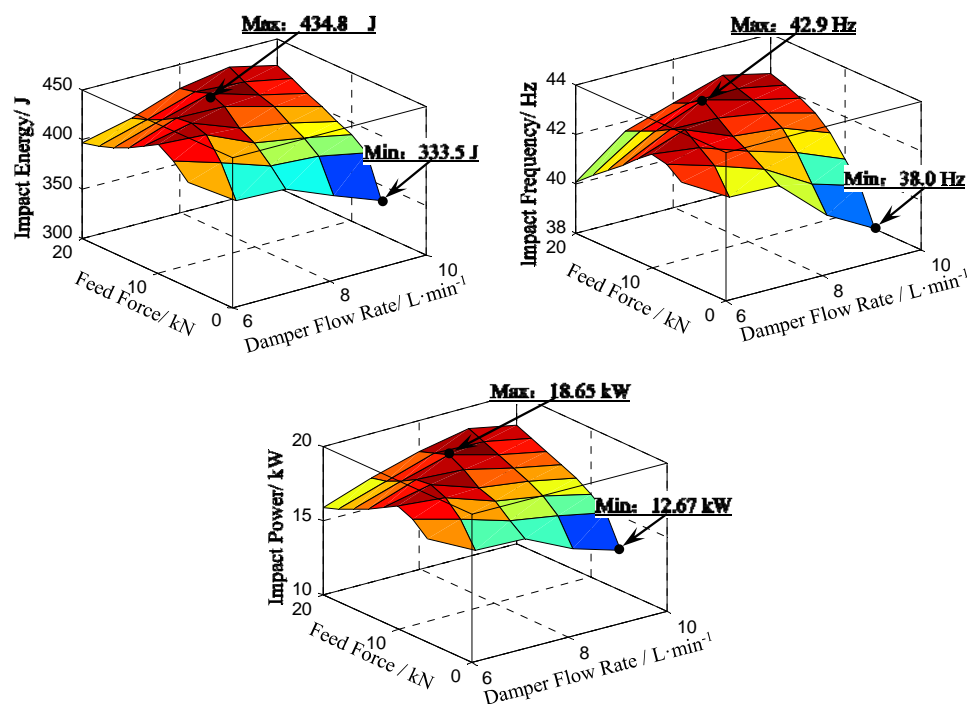
4.3. Analysis of Experiment Result

4.3.1. Grouping experiments. According to drilling condition, damper flow rate was assigned 6, 7, 8, 9, 10 L/min and feed force was assigned 6, 8, 10, 12, 14, 16, 18, 20 kN respectively. So there was 40 different combinations. Besides, impact flow rate was 105 L/min, relief valve pressure for impact system was 20 MPa.

4.3.2. Comparison of percussive performance. The rock drill's percussion performance was tested with 40 various combinations of (Qd, Fd) using the above experimental system. Experimental results were gathered and drawn into three-dimension curved surface in Figure 5.

Figure 5 shows that:

(1) The effect of different combinations of (Qd, Fd) on rock drill's impact energy and impact frequency was obvious. The effect tendency is consistent, so was the impact power.

(2) Large damper flow rate should match large feed force and vice versa.

(3) The rock drill had the maximum impact energy, frequency and power simultaneously at (8 L/min, 16 kN), whose value were 434.8 J, 42.9 Hz and 18.65 kW respectively. The minimum were 333.5 J, 38 Hz and 12.67 kW which were acquired simultaneously at (10 L/min, 6 kN).
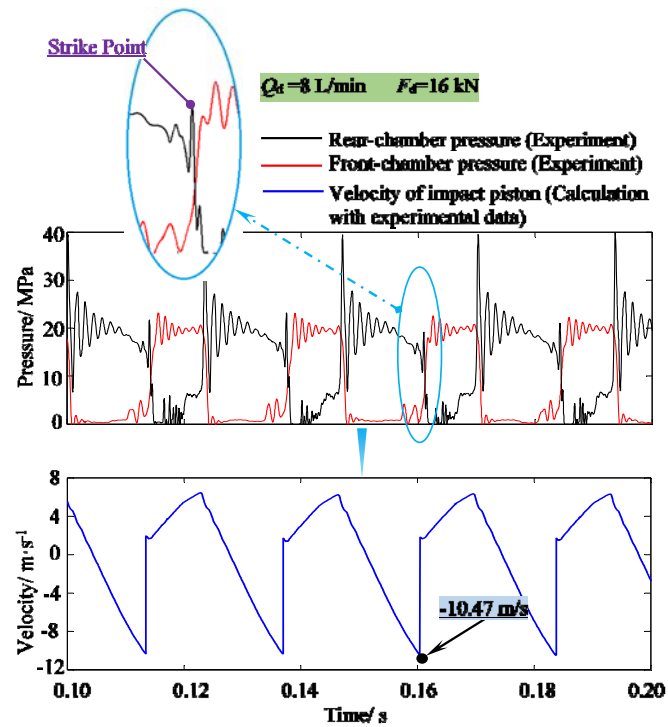

Figure 5. Contrast curves of the rock drill's percussion performance
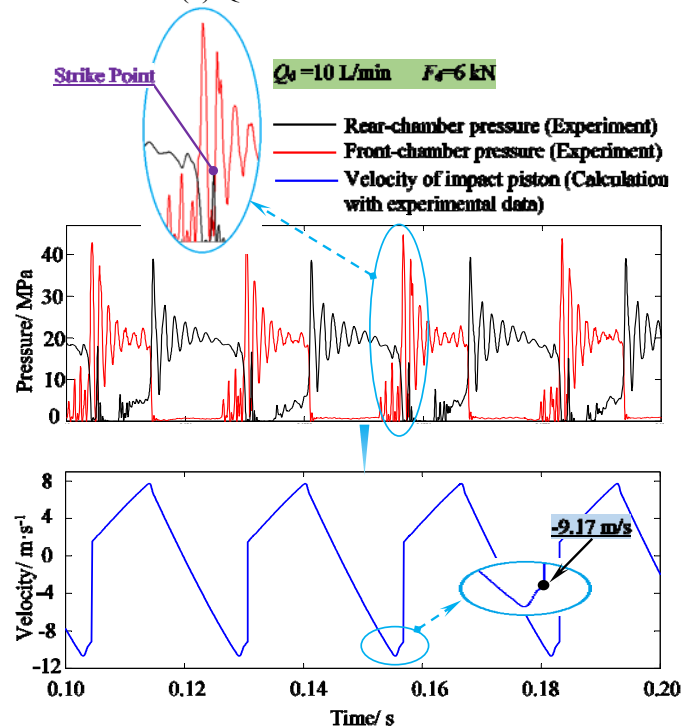
Now the influence of (Qd, Fd) on rock drill's percussion performance can be seen clearly. But its basic reason remains unknown. To know that, the moving law of impact piston will be researched.

4.3.3. Comparison of impact piston moving law. According to drilling condition, damper flow rate was assigned 6, 7, 8, 9, 10 L/min and feed force was assigned 6, 8, 10, 12, 14, 16, 18, 20 kN respectively. So there was 40 different combinations. Besides, impact flow rate was 105 L/min, relief valve pressure for impact system was 20 MPa.

The result indicates that the rock drill has the maximum and minimum impact power at (8 L/min, 16 kN) and (10 L/min, 6 kN) respectively. The impact piston moving law under the two condition will be researched next.

(a) Qd =8 L/min   Fd=16 kN

(b) Qd =10 L/min   Fd=6 kN

Figure 6. Contrast curves of the impact piston moving law

Figure 6 shows that:

(1) Impact piston's springback caused pressure peak in rear-chamber, which can be used to judge the strike point. The effect of different combinations of (Qd, Fd) on rock drill's impact energy and impact frequency was obvious. The effect tendency is consistent. So was the impact power.

(2) The maximum velocity of impact piston is the same at (10 L/min, 6 kN) and (8 L/min, 16 kN) although the impact velocity is different. The impact piston decelerated at the end of forward stroke at (10 L/min, 6 kN), which leaded to impact velocity decrease.

(3) The reason of impact piston deceleration at (10 L/min, 6 kN) is that the impact position is forward excessively. When impact piston hit the shank adapter, the front-chamber had connected to high pressure oil. Therefore, the front-chamber arose fierce pressure fluctuations, which also lead to impact frequency reduction.

5. Conclusion

(1) The floating characteristic manifests as motion units in damper system float while drilling. It plays a positive role in absorbing rebound energy and also has a certain negative effect on the utilization rate of the impact energy. The effect will be more obvious with the increase of impact power. The change law of damping piston's equilibrium position was analyzed.

(2) On this basis, two key parameters indicating floating characteristic were ascertained which are damper flow rate and feed force. Experiments were made to analyze the influence on rock drills' percussion performance with different combinations of damper flow rate and feed force.

(3) The results showed that the rock drill had the best impact position, in which it could give maximum power. But the impact position become uncertain because of the floating characteristic. There was a greatly effect on rock drills' percussion performance of the damper flow rate and feed force. The greatest impact power discrepancy was 5.98 kW.

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