Mathematical modeling and experiment for hydraulic ejecting system of ceramic brick press

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Abstract: Taking the ejecting system of hydraulic system of 7200t ceramic brick press as the research object, the basic constitution and working principle of the hydraulic ejecting system are described, and its mathematical model is established and calculated. In order to verify the accuracy of the mathematical model, the experiment was carried out, and the experimental results were compared with the calculated according to the mathematical model. The two results were basically consistent, indicating that the mathematical model is accurate, and providing a theoretical basis for further research on the ceramic brick press.

1. introduction
Ceramic brick press (referred to as brick press) is used to press ceramic powder into regular green bricks. It is a high-tech, high-precision modern ceramic mechanical equipment integrating machinery, electrics and hydraulics. With the continuous development of China's ceramic industry, higher requirements are put forward for the performance of the brick press\textsuperscript{1}. Hydraulic system is the core part of the brick press, its stability, reliability and accuracy affect the stable operation of the brick press and the working rate and the dynamic performance of the hydraulic system of the brick press, largely determines the quality of brick forming, so it is necessary to analyze the hydraulic system of the brick press\textsuperscript{2}. The ejecting system in the hydraulic system consists of two cartridge valves, proportional valves, asymmetric cylinders, pipelines and other hydraulic components. Mathematical modeling for the ejecting system has both universal and guiding significance for the modeling and simulation of the whole hydraulic system. Through the establishment of 7200t ceramic brick molding machine hydraulic system of the packing system and solving the mathematical model, using ceramic brick molding machine experiment, then the results are compared with the results of mathematical modeling to solve, comparison and verification mathematical model can reflect physical properties of the brick molding machine packing system for further analysis of the dynamic performance of packing system to provide theoretical basis\textsuperscript{3}.

2. Basic structure and working principle of ejecting system
The hydraulic schematic diagram of the packing system is shown in Figure 1. After the hydraulic oil is output from the pump station, it enters the packing system through auxiliary systems such as the filtration system. The main hydraulic components of the packing system include: two-way cartridge valve V1 and V2, electromagnetic directional valve (valve 1, valve 2, valve 3, valve 4), pit type single cylinder ejecting device. The specific working principle is as follows.
Figure 1 Hydraulic schematic diagram of ejecting system of ceramic brick press

(1) Mold locking and loosening
The locking and loosening of the mold is controlled by the electromagnetic directional valve 4, so that the lower mold core support plate and the push rod group reach the locking and loosening state. When the electromagnetic directional valve 4 is in the state of power failure, the pressure oil of the system enters the upper cavity of the mold locking cylinder, and the lower cavity is in the state of oil discharge. The mold is locked: when the electromagnetic directional valve 4 is powered, the pressure oil enters the lower cavity of the mold locking cylinder, and the upper cavity of the mold locking cylinder is in the state of an oil discharge, and the mold is loosened.

(2) the lifting movement of the lower die core
The lifting movement of the lower mold core includes ejecting blank (the ejecting of the lower mold core), packing (the first drop of the lower mold core), compacting (the second drop of the lower mold core) and cleaning mold core (the offside ejecting of the lower mold core). The first three movements are the working state of ejecting mold device, and the fourth movement only occurs when cleaning the mold.

Ejecting blank (pushing out of lower die core). The electromagnet of the solenoid directional valve 2 loses power, and the corresponding cartridge valve V2 closes. The electromagnet of solenoid directional valve 1 is charged, and the corresponding cartridge valve V1 is opened; The pressure oil enters the upper cavity of cylinder A of the top mold device through cartridge valve V1, cylinder A rises, and the pressure oil of the lower cavity of cylinder A is discharged back to the oil tank through electromagnetic reversing valve 2. At the same time, the electromagnet of the electromagnetic directional valve 3 is charged, and the pressure oil enters the Cylinder B through the one-way throttle valve of the electromagnetic directional valve 3, so that the Cylinder B sleeve rises, and the lower die core is in working state of ejecting blank.

Packing (one drop of the lower die core). The electromagnet of the solenoid directional valve 2 is charged, and the cartridge valve 2 is opened; The electromagnet of solenoid directional valve 1 loses power, and cartridge valve V1 closes; The pressure oil enters the lower cavity of ejecting cylinder A through electromagnetic reversing valve 2, and the oil in the upper cavity of the ejecting cylinder A is discharged back to the oil tank through cartridge valve V2, and the ejecting cylinder realizes a drop. The empty space is the packing space.

Compaction (secondary drop of lower die core). After packing, the movable beam begins to drop, the electromagnet of the reversing valve 3 loses power, and the pressure oil in cylinder B is discharged back to the tank through the one-way throttle valve.
3. Mathematical Modeling

3.1 Electromagnetic directional valve
The flow equation of the electromagnetic directional valve used in the system is:

\[ q_V = C_V A_V \sqrt{\frac{2}{\rho} \Delta p} \]  

Among them: \( q_V \) is the flow into the valve port;
\( C_V \) is the flow coefficient of valve port;
\( A_V \) is the flow area of the valve port;
\( \rho \) is the density of hydraulic oil;
\( \Delta p \) is the pressure difference between valve ports.

3.2 Cartridge valve
Cartridge valve simple structure, spool action sensitive, good sealing. The function is relatively simple, mainly realize on or off, combined with ordinary hydraulic control valve, realize the control of the system oil direction, pressure and flow. As shown in Figure 2, hydraulic oil flows into port A and out of port B. C is the pilot control port[4].

![Figure 2 Schematic diagram of cartridge valve](image)

Main valve port flow continuity equation:

\[ q_A = C_d A_d \sqrt{\frac{2}{\rho} \Delta p} = C_d \pi d_A x \sin \alpha \sqrt{p_A - p_B} \]  

\[ q = q_A + K_0 p_A + \frac{V_A}{E} \frac{dp_A}{dt} + A_A \frac{dx}{dt} \]  

Main spool force balance equation:

\[ p_A A_A - p_B A_A - p_C A_C = m \frac{d^2 x}{dt^2} + B \frac{dx}{dt} + K_s (x_0 + x + mg + K_p p_B) \]  

Pilot flow equation:

\[ A_c \frac{dx}{dt} = q_c + K_0 p_C + \frac{V_c}{E} \frac{dp_C}{dt} \]  

Flow equation of pilot orifice:

\[ q_c = C_d A_c \sqrt{\frac{2}{\rho} \Delta p} = C_d \pi d^2 \sqrt{\frac{2}{\rho} \Delta p} \]  

Among them: \( q_A \) is the flow into the main valve port;
\( C_d \) is the flow coefficient of the main valve port;
\( A_A \) is the flow area of the valve port;
$x$ is the displacement of spool opening;  
$\alpha$ is the half-cone Angle of the spool;  
$p_A$ is the main valve port pressure;  
$K_0$ is the pressure leakage coefficient;  
$E$ is the effective volumetric elastic modulus of liquid;  
$V_A$ is the main valve inlet-controlled chamber volume;  
$m$ is the mass of the spool;  
$B$ is the viscosity damping coefficient of liquid;  
$K_S$ is the main valve spring stiffness;  
$k_y$ is the hydraulic dynamic stiffness of the main valve port;  
$d_H$ is the diameter of the damping hole.

### 3.3 Pipeline flow equation

$$q_g = C_a A_g \sqrt{\frac{2}{\rho} \Delta p} = C_a \frac{\pi}{4} d_g^2 \sqrt{\frac{2}{\rho} (p_1 - p_2)} \quad (7)$$

### 3.4 Asymmetrical hydraulic cylinder

The implementation components of the ejecting system studied in this paper include ejecting cylinder (A), compaction cylinder (B) and mold locking cylinder, as shown in Figure 3, the asymmetric cylinder is used. When ejecting, hydraulic oil flows in from 1 and flows out from 2. Taking the ejecting cylinder as an example, the flow continuity equation is as follows$^{[5]}$:

![Figure 3 Schematic diagram of the ejecting system actuator](image)

Flow continuity equation of head port:

$$q_1 - C_{ic}(p_1 - p_2) - C_{ec} p_1 = A_i \frac{dv}{dt} + \frac{V_1}{E} \frac{dp_1}{dt} \quad (8)$$

Flow continuity equation of rod port:

$$C_{ic} (p_1 - p_2) - C_{ec} p_2 - q_2 = -A_2 \frac{dv}{dt} + \frac{V_2}{E} \frac{dp_2}{dt} \quad (9)$$

Force equation of piston:

$$F_g = A (p_1 - p_2) = m_p \frac{d^2 y}{dt^2} + B \frac{dy}{dt} + F \quad (10)$$

Among them: $C_{ic}$ is the internal leakage coefficient;
Cec is the external leakage coefficient;
$m_p$ is the piston mass;
y is the piston displacement;
$F$ is the external load force acting on the piston, here refers to the total gravity of the ejected part.

According to the working principle of the brick press, the correlation value of the system can be calculated by combining the above equations (1)-(10). The curve of the ejecting-displacement of the ejecting-cylinder with time and the curve of the pressure of the head port of the ejecting-cylinder with time are calculated.

### 4. Experimental verification and result analysis

In order to verify the accuracy of the mathematical model, experiments were carried out on the ceramic brick press, and the displacement-time curve and the pressure-time curve of the ejecting cylinder were recorded. During the experiment, the filling time and compaction time were set to 4s. The main structural parameters of the ceramic brick press were shown in Table 1, and the control sequence of solenoid valve was shown in Table 2.

| Table 1 Main structural parameters of brick press |
|-----------------------------------------------|
| Name of the element | The parameter name | The parameter value |
|---------------------|--------------------|--------------------|
| Variable pump       | Displacement       | 100mL/r            |
|                     | Speed              | 2000r/min          |
| The motor           | Speed              | 2000r/min          |
| The overflow valve  | Opening pressure   | 150Mpa             |
|                     | Trip               | 0.06 m             |
| Ejecting cylinder   | Load               | 7.5 kN             |
|                     | Piston diameter    | 135mm              |
| The piston of rod A. | Diameter          | 125mm              |
|                     | Trip               | 0.01m              |
| Block material cylinder | Piston rod diameter | 155mm           |
| The piston of rod B | Diameter           | 125mm              |
| Cartridge valve     | Entrance aperture  | 40mm               |
|                     | Export aperture    | 40mm               |

| Table 2 Solenoid valve control timing |
|--------------------------------------|
| Timing/s | YV1 | YV2 |
|-----------|-----|-----|
| 0~4       | 40  | 0   |
| 4~8       | 0   | 40  |
| 8~10      | 40  | 0   |

For comparison, the experimental results are listed together with the solution results of the underlying mathematical model, as shown in Figure 4 and Figure 5.
Figure 4 is the ejecting displacement curve of the ejecting cylinder. After the system starts running, the displacement of cylinder A increases from 0 to 0.06m, which is the ejecting cylinder (cylinder A) is pushed out to the working position; When t=4s, the displacement decreases from 0.06m to 0. When it is equal to 8s, it pops out again and circulates. Compared with Figure 4 (a) and (b), it can be seen that the experimental results are basically consistent with the calculated by mathematical model, indicating that the mathematical model is accurate. After the valve is opened and closed, there is no oscillation in Figure 4 (b), which is due to the convenience of calculation of the mathematical model, some parameters such as leakage coefficient, hydraulic force coefficient and liquid compression coefficient are omitted.

Figure 5 is the pressure curve of the head port of the ejecting cylinder. It can be seen that in the ejecting process, the pressure is very small, close to zero. This is because when the ejecting works, the head port is connected to the oil cylinder by opening the reversing valve 2. The pressure of the head port is about equal to the pressure of the oil cylinder, and the pressure of the oil cylinder is close to 0. When t=4s, the pressure of the head port suddenly rises to 15MPa and keeps constant until t=8s. This phenomenon is because when cylinder A falls back, the hydraulic oil enters the head port, and the pressure of the head port is close to the system pressure.

5. Conclusion
The mathematical model of the ejecting system in hydraulic system of ceramic brick press is established, the displacement curve of the ejecting cylinder and pressure curve of the head port are obtained, and verified by experiment. Compared with the results calculated according to the mathematical model, the trend of the two results is consistent, indicating that the mathematical model is correct, which can play a positive role in the research of the hydraulic system of ceramic brick press and provide new thought and theoretical guidance.
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