Hydraulic System Design for Earth Brick Press

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ABSTRACT

An earth brick press is introduced in this paper. Bake-free bricks produced by this machine are low in cost and environmentally friendly. Moreover, they may be substituted for other building materials required in building breeding sheds and greenhouses. In this paper, calculation and selection of design and type are respectively conducted by introducing the structure and operation of key hydraulic parts for the machine.

INTRODUCTION

An earth block is a type of building material with the longest history and the widest application. In fact, its history can be traced back to 8,000 BC. Until China's initiation of reform and opening up policy, houses in China were built with earth in most rural areas. As an earth house has a high coefficient of heat accumulation, high thermal resistance, and thermal inertia, it is warm in winter and cool in summer, with a stable indoor temperature. With the development of the Chinese economy, this kind of earth house exited the stage of history. In foreign countries, however, earth is still being used for building houses. At the end of the 20th century, about 200,000 mud houses were built in the southeastern area of the United States, most of which were built with earth. In earth-building cities of California and New Mexico, namely Santa Fe, traditional construction methods with earth have been inherited, and compaction techniques have been attempted to show new possibilities of earth buildings. At present, with the development of animal husbandry in China, especially the development of sheep (cattle) raising with crop straw, compressed earth bricks should be more widely used in the construction of sheds for sheep or cattle. As materials can be obtained from local sources, there are no transport costs. Additionally, as no brick baking is needed, energy is conserved. The bricks can also be recycled without destroying crops, damaging the environment, or producing construction waste. Meanwhile, the bricks have better anti-seismic performance than sintered bricks and good sound-absorbing
performance. Furthermore, the sheds are warm in the winter and cool in the summer. In this paper, the structure, operating principle, and hydraulic parts of an earth brick press will be introduced and designed.

STRUCTURE AND OPERATION OF EARTH BRICK PRESS

Structure

This brick press is a small and movable piece of equipment for field operation. To achieve power-free and fully-automatic brick pressing, the machine should include the following components:

1. Running part: this component has wheels and can be pulled by a tractor to the field for operation;
2. Dynamic part: this mainly uses a diesel engine as a source of power and can occasionally be used without a power supply;
3. Hydraulic part: the diesel engine drives a hydraulic pump to provide a pressure source, and a hydraulic circuit comprises hydraulic components to implement specific action requirements;
4. Feed box: this is mainly comprised of a feed box and a feeding belt to feed the earth in the feed box to a hopper;
5. Feeding part: this is mainly comprised of a hopper and a hydraulic cylinder that drives the hopper and is used to add earth in the feed box to the brick mold, push out the molded bricks, and serve as an upper cover plate of the brick mold;
6. Brick pressing part: this is mainly comprised of a main pressure cylinder and brick mold to realize brick molding and production;
7. PLC part: this component adopts a PLC automatic control system to realize precise control, which can be easily operated.

The structure diagram is shown in Fig. 1[4].

Figure 1. Structural diagram of an earth brick press.
Operation

This earth brick press is movable and has a diesel engine to provide a dynamic force for field brick production. Additionally, it provides convenience and is low in cost. Its operation is as follows: First, the excavator excavates the earth with a certain amount of clay and allows it to dry until the moisture content is about 8%. Then, the earth is sent to a soil-crushing device to crush any large clods. The crushed earth is evenly mixed with high-lime fly ash in a mixer and then lifted to the feed box by a slope belt. Next, the earth at the bottom of the feed box is sent to a hopper by a conveyer belt driven by a hydraulic motor. A distribution hydraulic cylinder drives the hopper to move forward, and when the hopper reaches the top of the earth brick mold cavity (the lower part is the top plate of the pressing hydraulic cylinder), the earth will fall into the cavity and fill it full. The distribution hydraulic cylinder continuously drives the hopper to move forward, and when the hopper reaches the front limit position, the rear base plate connected with the hopper will reach the top of the earth brick mold cavity and become the top cover plate to form a closed cavity. With the rise of the pressing cylinder piston, the earth is compressed and the pressure on the top cover plate is passed to the eccentric horizontal shaft through the hopper beneath it. Then, the pressure is passed from the eccentric horizontal shaft to the chassis to achieve balance and the earth brick is molded. After holding for some time, solenoid valve 6 of the main hydraulic cylinder is opened (see Fig. 3) and moves slightly downward to reduce the pressure on the top plate of the mold cavity connected with the hopper. At the same time, the return force of distribution hydraulic cylinder is reduced. When the distribution hydraulic cylinder moves to the rear limit position, the top cover plate of the mold cavity and the hopper also moves to the rear limit position. The hopper is also filled by the earth sent by the conveyer belt from the bottom of the feed box. Meanwhile, the pressing hydraulic cylinder rises and pushes the molded earth brick out of the mold cavity. As the distribution hydraulic cylinder is driving the hopper to move forward, the front part of the hopper pushes the molded earth brick to the next position, and the mold cavity is filled full with earth from the hopper. Then, the upper cover plate continuously moves forward to position itself close to the mold cavity for compressing a new brick. With such a cycle, bricks are produced one after another. Bricks are pushed by the bricks that follow in order to move them forward, and all bricks are pushed to the roller conveyer and moved away. Please refer to Fig. 2 for the brick production process.
HYDRAULIC SYSTEM DESIGN

According to work process requirements, the hydraulic system should serve the following functions:

1. Pressing hydraulic cylinder increases the pressure and ejects bricks out of the mold;
2. Pressing hydraulic cylinder releases pressure and returns;
3. Feed box takes material, feeds the material, and pushes the bricks out;
4. The conveyor belt is driven to run.

The principle of the hydraulic system is shown in Fig. 3.
The hydraulic system is mainly composed of hydraulic pump 2, diesel engine 3, solenoid valve 6, pressing hydraulic cylinder 7, solenoid valve 8, distribution hydraulic cylinder 9, solenoid valve 10, hydraulic motor 11, governor valve 12, solenoid valve 13, valve terminal 14, cooler 15, pressure relay 16, solenoid valve 17, and overflow valve 18. Solenoid valves 8, 10, and 13 are installed on valve terminal 14 for easy installation and circuit simplification. Hydraulic oil flows into the valve terminal through hydraulic pump 2, and solenoid valve 8 controls hydraulic cylinder 7 to extend, withdraw, and stop in order to load earth, press it, and maintain pressure. Solenoid valve 6 is connected and disconnected to reduce resistance in the return of the distribution hydraulic cylinder. Solenoid valve 10 controls hydraulic cylinder 9 to extend, withdraw, and stop in order to move the hopper forward and backward, and stop it. Solenoid valve 13 is connected and disconnected to control the running and stopping of hydraulic motor 11, and governor valve 12 can regulate the speed of hydraulic motor 11, thus feeding earth to the hopper with a conveyer belt. Solenoid valve 17 is connected and disconnected according to the signal of the pressure relay, and unloading valve 18 is used in the hydraulic circuit to guarantee safety.
DESIGN AND SELECTION OF COMPONENTS FOR HYDRAULIC SYSTEM[6][7]

Design of Pressing Hydraulic Cylinder

A pressing hydraulic cylinder is not only a core part of the hydraulic system of an earth brick press, but also an important part of the whole machine. The outline of the main hydraulic cylinder studied in this paper is shown in Fig. 4.

Figure 4. Outline of the hydraulic cylinder.

Earth bricks produced by this machine are mainly used for wind proofing and thermal insulation of breeding sheds and greenhouses, which are usually supported by a steel frame, so the pressure on bricks is not high. According to the technical requirements of brick production, the pressure intensity capacity of bricks ≥ #75 should be greater than 5 MPa[8]. According to the dimensions of earth brick mold cavity of 350 mm × 250 mm × 160 mm and the equation

\[ F = PS \]

where:

- \( F \): brick pressing force, in N;
- \( P \): pressure intensity on the brick, in MPa;
- \( S \): pressure bearing area of brick, in m².

Substitute pressure intensity \( P = 5 \) MPa and \( S = 350 \times 250 \times 10^{-6} \) m² into Equation (1), and we have \( F = 437,500 \) N. In other words, the pressure passed by the pressing hydraulic cylinder is at least 437,500 N. According to the experimental and technical requirements, the system’s rated pressure \( P = 20 \) MPa; piston rod diameter \( d_1 = 100 \) mm; piston diameter \( D_1 = 200 \) mm; and stroke \( L_1 = 160 \) mm, which meets the brick pressing requirement of \( F = 437,500 \) N.

Design of Distribution Hydraulic Cylinder

The distribution hydraulic cylinder is an important part for material taking and feeding. The end of the piston rod of a distribution hydraulic cylinder is connected with a hopper frame by welding. When the piston rod withdraws, the hopper frame moves to the bottom of the feed box to receive the material. Then, the piston rod extends and pushes the hopper frame forward. When the hopper moves to the top of the mold cavity, the earth enters the cavity and the previous brick is ejected out. When the top cover plate is in position, it begins to press.

The distribution device needs to complete brick ejection and material distribution by a reciprocating motion, so a single-piston double action cylinder is
generally used as the distribution hydraulic cylinder. As the hydraulic cylinder needs to drive the distribution frame to move back and forth, the thrust force of the piston rod shall be great enough. According to the experiment, the diameter of the piston rod for the distribution hydraulic cylinder is \( d_2 = 32 \text{ mm} \), and the piston diameter \( D_2 = 50 \text{ mm} \). According to the requirements, the operating stroke of the distribution hydraulic cylinder is determined to be \( L_2 = 580 \text{ mm} \).

**Selection of Hydraulic Motor**

The maximum productivity of this machine is eight bricks per minute. According to the experiment, the speed of the conveyor belt driver is 160 r/min, with great torque. Considering the efficiency loss of the hydraulic motor, a hydraulic motor with a higher speed is selected. In order to make the brick press stable and reliable, the WS4000, a hydraulic motor manufactured by White Drive Products Inc. is selected. The parameters of this hydraulic motor are shown in Table 1.

<table>
<thead>
<tr>
<th>Model</th>
<th>Nominal displacement (V)</th>
<th>Speed (n)</th>
<th>Pressure (( P_{\text{max}} ))</th>
<th>Torque (( T_{\text{max}} ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>399 ml/r</td>
<td>190 r/min</td>
<td>224 bar</td>
<td>816 Nm</td>
</tr>
</tbody>
</table>

**Selection of Hydraulic Pump**

1) Determination of hydraulic pump flow

In the process of brick production, two hydraulic cylinders and a hydraulic motor work one after another rather than simultaneously. The output flow of the hydraulic pump should be:

\[
q_p \geq K \sum q_{\text{max}}
\]  

(2)

where:

- \( K \) – system leakage coefficient, within the range of 1.1 and 1.3;
- \( \sum q_{\text{max}} \) – the largest flow among the two hydraulic cylinders and the hydraulic motor.

According to the requirements of this equation, the flow of the pressing hydraulic cylinder is obviously larger than the distribution hydraulic cylinder. Thus, it is not necessary to consider the flow requirement of the distribution hydraulic cylinder, and only a comparison should be made of the flows of the pressing hydraulic cylinder and the hydraulic motor.

**Calculation of pressing hydraulic cylinder flow**

The known conditions are as follows:

1) Inner diameter of the pressing hydraulic cylinder \( D_1 = 200 \text{ mm} \);
2) Diameter of the piston rod \( d_1 = 100 \text{ mm} \);
3) Stroke length \( L_1 = 160 \text{ mm} \);
4) Brick productivity is 400 pcs per hour.

Then,

\[
A_1 = \frac{\pi}{4} D_1^2
\]  

(3)

Substitute \( D_1 = 200 \text{ mm} \) into Equation (3), and we have \( A_1 = 314 \text{ cm}^2 \).
Rod chamber area: \[ A_2 = \frac{\pi}{4}(D_1^2 - d_1^2) \] (4)

Substitute \( D_1 = 200 \text{ mm} \) and \( d_1 = 100 \text{ mm} \) into Equation (4). Then, we have \( A_2 = 235.5 \text{ cm}^2 \).

The number of bricks produced per minute: \( n_1 = 6.7 \) (pcs)

Let the volume of the hydraulic oil needed by the hydraulic cylinder for pressing one brick be \( V_1 \). Then,
\[ V_1 = A_1L_1 + A_2L_1 \] (5)

Substitute \( A_1 = 314 \text{ cm}^2 \), \( A_2 = 235.5 \text{ cm}^2 \), and \( L_1 = 160 \text{ mm} \) into Equation (4). Then, we have \( V_1 = 8,792 \text{ cm}^3 \).

Let the flow of the pressing hydraulic cylinder be \( q_1 \), then
\[ q_1 = V_1n_1 \] (6)

Substitute \( V_1 = 8,792 \text{ cm}^3 \) and \( n_1 = 6.7 \) into Equation (6). Then, we have \( q_1 \approx 58.9 \text{ L/min} \).

**Calculation of hydraulic motor flow**

We have the equation
\[ q_3 = \frac{nV}{\eta_v} \] (7)

where
- \( q_3 \): the maximum flow of the hydraulic motor, in L/min;
- \( n \): the speed of the hydraulic motor, in r/min;
- \( \eta_v \): the volumetric efficiency of the hydraulic motor, with the value \( \eta_v = 0.8 \).

Substitute the values in Table 1 into Equation (7), and we have \( q_3 \approx 94.8 \text{ L/min} \).

The hydraulic motor drives the conveyor belt roller to send materials, so it runs intermittently. The running time is no more than 0.5 min within 1 min of loading time. Therefore, the value of \( q_3 \) is 50 L/min, and we have \( q_{\text{max}} \), which is the flow of the pressing hydraulic cylinder \( q_1 \approx 58.9 \text{ L/min} \).

In this paper, the system’s leakage coefficient \( K \) is the median 1.2. Substitute \( q_1 = 58.9/\text{min} \) in Equation (2). Then, we have \( q_p = 70.9 \text{ L/min} \).

2) **Selection of hydraulic pump**

A hydraulic pump is selected according to the values of \( P \) and \( q_p \) obtained above and the hydraulic type determined for the system. To allow the hydraulic pump to have certain pressure reserves, the rated pressure of the selected hydraulic pump should be higher than the system’s rated working pressure. In general, it is recommended that the rated pressure of the hydraulic pump should be 25%-60% higher than \( P \) (take the smaller value for the high pressure system and the larger value for the low and medium pressure system). The rated flow of the hydraulic pump should be nearly equivalent to and cannot be much larger than \( q_p \).

Oilgear Hydraulic Co., Ltd. is the world’s leading manufacturer of plunger pump and electro-hydraulic control products. The PVM034, an axial plunger pump of the company, is selected, and the related parameters are shown in Table 2.

<table>
<thead>
<tr>
<th>Table 2. Hydraulic Pump Parameters.</th>
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<tr>
<td>Rated pressure (MPa)</td>
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<tr>
<td>---------------------</td>
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<tr>
<td>24.14</td>
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</tbody>
</table>
Determination of Power for Diesel Engine

The hydraulic pump is driven by a diesel engine. Its input variables are torque and speed, and its output variables are fluid flow and pressure. The power of the diesel engine can be calculated as follows:

\[ P = \frac{P_P q_P}{\eta} \]  

where:
- \( P_P \): the maximum working pressure of the hydraulic pump, in Pa;
- \( q_P \): the maximum flow of the hydraulic pump selected, in \( \text{m}^3/\text{s} \);
- \( \eta \): the total efficiency of the hydraulic pump, with the value \( \eta = 0.8 \).

Substitute \( P_P = 27.59 \times 10^6 \text{ Pa} \) and \( q_P = 70.9 / (60 \times 1000) \text{ m}^3/\text{s} \) into Equation (8). Then, we have the power of the diesel engine \( P = 40.75 \text{ Kw} \).

According to the calculated power of the diesel engine and in consideration of the power loss and the power requirements of the power generation unit and other auxiliary facilities, the power of 40.75 kW is selected. In other words, a diesel engine of 55 hp can meet the requirements, with the speed of approximately 3,000 r/min.

CONCLUSION

In this paper, by studying and learning from American earth brick presses, the structure and the hydraulic system of an earth brick press is redesigned and the following conclusions are drawn:

(1) The earth brick press developed has a compact structure, small size, and low production cost;

(2) This earth brick press can be used for building enclosing walls of breeding sheds and greenhouses, while saving energy and being environmentally friendly and economical;

(3) The machine is designed to be movable, and with the diesel engine as the source of power, it is adaptable for various occasions.

REFERENCES