Research on Key Technologies of Double-cylinder Synchronous Hydraulic Machine

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Abstract—In the operation of the double-cylinder gantry hydraulic machine, whether the two oil cylinders as the power transmission element are synchronized is an important factor affecting the precision of the workpiece manufacturing. Because the oil cylinder directly affects the horizontal precision of the beam of the actuator during the work of the press. Therefore, the double-cylinder synchronous precision control of the hydraulic machine is one of the key technical problems that needs to be solved in the manufacturing process of the hydraulic machine. This paper proposes a design scheme for the mechanical structure of the synchronous precision control of the double-cylinder gantry hydraulic machine. On the basis of using a simple hydraulic circuit to ensure the basic synchronization of the two oil cylinders, the flexible connection of the piston rod of the oil cylinder and the beam is used to reduce the damage caused by the deflection of the beam of the hydraulic system and machinery of the hydraulic machine. At the same time, a conehead is added at the end of the piston rod, and a taper hole is added to the corresponding part of the beam. By the alignment of the cylinder rod and the taper hole of the beam, the position of the beam is corrected so as to ensure the machining precision of the workpiece.

1. INTRODUCTION

With the continuous development of society, hydraulic machines are widely used in various fields such as machinery manufacturing and aerospace. There are many types of presses. According to the power source of pressure, they are mainly divided into mechanical and hydraulic types. Among them, hydraulic machines have the advantages of large transmission power, long stroke, easy control, and simple structure. According to its structure, hydraulic machines also can be divided into three types: single-arm hydraulic machines, four-column hydraulic machines, and gantry hydraulic machines. The single-arm hydraulic machine has an oil cylinder to provide power. The rated pressure cannot be too large, and the area of the workbench is small, which is only suitable for processing workpieces with small volume and surface machine. The four-column hydraulic machine is guided by four columns when working, and the pressure can be provided by one or more hydraulic cylinders. Multiple hydraulic
cylinders synchronization can overcome the problems of small working area and small pressure surface of the single-arm hydraulic machine, so that the hydraulic machine with large volume and large working pressure can be manufactured. However, the synchronization of multiple cylinders is difficult to control. At the same time, the guide of the slider is completed by four columns, which requires high manufacturing precision of the guide column and the slider. Also, the strong pressure requirements of the hydraulic system correspondingly increases the strength and stiffness of the relevant pressure-bearing parts, so the production cost of the hydraulic machine is greatly increased.

The double-cylinder gantry hydraulic machine is widely used in various metal and non-metal forming processes due to its simple structure, large processing area and low manufacturing cost. The workpiece forming process needs high precision, which puts forward higher requirements for the synchronous precision control of the two cylinders of the double-cylinder gantry hydraulic machine. So the main research direction is focused on how to improve the synchronous precision of the two oil cylinders. At present, the synchronous control methods for high precision double-cylinder or multi-cylinder are: electro-hydraulic control using sensors, electro-hydraulic digital servo double-cylinder synchronous control[1], digital cylinder or digital valve based on digital theory for synchronous driving control of dual-cylinder or multi-cylinder[2], etc. Their purpose is to control the flow of the oil cylinder to achieve synchronization of two or more cylinders, and certain results have been achieved. However, no matter what kind of control method, the ultimate goal is to maintain a certain level of precision in the beam connected to the cylinder. And high-precision control methods all need to use sensors, computers, and PLC as component support for detection and control. The system is relatively complicated and the manufacturing cost is high.

This paper proposes a method: use a simple hydraulic circuit and change the rigid connection of the cylinder piston rod and the beam, and then supplement the piston rod and beam with a mechanical positioning mechanism, which can control the precision of the dual cylinder synchronization of the hydraulic machine at a lower cost, thereby ensuring the precision of workpiece processing.

2. WORKING PRINCIPLE OF DOUBLE-CYLINDER GANTRY HYDRAULIC MACHINE
The overall structure of the hydraulic machine’s body adopts a gantry frame type. When the machine is working, it is powered by two synchronous hydraulic cylinders that are parallel, equal in height, and of the same model, which drives the movable beam to run vertically downwards, and performs various workpieces’ processing or structural parts’ shape righting.

2.1. Influence of the rigid connection on the beam
In production practice, the common connection method between the piston rod and the beam of the double-cylinder gantry synchronous hydraulic machine is rigid connection. This connection method requires that the synchronous precision of the two cylinders must be strictly ensured when the machine is working. Only in this way can the smooth operation of the press be guaranteed. However, in real production practice, the beam may tilt. There are several reasons for this situation:

(1) The hydraulic machine is driven by two hydraulic cylinders at the same time. There are errors in the components and parts during manufacturing and installation. Therefore, the arrangement of the hydraulic cylinders cannot be absolutely geometrically symmetrical, which may cause the hydraulic cylinders to be out of synchronization. The inevitable mold installation error will also make the resistance distribution uneven when the upper and lower molds are pressed together, causing the movable beam to incline.

(2) There may be a certain degree of leakage during the working process of the hydraulic system. Also, the hydraulic oil itself has a certain compressibility, so it is difficult to ensure that the movable beam always maintains an ideal level during the operation. Non-linear characteristics such as dead zone saturation of the electro-hydraulic control element and leakage of the hydraulic cylinder mechanism will also generate synchronization errors, causing the movable beam to incline [3].

(3) The unevenness of the processed workpiece’s material will cause differences in the deformation force of the material when the workpiece is stressed, so the resistance of the workpiece to the upper
mold is easy to eccentric. This resistance is transmitted to the hydraulic cylinder through the movable beam, which causes the hydraulic cylinder to be unevenly stressed, and leads to differences in hydraulic cylinder oil pressure and cavity leakage. It will cause the hydraulic cylinder pistons to move at different speeds and then make the piston displacement inconsistent, then cause the hydraulic cylinders to move out of sync and movable beam to incline [3]. Once the movable beam inclines, the situation will range from reducing the machining accuracy of the workpiece and directly causing damage to the hydraulic system or mechanical mechanism, finally leading to reduce the hydraulic machine’s service life. Therefore, for a long time, the engineering and scientific researchers have conducted a lot of research on how to control the level of movable beams, and formed a series of control schemes.

2.2. Hydraulic principle of double-cylinder gantry hydraulic machine

The hydraulic system supplies oil to the system with a plunger variable pump; the relief valve is used as a pressure-stabilizing safety valve of the hydraulic system circuit; the flow is controlled by the diverting and collecting method (self-made three-way split valve) to achieve the basic synchronization of the operation of the two oil cylinders; the three-position four-way electromagnetic directional valve is used to control the movement of the two oil cylinders. This solution has the advantages of simple hydraulic system, short hydraulic pipeline, and low manufacturing cost. The basic circuit of the hydraulic system is shown in Figure 1.

![Figure 1. Double-cylinder hydraulic synchronization circuit.](image)

2.3. Synchronous precision hydraulic control of double-cylinder gantry hydraulic machine

It can be seen from the hydraulic circuit of Figure 1 that the synchronous precision control of the two oil cylinders is completely controlled by the flow of the hydraulic oil, which is pushed out from the hydraulic pump and then diverted into two hydraulic cylinders via diverter valve. The synchronous precision of the two cylinders controlled by this hydraulic circuit is relatively low, which can be controlled within the range of 2 to 5% [4]. Such a precision range cannot meet the requirements when the precision of the workpiece is high. If the cylinder beam and the piston rod are rigidly connected, after a long period of operation, it will also cause damage to the hydraulic machine’s hydraulic system and mechanical mechanism, and reduce the life of the hydraulic machine. Therefore, the synchronous precision needs to be controlled from other aspects.

3. Controlling Cylinder Synchronous Precision on Mechanical Structure

3.1. Improvement of the cylinder piston rod end’s structure

Figure 2 shows the details on how to improve the structure of the piston rod end of the cylinder. A shorter taper structure is added at the end of the piston rod. At the same time, a taper hole is added at the corresponding beam position to cooperate with the piston rod conehead, which is shown in Figure 3. The purpose is to use the piston rod end conehead to align the taper hole of the beam when the beam is
deflected, and then correct the position of the beam. When the workpiece is processed, the alignment state of the conehead and the taper hole is shown in Figure 4.

Figure 2. Piston rod end diagram.

Figure 3. Beam conehead diagram.

Figure 4. Cooperation between piston cone and taper hole.

3.2. Flexible connection between the oil cylinder piston rod and the beam

In the rigid connection of the piston rod and the beam, unsynchronization of the two oil cylinders will deflect the beam, affect the machining precision of the workpiece and cause damage to the hydraulic machine, therefore, the connection between the beam and the piston rod is changed to flexible connection, as shown in Figure 5-6. In this connection, the connecting sleeve and the piston rod are connected by fine thread, and the flange and the beam are connected by evenly distributed bolts. The joint of connecting sleeve and flange are designed with unilateral gaps of size A, B, and D respectively. The size of B is preferably that the connecting sleeve is not constrained by the flange when the connecting sleeve has a maximum inclining relative to the piston rod. At the same time, in order to prevent interference and stress concentration between the connecting sleeve and the flange, it is necessary to design a suitable fillet at the connection as shown in Figure 6.

Figure 5. Before the beam is subjected to pressure during ascent or descent.
3.3. Improved working principle of the beam
During the period that the two piston rod connection sleeves drive the beam to run upward or the beam runs downward before bearing the pressure from the piston rod, due to gravity, the weight of the beam acts on the connecting sleeve end face W. When the two cylinders are synchronized, the state of connecting sleeve, flange and beam is shown in Figure 5. If the two piston rods are out of sync during this process, causing the beam to tilt, the gaps A and B between the connecting sleeve and the flange will offset part of the tilt or completely cancel out. This method can protect the sealing element in the inner cavity of hydraulic cylinder, piston rods and beams, and also reduce the damage to the hydraulic machine, and extend machine’s service life.

In the short time before the beam runs downwards and enters the processing of the workpiece, when the two piston rods are synchronized, the beam appears naturally horizontal due to gravity. During the descending process, the beam firstly contacts with the workpiece. If the position deviation occurs, the piston rod end conehead will correct the position of the beam by aligning with the beam taper hole. The flange and the beam are floating relative to the connecting sleeve, and the effective length of the piston rod thread is longer than the connecting sleeve, and the upper end of the conehead protrudes from the lower end of the connecting sleeve. With the continuous extension of the cylinder piston, the upper end of the piston rod conehead comes into contact with the upper plane of the beam, and the pressure acts on the beam, so as to complete the processing of the workpiece. The state of the beam bearing the piston rod pressure is shown in Figure 6.

In addition, since the hydraulic system requires the two oil cylinders synchronous precision to be in the range of 2 to 5%, in order to improve the precision, the design of the hydraulic pipeline must be optimized. In the design, as to the pipelines from the oil pump outlet to the upper cavity of the two cylinders, try to make them have same diameter, same length and symmetrical direction, or use rigid pipelines. All these measures is to make the hydraulic oil into the two cylinders upper cavity’s flow equal. In addition, the gaps A and B between the connecting sleeve and the flange are related to the center distance and stroke of the two cylinders piston rods. The larger the center distance, the smaller the gap, and vice versa. When the stroke of the piston rod is constant, the maximum value of the synchronous precision error can be estimated, and the sizes of A and B are designed based on this. In order to reduce the friction between the connecting sleeve and the flange, the piston rod end conehead and the taper hole of the beam, grease can be applied between them.

4. Conclusion
The synchronous precision control method of the double-cylinder gantry hydraulic machine is: on the basis of using a simple hydraulic system circuit to ensure the synchronization of the two cylinders, use the floating gap between the connection sleeve and the flange to offset the synchronization error caused by not only the manufacturing and installation of equipment parts but also the hydraulic system circuit.
When processing the workpiece, the beam is in a natural level due to gravity, which protects the hydraulic system and mechanical parts of the hydraulic machine from damage and extend hydraulic machine’s service life. At the same time, use the end conehead of the oil cylinder and the beam hole positioning device to correct position of the beam, which can ensure the machining precision of the workpiece. This solution is suitable for the design of hydraulic machine with simple hydraulic circuit and low precision of hydraulic synchronization between two cylinders. The hydraulic machine has a simple structure, low manufacturing cost, and can meet the requirements of certain precision workpiece processing, which has certain value of application and market promotion.

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