Structure of an ultrahigh internal pressure compound cylinder and its simulation by AMESim

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Abstract: This study presents an ultrahigh internal pressure compound booster cylinder and analyses the structure and principle of the cylinder. Its advantages include low input, high pressure output, and direct action on the execution cylinder. The model of the ultrahigh internal pressure compound booster cylinder is constructed by AMESim, and the result is analysed. By analysing the research and simulation results for this cylinder, the authors eventually designed an integrated composite hydraulic cylinder assembly that can realise the large pressure output of fast-forward and quick return actions.

1 Introduction

In recent years, hydraulic presses used in metal hot forging, hot extrusion, cold extrusion, powder metallurgy, complex iron crafts forging and other industries require a reasonably compact structure and a tonnage of output pressure. Due to space constraints, frequently moving car frames, coal mine machinery, railway locomotives, bridges, other riveting industries and hydraulic rescue tools for field rescue operations require a small volume with large output pressure and easy operation [1]. The working principle includes fast-forward (clamping), work-in (forming) and quick return (release) actions; fast forward and quick return require low pressure and fast speed, whereas work advance requires high pressure, slow speed, perfect pressure retention and the moulding effect.

At present, for the hydraulic equipment, high output forces can be achieved by two methods. One is to use a hydraulic cylinder of a large diameter, and the other is to use a booster cylinder to increase the working pressure. Since the working pressure of the basic hydraulic components and accessories, such as hydraulic pumps, hydraulic valves and the upper limit of the output pressure of the high-pressure hose, is low, the first method to increase the output force by increasing the diameter of the hydraulic cylinder can achieve a certain productivity, but it increases the manufacturing cost and greatly increases the size of the motor. Adding a booster control system can overcome these shortcomings, we put forward an ultrahigh internally supercharged composite cylinder.

2 Structure and characteristics of an ultrahigh internally supercharged composite cylinder

The body of the ultrahigh internally supercharged composite cylinder is composed of a front cylinder block and a rear cylinder block. A working piston is loaded in the middle of the front cylinder block, a throttle spacer is arranged at the left of the rear cylinder block, a throttle spacer is connected with the front cylinder block, a pressurised composite piston is installed in the rear cylinder block, and there is a hole at the central portion of the throttle spacer to match the piston rod of the pressurised composite piston [3]. In the middle of the pressurised composite piston, there is a valve mounting hole, a two-way opening and a closing valve; a valve guide sleeve is installed in the valve mounting hole, and a throttle damper is installed on the rear cylinder block. There are oil inlet and outlet holes on the rear cylinder block. The structure of the cylinder is shown in Fig. 1 [4].

The main structural features of the ultrahigh internally supercharged composite cylinder are as follows: First, the front of the front cylinder has a U-shaped groove, and the wall of the front cylinder has oil inlet and outlet holes, and the front portion of the throttle spacer has an oil channel in the radial direction [5].

Fig. 1 Schematic diagram of the ultrahigh internally supercharged composite cylinder
1: Front cylinder head 2: Front cylinder 3: Working piston 4: Rear cylinder 5: Throttle spacer 6: Pressurised composite piston 7: Two-way opening and closing valve 8: Throttle adjustment rod 9: Valve guide sleeve 10: Rear cylinder cover

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channel has an oil inlet annular groove in the middle and a circular umbrella at the rear; the piston rod of the pressurised composite piston has an oil passage in the centre and annular inlet and outlet oil grooves at the middle of the piston end; the inlet and outlet oil grooves communicate with the oil passage through a plurality of holes. Second, the front cylinder block and the rear cylinder block are screwed together; the front cylinder head and the front cylinder block are also threaded [6]. Strengths of all the threads are accurately calculated and checked to ensure the safety and reliability of the cylinder.

3 Working principle of the ultrahigh internally supercharged composite cylinder

Fast-forward (clamping): The hydraulic oil enters the upper end of the front cylinder block 2 through the upper-end oil inlet port through the composite piston 6 and the two-way opening and closing valve 7, and pushes the working piston 3 to advance rapidly. At this time, an annular gap is formed between the annular umbrella at the rear end of the throttle sleeve 5 and the body wall of the rear cylinder 4, and a resistance is generated to prevent the composite piston 6 to advance forward when the working piston 3 advances rapidly. The throttle adjustment lever 8 of the rear cylinder wall 4 forms a throttle damper, which generates a certain resistance to prevent the hydraulic oil entering the upper end of the composite piston 6, and also effectively prevents the composite piston 6 from advancing forward when the working piston 3 advances rapidly. It is ensured that the working piston 3 and the composite piston 6 operate in accordance to the working sequence. Fig. 2 shows the fast-forward principle.

Work-in (forming): When the working piston 3 contacts the workpiece, the pressure in the cylinder gradually rises, at which time the oil pressure oil enters the upper end of the composite piston 6 through the throttle damper 8, and then pushes the composite piston 6 forward; due to the relative movement of the composite piston 6 and rear cylinder 4, the oil inlet of the composite piston 6 is closed, and under the pressure of the hydraulic oil, the two-way opening and closing valve 7 rises and closes the oil port, thereby closing the upper end of the working piston 3. The composite piston 6 continues to advance, generating a pressurising action that urges the working piston 3 to advance at a high pressure until a set pressure or workpiece formation is reached. At this time, the pressure in the front cylinder 2 would be very high, and the pressure in the rear cylinder 4 will be relatively low. When the pressure oil is stopped from being supplied to the cylinder, the pressure in the front cylinder 2 can push the composite piston 6 backward. Since the area difference between the front and rear ends of the composite piston 6 is very large, the ultrahigh pressure can be instantaneously released inside the cylinder, which can effectively absorb the hydraulic shock generated by the quick return, and reduce the cracking risk of the pipeline and cylinder. Fig. 3 shows the working principle.

Quick return (release): The hydraulic oil enters the lower end of the front cylinder block 2 through the throttle port 5 and the oil passage in the wall of the front cylinder block 2, and pushes the working piston 3 to return quickly. Since the oil port of the two-way opening and closing valve 7 is in the closed state at this time, the oil at the upper end of the working piston 3 also pushes the composite piston 6 backward. When the composite piston 6 begins to contact with the bottom of the cylinder, the two-way opening and closing valve 7 is gradually opened to discharge excess hydraulic oil. The cylinder is again ready for the next working cycle. Fig. 4 shows the quick return principle [7].

4 Technical advantages of the ultrahigh internally supercharged composite cylinder as compared with an ordinary cylinder

i. The structure is simple and compact, is easy to manufacture, has large output pressure, and much smaller volume than that of the equivalent-tonnage output cylinder.

ii. When the input of the working cylinder is set at a lower pressure, a large output pressure can be obtained without any leakage using the in-cylinder pressurisation system.

iii. According to actual needs, the structure cylinder can increase the output pressure by more than 12.5 times compared to that of the input pressure, and the working cylinder can withstand the pressure of 125 MPa. The ultrahigh pressure can be slowly released inside the cylinder, which can effectively absorb the hydraulic shock generated by the quick return. It also reduces the risk of pipe and cylinder cracking.

iv. The compound cylinder can realise low-pressure rapid advancement, high-pressure work-in and low-pressure quick return; it has several advantages of high pressure, high speed, high safety, low energy consumption, low cost and low leakage.

v. The composite cylinder is the same in appearance and installation as other ordinary cylinders, and does not need increase the additional manufacturing costs.

vi. Compared with common cylinders, the motor of the composite cylinder has less power and lower relative energy consumption [8].

5 AMESim simulation analysis of the ultrahigh internal pressure composite cylinder

5.1 AMESim model
The structural principle of the ultrahigh internally supercharged composite cylinder is shown in Fig. 5, which is simulated by two containers connected by a two-way opening and closing valve controlled by a supercharged composite piston. According to the structural performance parameters of the ultrahigh internally supercharged composite cylinder, the parameters of the simulation model are listed as follows:

i. Working cylinder: Piston diameter is 75 mm, piston rod diameter is 50 mm, mass of moving parts is 7 kg, and working stroke is 72.8 mm.

ii. Pressurised cylinder: The diameter of the booster cylinder is 28 mm, the diameter of the piston rod is 14 mm, the working stroke is 15.2 mm, and the mass of the pressurised composite piston is 3.2 kg.

iii. Processing workpiece: Equivalent to the spring damping system, the return stroke is automatically converted to no-load, the spring stiffness is \( 1.23 \times 10^7 \) N/m, and the damping is \( 1 \times 10^5 \) N·s/m.

iv. Other settings: The system pressure is 8.8 MPa, the sliding friction coefficient between the piston and the cylinder is 0.5, and the simulation time is 2.5 s.

5.2 Simulation result analysis

Through the modelling and simulation analysis of the working process of the ultrahigh internally supercharged composite cylinder, the relationship among the system pressure, the overflow area of the high-pressure seal and the dynamic performance of the ultrahigh internally supercharged composite cylinder is determined [9].

5.2.1 Relationship between the system pressure and performance of the ultrahigh internally supercharged composite cylinder: The system pressure is equal to the front chamber pressure at the initial state, and the system pressure is set to be 8.0, 8.4 and 8.8 MPa. The performance of the ultrahigh internally supercharged composite cylinder under different system pressures is shown in Fig. 6. As can be seen from the figure, the system oil pressure is 8.0, 8.4 and 8.8 MPa, the booster cylinder pressure can reach the maximum value of 50, 70 and 90.6 MPa, and the punch force reaches the maximum value of 220, 315 and 400 kN. With three driving pressures, the punch reaches the workpiece at 15 mm at almost the same time, and reaches the maximum pressurising stroke of 14, 14.7 and 15.2 mm, respectively. In the fast process, the speed of the punch is basically the same, but the return speed at 8.8 MPa is not relatively increased, which indicates that the return resistance is mainly coming from the oil pressure [10] (see Figs. 7–9).

5.2.2 Relationship between the over-flow area of the high-pressure seal and the performance of the ultrahigh internally supercharged composite cylinder: When the system pressure is 8.8 MPa, the over-flow area of the high-pressure sealing ring to connect with the front cylinder block and the rear cylinder block is set as 19, 78 and 490 mm², respectively. The influence of different flow areas of high-pressure seals is shown in Fig. 10 [11].

It can be seen from the figure that when the flow area is 19 and 78 mm², the oil pressure of the front cylinder is quickly stabilised at 1 MPa after the reset of the ultrahigh internal pressure composite cylinder, and the flow area of the front cylinder is 490 mm². The oil pressure continued to oscillate and eventually stopped at 1 MPa. The above description shows that the high-pressure seal acts as a liquid resistance, and the small liquid resistance cannot reduce the oscillation of the oil pressure when the load changes. Therefore, it is most reasonable when the over-flow area of the simulation is 19 mm².
6 Conclusion

i. An ultrahigh internally supercharged composite cylinder is proposed, and the structural scheme is described. The simulation model of the composite supercharged cylinder is established by using AMESim simulation software to simulate the working cycle of the cylinder to verify the rationality of the program.

ii. The simulation results show that the return resistance of the working piston mainly comes from the oil pressure. Therefore, when designing the front cylinder block, the reasonable overflow area of the high-pressure seal should be designed to be as large as possible. If the value is too large, it will create pressure oscillation of the oil storage chamber at the return state; on the contrary, it will change the speed of the return oil.

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8 References

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Fig. 9 Punch speed

Fig. 10 Pressure of the front cylinder