AI based design of camshaft-free valve train driven by diesel engine

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Abstract. Aiming at ZS1105 single-cylinder diesel oil, based on AI technology, a camshaft-free valve train compared with the original engine was developed by electro-hydraulic drive. The test results show that the mechanism can improve the intake and exhaust efficiency and reduce the valve seating impact.

1. Introduction

The valve timing and valve lift of the traditional valve train of diesel engine are designed based on the requirements of engine performance under common working conditions, and the size is fixed, so this design cannot meet the performance requirements of diesel engine under all working conditions. In order to meet the performance requirements under working conditions, it is necessary that the valve timing and valve lift can change continuously with the change of rotating speed. Because of the limitation of cam profile, the valve timing, valve phase and opening duration can not be changed continuously under any working conditions. The valve timing, valve lift and valve duration can be realized by canceling the camshaft and using electromagnetic force and hydraulic pressure to drive the valve to open and close at any time [1]. The control is flexible, which can meet the torque of the engine at low speed and the power demand at high speed, and has good fuel economy and low emission. When the valve train is directly driven by electromagnetic force, the difficulties rely on control of valve seating speed and impact noise. Using hydraulic pressure to drive the valve can reduce the seating speed of the valve, thus reducing the impact. In this paper, the valve train of ZS1105 single-cylinder diesel engine was reformed, and the camshaft-free electro-hydraulic valve train was developed without changing the structural size and cylinder head structure of the original engine. The bench test was carried out and the intake and exhaust performance was compared with that of the original engine.

Parameter values of inlet and outlet valves of ZS1105 single-cylinder diesel oil are shown in the following table.
Table 1. Inlet and exhaust valve parameters of zs1105 single cylinder diesel engine.

| Valve Type | Opening Time | Closing Time | Maximum Lift |
|------------|--------------|--------------|--------------|
| Inlet valve | 14° CA BTDC  | 223° CA ATDC | 11mm         |
| Exhaust valve | 223° CA BTDC | 14° CA ATDC  | 11mm         |

The system mainly includes three parts: hydraulic power source, valve actuator and control unit.

2. Working principle of system

The mechanism adopts hydraulic unidirectional plunger structure, and the control unit controls the valve timing and lift by feedforward control according to the collected engine speed, load, hydraulic oil temperature and other parameters. The valve is opened and closed by controlling the two-position three-way high-speed solenoid valve [2]. When opening, the plunger is pushed by hydraulic pressure to overcome the elastic force of the valve spring and open the valve. When closing, the hydraulic pressure is removed, and the valve is closed by the extension force of the valve spring. The work of this institution can be divided into the following stages:

![Figure 1. Schematic diagram of electro-hydraulic valve train without camshaft.](image)

1. oil tank 2. filter 3. hydraulic pump 4. motor 5. one-way valve 6. overflow valve 7. pressure relay 8. pressure gauge 9. accumulator 10. two-position three-way high-speed solenoid valve 11. control unit 12. throttle valve 13. one-way valve 14. actuator 15. valve group
2.1. Constant pressure process of hydraulic oil in valve actuator

The oil is pressurized by the hydraulic pump and enters the accumulator. Under the action of the overflow valve, the pressure is kept at the set pressure value. When the pressure needs to be changed, the pressure can be stabilized at the required value by adjusting the overflow valve.

2.2. Valve opening process

The control unit sends an instruction to make the two-position three-way high-speed electromagnetic valve open the passage of high-pressure oil into the hydraulic cylinder. High-pressure oil enters the hydraulic cylinder, pushing the plunger to move downwards, overcoming the residual pressure in the cylinder and the elastic force of the valve spring, and the valve runs downwards in an accelerated state. When approaching the maximum valve lift, the orifice produces damping effect, exerting upward resistance on the valve, and the acceleration of valve operation is negative, which reduces the opening speed of the valve, the impact force when the valve reaches the maximum lift and the noise of the valve at the same time.

2.3. Valve holding process

The two-position three-way valve keeps its state unchanged, and the hydraulic pressure always acts on the plunger. When the valve is fully open, the hydraulic pressure is greater than the elastic force of the valve spring. Under the action of the limiting device, the valve is kept at the maximum valve lift. When the valve is opened in partial lift, the hydraulic pressure is equal to the acting force of the valve spring, and different hydraulic pressures make the valve reach different valve lifts.

2.4. Valve closing process

The control unit sends an instruction, and the two-position, three-way high-speed electromagnetic valve communicates with the passage of the hydraulic cylinder and the oil return pipe. At this time, the plunger is acted by the resilience of the valve spring, and the valve moves upwards, pushing the oil in the hydraulic cylinder to flow back to the oil tank. When the valve returns to the close seating position, the orifice produces damping effect, and the valve movement speed decreases, thus ensuring the flexible landing of the valve, reducing noise and delaying the service life of the valve seat.

3. Design of electro-hydraulic valve train without camshaft

3.1. Hydraulic power source design

This part provides hydraulic power for the system, and requires stable instantaneous pressure. System rated pressure:

\[ p = \alpha \frac{\Delta F}{A} \]  \hspace{1cm} (1)

Where:
- the thrust to be output by the hydraulic cylinder;
- working area of piston;
- Total pressure loss coefficient of hydraulic system;
- safety margin of hydraulic system.

According to calculation, the rated pressure of the system is 12MPa. Rated flow of hydraulic system:

\[ Q = \beta \frac{AS}{T} \]  \hspace{1cm} (2)

In which:
- piston stroke;
- Piston movement time;
- Total flow loss coefficient of hydraulic system.

After calculation, the rated flow rate of the system is 8L/min and the accumulator volume is 2.5L.
3.2. Valve actuator design
Under the control of the control unit, this part can accurately open and close the intake and exhaust valves, ensuring that the acceleration, the height of valve lift and the speed of valve movement meet the design requirements. Two-stage hydraulic piston is used as valve driving structure. The first stage: the two pistons accelerate together to open the valve downwards. The second stage: the large-diameter piston stops using, and the small-diameter piston continues to open the valve downwards until the valve reaches the maximum lift position, thus reducing the impact of the valve.

3.3. Design of control unit
As the center of the whole system, this part uses control strategy to control the valve actuator, and communicates with the upper computer to complete online calibration. Engine speed signal is generated by photoelectric encoder installed at the front end of crankshaft, which provides position and speed feedback for processor.

4. Bench test and analysis

4.1. Experimental scheme
The bench without camshaft valve train can simulate the engine's top dead center signal, crankshaft angle signal, engine speed and other parameters, so that the developed camshaft valve train can run independently without depending on the actual engine. The bench is mainly composed of engine parameter simulation system, hydraulic source system, valve actuator and data measurement system.

4.2. Research on performance of valve train without camshaft
The structure of the intake and exhaust valve driving mechanism without camshaft valve train is the same. Although there are machining errors and the influence of inconsistent driving devices, the valve lift curves of the intake and exhaust valves are very similar in measurement, so the following analysis is made by using the lift curves of the exhaust valves. Fig. 1 is a comparison between valve lift of camshaft-free valve train and valve lift of original camshaft valve train at speed of 1200r/min. The maximum valve lift in the figure is 11mm.

![Figure 2. Comparison of valve lift between camshaft-free valve train and original engine.](image)

It can be seen from the figure that the time-section coefficient of the electro-hydraulic camshaft-free valve train is 2.3 times that of the original machine at 1200r/min and hydraulic pressure of 11MPa,
and the intake capacity is similar to that of the original machine at hydraulic pressure of 6.5MPa. It shows that it has the potential to reduce the residual exhaust gas in the cylinder, improve the intake capacity, improve the charging efficiency and improve the engine power performance. When the pressure is 11MPa, the valve is fully open, and with the decrease of pressure, the lift of the valve decreases.

Figure 3 is a comparison of valve movement speed with the original mechanism at 1200r/min and 6.5MPa. It can be seen that the maximum movement speed of the camshaft-free valve is lower than that of the original valve. Since the lift height of the valve depends on the equilibrium position of hydraulic pressure and spring force, after reaching the equilibrium position, the inertia valve continues to move. It can be seen that in Figure 3, the lift of the valve with pressure of 6.5MPa has a convex part, and then the valve falls back under the action of spring force. After reaching the equilibrium position, the lift fluctuates slightly. The valve lift has a holding stage, while the original valve falls back directly after reaching the maximum lift without a holding stage. When the valve is closed, the resilience of the valve spring is used to make the valve fall down. Under the action of resilience, the valve falls down at a high speed. When the valve is close to the seat, the valve falls down buffer device acts. It can be seen from the speed curve in Figure 3 that the speed at the moment of falling down is 0.08m/s, thus realizing the flexible landing of the valve.

5. Conclusions
The valve lift of the electro-hydraulic camshaft-free valve train is larger than that of the original engine, which can improve ventilation and make combustion more complete.

Electro-hydraulic drive camshaft-free valve train can effectively control valve seating speed, thus reducing valve seating impact, facilitating noise control and prolonging its service life.

References
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