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Adjustment Performance of a Novel Continuous Variable Valve Timing and Lift System

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A new variable valve technology that is named continuous variable valve timing and lift system by hydraulic volume adjustable is presented in the paper. The AMESim simulation model of continuous variable valve timing and lift system by hydraulic volume adjustable is established. The adjustment performance of the system is studied deeply by the simulation model. The results show that both the valve timing and valve lift of the system can be adjusted independently and continuously, the valve advance angle, the valve retard angle and the valve duration angle increase with the increase of engine speed, and the valve lift increases with the increase of engine speed or load, decreases with the increase of engine speed or load. The novel continuous variable valve timing and lift system would more meet the distribution requirements of engine.

1. Introduction

The variable valve technology can change the timing, duration angle and lift of valve in line with the changes of engine working conditions, making the engine gain reasonable gas distribution under every working condition, so as to improve the engine idling speed stability, promote the external characteristic torque at low speed, enhance the thermal efficiency, increase the fuel economy, reduce emission and improve the vehicle driving comfort, and so on (Chen, 2014). Since the British Dugald Clerk obtained the first variable valve technology patent in 1880(Thomas, 1989), the variable valve technology has been studied by many people for a long time, and a lot of variable valve systems have been presented, some of them have been applied to the car (Allen et al., 2002; Qu et al., 2012), such as Honda's VTEC, BMW's Valvetronic (Flierl et al., 2000) and Fiat's Multiair (Lucio et al, 2010). However, there are a few disadvantages such as complex structure, complex control process, high cost, limiting to improve the engine valve in these technologies. These disadvantages restrict the application of variable valve technology in practical engineering (Hu et al., 2015). At present, though many different variable valve technologies have been commercial, it has not yet to find out the integrated solution that is excellent in various aspects, such as performance, structure, applicability, economy and so on.

A continuous variable valve timing and lift system by hydraulic volume adjustable (CVVTL) that can realize the independent and continuous adjustment of valve timing and lift, satisfy the reasonable gas distribution demands of engine in all working conditions is presented. The AMESim simulation model of CVVTL is established to study the adjustment performance of CVVTL, and the simulation results are analysed in detail.

2. The CVVTL system

The structure of CVVTL is shown in figure 1. The CVVTL is composed of cam, cam cylinder, valve cylinder, valve assembly, phase regulator, lift regulator, seating buffer and oil supply system, and so on. The valve phase regulator and lift regulator mainly consists of cylinder, piston, spring, gag lever post, and adjusting device. The oil supply system consists of oil tank, oil pump, check valve, relief valve and pipeline. The CVVTL system realizes the continuous adjustment of the valve advance angle and the valve retard angle by controlling the time that the oil flows into and flow out from the valve cylinder, which by fairly adjusting the position of gag lever post of phase regulators. And the system can realize the continuous adjustment of valve

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lift by controlling the liquid volume flows into the valve cylinder and lift regulator, which can control by fairly adjusting the position of gag lever post of lift regulator.

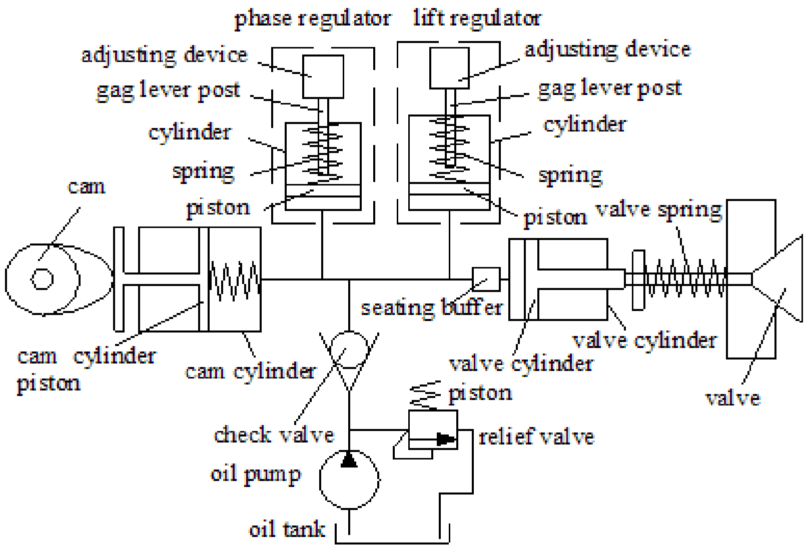
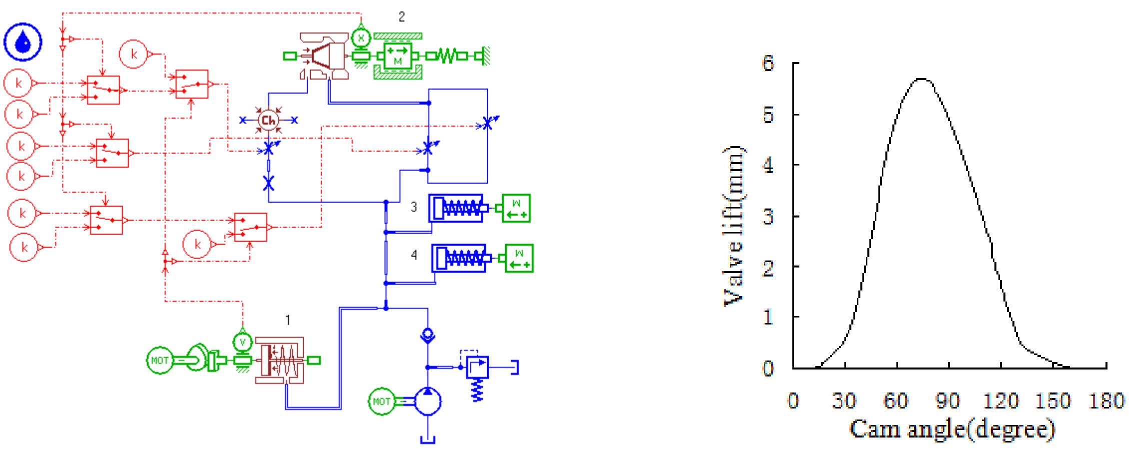


Figure 1: Schematic diagram of CVVTL

3. Simulation Model

Figure 2 is the AMESim simulation model of CVVTL. The compressibility of hydraulic oil and pressure loss existing in the physical system are fully considered in the simulation model. And hydraulic pipelines of simulation model have similar parameters with physical system. The switchover of oil circuit from cam cylinder to valve cylinder at different time in physical system is simulated by the controlling subsystem in the model. The electromotor is used to simulate the engine rotation driving the rotation of cam to bring about the reciprocating movement of cam cylinder piston, and then generate the oil pressure to drive the motion of the valve cylinder piston, phase regulator piston, and lift regulator piston. The displacement sensor is used to detect the displacement of valve oil cylinder piston. The speed sensor is used to detect the direction of reciprocating motion of cam cylinder piston. It can realize the simulation of valve cylinder and seating cushioning mechanism by using the signal of displacement sensor, the signal of speed sensor and control system cooperatively and the combination of variable throttle, mass block, spring, spool with hole section orifice of HCD. The phase regulator and lift regulator are simulated by the combination of one-way cylinder and mass block. The parameters setting of simulation model should be refer to the physical system, the simulation parameters are shown in table 1.



(a) simulation model *(b) Cam profile*

Figure 2: The AMESim simulation model of CVVTL

Table 1: Simulation parameters

Item	Parameter
Cross-section area of check valve(mm^2)	10
Discharge coefficient	0.6
Diameter of cam oil cylinder piston (mm)	16
Diameter of phase regulator piston (mm)	10
Diameter of valve oil cylinder piston (mm)	10
Diameter of lift regulator piston (mm)	16
Diameter of pipeline (mm)	8
Pre-tightening force of phase regulator spring (N)	10
Pre-tightening force of valve spring (N)	120
Pre-tightening force of lift regulator spring (N)	157
Gap height between valve oil cylinder and its piston(mm)	0.225
Stiffness of phase regulator spring (N/mm)	1.25
Stiffness of lift regulator spring(N/mm)	1
Stiffness of valve spring(N/mm)	40
Buffer length (mm)	1.5
Length of the pipe connects the cam oil cylinder and phase regulator (mm)	400
Length of the pipe connects the cam oil cylinder and lift regulator (mm)	450
Length of the pipe connects the cam oil cylinder and valve oil cylinder (mm)	600
Equivalent quality of valve assembly(kg)	0.08
Equivalent quality of phase regulator piston assembly(kg)	0.005
Equivalent quality of lift regulator piston assembly(kg)	0.02
Density of hydraulic medium(kg/mm^3)	870×10^{-9}

4. Simulation Results and Analysis

Define the cam angle 0° the same as the crank angle 0°.

4.1 Timing adjustment

When adjusting the valve timing, the displacement of lift regulator piston should be set to 0mm, and the displacement of phase regulator piston will be adjusted according to the engine speed. Figure 3 and figure 4 are the simulation results of valve timing adjustment. The values in the legend of figure 3 are the adjustments of phase regulator. From the figure 3, it can be known that:

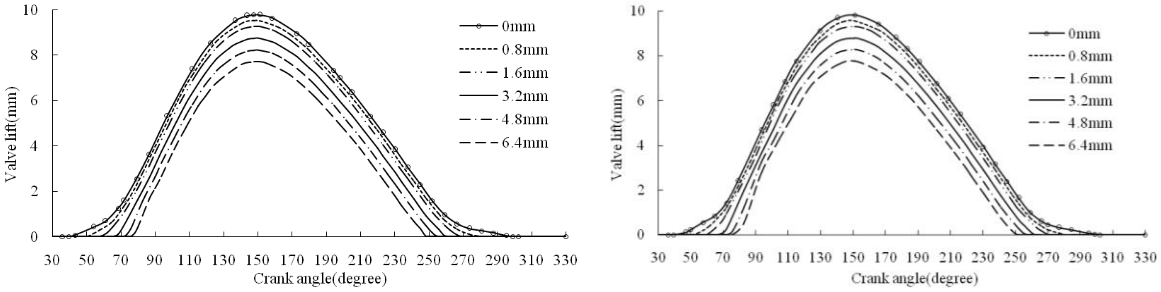
(1) In the displacement adjustment range of phase regulator piston, the valve advance angle, the valve retard angle and the valve lift gradually decrease with the increase of the adjustment of phase regulator piston. The greater of the adjustment of phase regulator piston, the more liquid volume flows into the phase regulator cylinder, the slower system oil pressure goes up, and the longer system to get the oil pressure value to open the valve. Therefore, the valve advance angle, the valve retard angle and the valve lift decrease correspondingly. The decrease of valve lift in the timing adjustment accord with the tendency of gas distribution requirement at the engine speed decreases and the load decreases as well. If the engine load is constant or increases, it can be compensated by increasing the adjustment of valve lift.

(2) The relationship between the adjustment of phase regulator piston and adjustment of the valve advance angle is nonlinear. The relationship between the adjustment of phase regulator piston and adjustment of the valve retard angle also is nonlinear. For the same increment of adjustment of phase regulator piston, the closer phase regulator piston to the zero position, the larger valve advance angle and valve retard angle will be changed. From the cam profile shown in figure 2(b), it can be seen that the closer to the starting point of cam lift, the lift of cam rise more slowly, the longer system oil pressure rises to the pressure point that can open the valve. The cam's fall curve is similar with the lift of cam. So the smaller adjustment of phase regulator piston, the larger changes of the valve advance angle and the valve retard angle.

(3) The CVVTL system can realize the continuous adjustment of the valve advance angle from 0°CA to 36°CA and the continuous adjustment of the valve retard angle from 0°CA to 54°CA by changing the adjustment of phase regulator piston at 800r/min.

Figure 4 presents the simulation results of different adjustments of phase regulator at different speeds. The adjustment is 0 mm at 4000r/min, the adjustment is 1mm at 3000r/min, the adjustment is 4mm at 1500r/min, and the adjustment is 6.4mm at 800r/min. From figure 4, it can be known that CVVTL can realize the valve advance angle and the valve retard angle increase with the increase of engine speed at the same time, and decrease with the decrease of engine speed at the same time, by adjusting the displacement of phase regulator piston according to the change of engine speed. The adjustment range of valve advance angle is

0°CA ~ 37°CA, and the adjustment range of retard angle is 0°CA ~ 61°CA. The simulation results indicate that the CVVTL system can realize the function of continuous adjustment of valve timing.



(a) 800 r/min *(b) 1500 r/min*

Figure 3: Valve lift curves of different adjustments of phase regulator

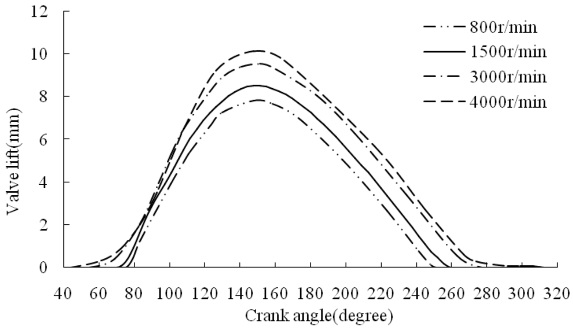


Figure 4: Simulation results of different adjustments of phase regulator at different speeds

4.2 Lift adjustment

When adjusting the valve lift, the displacement of phase regulator piston should be set to 0mm, and the displacement of lift regulator piston will be adjusted according to the engine speed or load. Figure 5 and figure 6 are the simulation results of lift adjustment. The values in the legend of figure 5 are the adjustments of lift regulator. From the figure 5, it can be known that:

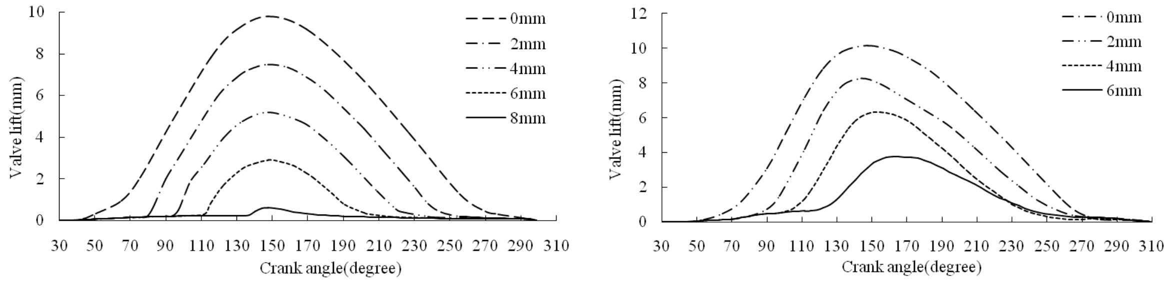
(1) The system can realize the continuous variable of valve lift by changing the adjustment of lift regulator piston. The oil total volume that flows into the lift regulator oil cylinder would be changed while changing the adjustment of lift regulator piston, and the oil total volume that flows into the valve cylinder would also be changed. So the continuous variable of valve lift is realized.

(2) All the starting point of curve at the same engine speed is the same point, all the end point of curves also is the same point. It is to say that the lift adjustment does not influence the valve timing. Since the design value of pre-tightening force of lift regulator spring is bigger than that of valve spring, when the force that system oil pressure acts on the lift regulator piston reaches the pre-tightening force of lift regulator spring, the valve has opened for a moment. So the lift adjustment always occurs behind the valve opening. This not only effectively avoids the false operation of lift regulator, but also ensures that valve timing is not influenced by the lift adjustment.

(3) Within the adjustment range of lift regulator piston, the valve lift gradually decreases with the increase of adjustment range of lift regulator piston. Since the stiffness of lift regulator spring is far less than that of valve spring, when system oil pressure reaches up to the oil pressure that corresponds to the working point of lift regulator spring, oil pumped from cam cylinder mainly flows into the lift regulator cylinder, and less oil flows into the valve oil cylinder. So, the change of valve lift is slowly. However, when the lift regulator piston reaches its adjustment position, oil pumped from cam cylinder mainly flows into the valve cylinder, the valve lift up sharply. The situation is opposite in the valve return. The bigger adjustment of lift regulator piston, the more oil flows into lift regulator cylinder. Accordingly, the less oil flows into valve cylinder. And the maximum valve lift is smaller.

(4) When engine speed reaches up to 4000r/min, the system still has good lift adjustment performance. The maximum valve lift is less than 4mm at 6mm of adjustment of lift regulator piston. Surely, this working condition is rare in practical engine running.

(5) This system can realize 0.6mm of the maximum valve lift at 800r/min. This will beneficial to the engine idle gas distribution, reducing oil consumption and emission.
(6) Compared with figure 5(a) and figure 5(b), it can be found that the higher the engine speed, the greater the maximum lift at the same adjustment. The increase of engine speed brings about the increase of hydraulic shock and oil movement inertia, eventually raises the oil pressure. And furthermore, the system pressure fluctuations and shocks will be further intensified with the increase of engine speed. So, it is necessary to adopt corresponding technical measures to control the pressure impact and fluctuation of system into reasonable range, to ensure the reliability of system in the high speed working conditions.



(a) 800 r/min *(b) 4000r/min*

Figure 5: Valve lift curves of different adjustments of lift regulator

Figure 6 presents the simulation results of different adjustment of lift regulator at different engine speeds. The adjustment of lift regulator is 0mm at 5500r/min., the adjustment of lift regulator is 2mm at 4000r/min, the adjustment of lift regulator is 4mm at 3000r/min ant the adjustment of lift regulator is 11mm at 800r/min. From figure 11, it can be known that the valve lift adjustment is not influence the valve timing. The system can realize the continuous adjustment of lift according to the engine speed by adjusting the lift regulator piston continuously, and get very small valve lift under the condition of low speed. The adjustment range of valve lift is 0.6mm to 11.25mm when the speeds of engine from 800r/min to 5500r/min.

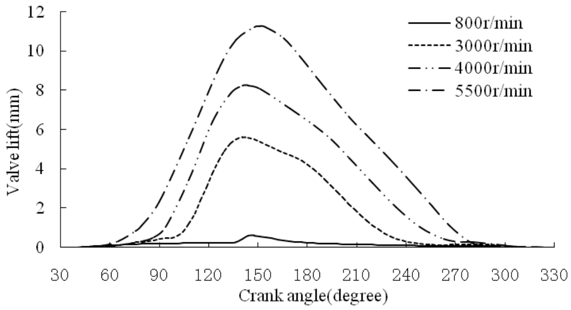


Figure 6: Valve lift curves of lift adjustment at different speeds

4.3 Both timing and lift adjustment

The simulation parameters of both valve timing and lift adjustment at different speeds are in table 2, and figure 7 is the simulation result. As shown in figure 7, the system can realize the continuous variable of valve timing and lift by adjusting the phase regulator and lift regulator at the same time according to the engine speed, the adjustment range of valve advance angle is 0~36°CA, the adjustment range of valve advance angle is 0~54°CA, and the adjustment range of valve lift is 0.6 mm ~11.25mm when the speeds of engine from 800r/min to 5500r/min.

Table 2: Simulation parameters at different speeds

	Curve 1	Curve 2	Curve 3	Curve 4
Engine Speed (r/min)	5500	4000	1500	800
Adjustment of Phase Regulator (mm)	0	0.4	2.4	5.6
Adjustment of Lift Regulator (mm)	0	1	5	6.5

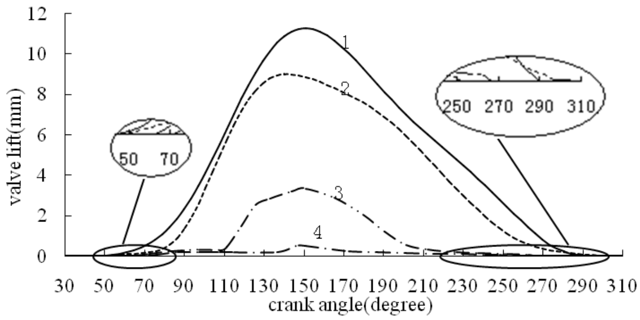


Figure 7: Valve lift curves of both timing and lift adjustment at different speeds

5. Conclusions

There are various realization approaches of variable valve technology. So far many of them have realized commercialization, but they cannot satisfy the gas distribution requirement of various working conditions of engine very well. This paper presents a novel variable valve system, namely the continuous variable valve timing and lift system by hydraulic volume adjustable which realizes the adjustment of valve timing by controlling the time that the oil flows in and out the valve cylinder, and realizes the adjustment of valve lift by controlling the volume of oil flows in the valve cylinder. Compared with the existing technologies, the CVVTL system has obvious advantages.

The AMESim simulation model of CVVTL is established. The adjustment performance of the system is studied deeply using the simulation model. The results show that both the valve timing and valve lift of the system can be adjusted independently and continuously. The valve advance angle, the valve retard angle and the valve duration angle increase with the increase of engine speed at the same time, and decrease with the decrease of engine speed at the same time. The valve lift increases with the increase of engine speed or engine load, decreases with the increase of engine speed or engine load. Adjusting both valve timing and lift, the adjustment range of valve advance angle is 0~36°CA, the adjustment range of valve advance angle is 0~54°CA, and the adjustment range of valve lift is 0.6 mm ~11.25mm when the speeds of engine from 800r/min to 5500r/min.

Acknowledgments

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Reference

Allen J. et al., 2002, Production electro-hydraulic variable valve train for a new generation of I.C. engines, SAE Tech. Paper 2002011109, DOI:10.4271/2002-01-1109

Chen J.D., 2014, Dynamic simulation and experiments of a novel variable valve timing system, International Journal of Multimedia and Ubiquitous Engineering, 7,383-394, DOI: 10.14257/ijmue.2014.9.7.32

Flierl R., Kluting M., 2000, The third generation of valve trains-New fully variable valve-trains for throttle-free load control, SAE Tech. Paper 2000011227

Hu Z.L, Gui Y., Xu M., Deng K.Y., Cui Y., Dou J.Y., 2015, Design of a variable valve hydraulic lift system for diesel engine, Journal of Mechanical Science and Technology, 4,1799-1807, DOI: 10.1007/s12206-015-0352-2

Lucio B., Andrea F., Darniano M., Aldo P., Rinaldo R., Francesco V., 2009, Electro-hydraulic valve control with MultiAir technology. AutoTechnology, 9, 32-37

Qu X., Kim D., 2012, Kinematic design and analysis of a four-bar linkage-type continuously variable valve actuation mechanism", Mechanism and Machine Theory, 57, 111-125.

Thomas D., 1989, A review and classification of variable valve timing mechanism, SAE Tech. Paper 890674