

Advanced Control System of Variable Compression Ratio (VCR) Engine with Dual Piston Mechanism

M. Kadota, S. Ishikawa, K. Yamamoto, M. Kato and S. Kawajiri
Honda R&D Co., Ltd.

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ABSTRACT

A dual piston Variable Compression Ratio (VCR) engine has been newly developed. This compact VCR system uses the inertia force and hydraulic pressure accompanying the reciprocating motion of the piston to raise and lower the outer piston and switches the compression ratio in two stages. For the torque characteristic enhancement and the knocking prevention when the compression ratio is being switched, it is necessary to carry out engine controls based on accurate compression ratio judgment. In order to accurately judge compression ratio switching timing, a control system employing the Hidden Markov Model (HMM) was used to analyze vibration generated during the compression ratio switching. Also, in order to realize smooth torque characteristics, an ignition timing control system that separately controls each cylinder and simultaneously performs knocking control was constructed. As a result, highly reliable compression ratio judgment and accurate ignition timing control were achieved to switch the compression ratio without torque steps. In addition, the fuel economy was improved to 7.4% by combining the Atkinson cycle with high compression ratio operation in Japanese 10-15 mode.

1. INTRODUCTION

The reduction of CO₂ amount by improving exhaust emissions and fuel economy has become a very important issue from the consideration to the global environment protection and the necessity of saving the natural resources. In recent years, the global warming prevention has been a pressing need, and various kinds of research have been actively done all over the world.

In this trend, mainly two kinds of research and development have been done on gasoline engines. The first approach is engine downsizing technology, and the second one is new combustion technology.

In downsizing a gasoline engine, there is an issue whereby although the fuel economy is enhanced due to reduced friction, the output falls. In order to overcome this, it is essential to install a turbocharger or a supercharger. However, as the boosting pressure rises, the knocking limit falls, causing the thermal efficiency to fall as well.

Therefore, the research on a VCR mechanism has been carried out with a view to simultaneously realizing improved fuel economy and output performance [1].

Also, enhancement of fuel economy has been promoted by new combustion technologies such as lean-burn, stratified combustion and homogeneous charge compression ignition (HCCI). These combustion technologies have been made practicable within lower speed and lower load region. However, in higher speed and higher load region, the conventional combustion technologies have been used to cover the whole operating range. Regarding HCCI, it has been reported that a high compression ratio realizes more efficient combustion characteristics [2], and a VCR mechanism that can simultaneously realize improved fuel economy and power performance has been demanded.

For this reason, a VCR mechanism has been focused to achieve further fuel economy and power performance in automobiles employing downsizing technology and/or new combustion technology [3].

In previous researches regarding VCR mechanisms [4,5,6], the link type and the sub-chamber type were composed with a lot of parts, resulting in penalty of a large engine block and a great increase in weight for a mass production engine. Furthermore, the operation mechanism became complicated, and consumed a large amount of power. With this increase of volume, weight and consumption power, the advantage with the VCR mechanism would disappear.

In contrast, the dual piston type could be installed without changing any of the major parts of the engine such as the engine block, so that it could be made into a compact form, and was superior to other types.

In this study, a dual piston type that consumed lower power to switch the compression ratio was adopted [7,8]. The vehicle equipped with this dual piston VCR engine could expect both better fuel economy and power performance.

However, during the two-stage switching between high and low compression ratios, as the compression ratio does not change continuously; there is a large gradient in the demanded ignition timing. Due to this, in switching from low to high compression ratio, knocking is likely to occur. In contrast, in switching from high to low compression ratio, the torque characteristics and fuel economy tends to be worsen.

Moreover, in order to accurately set the ignition timing, it is necessary to accurately distinguish between the compression ratio conditions at the two stages [9]. However, there had been no report on practical study which is able to distinguish the compression ratio in real time over a wide range of driving conditions.

The goal of our study is to establish the advanced VCR control system to achieve smooth torque transient response and the prevention of knocking during the compression ratio switching.

2. VCR ENGINE CONFIGURATION

2.1 VCR CONCEPT

A dual piston type was adopted, because it could switch the compression ratio in two stages with both lower power consumption and compactness, by raising and lowering the outer piston under the inertia force and hydraulic pressure accompanying the reciprocating motion of the piston. The VCR concept is shown in Figure 1. There are two stages determined by the position of the top face of the piston, being raised and lowered by 3.5 mm with reference to the piston pin. The compression ratio can be changed by 4.6, that is from 9.6 to 14.2.

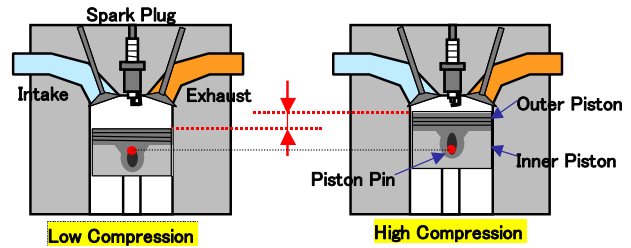


Figure 1 VCR Concept diagram at top dead center

2.2 ENGINE OUTLINE

Table 1 shows a comparison of a dual piston VCR engine and a conventional engine. The VCR mechanism was installed in a mass production 2.0 L naturally aspirated engine. In the valve train, the closing of the intake valve was delayed based on i-VTEC in order to realize an Atkinson cycle [10].

Table 1 Engine configuration

		Mass Production	VCR
Cylinder Configuration		In-line 4-cylinder	
Bore	mm	86	
Stroke	mm	86	
Displacement	cm ³	1998	
Compression Ratio		9.6:1	9.6:1 / 14.2:1
Valve Train		DOHC i-VTEC	
Number of valves		4	
Valve Diameter (IN/EX)	mm	35 / 30	
Valve Timing (IN, open/close)	deg. C.A.	-15 / 40	-15 / 40~90
(EX, open/close)	deg. C.A.	30 / 15	

The switching of the compression ratio used the inertia force of the piston itself and hydraulic pressure as an external force. The required hydraulic pressure for the switching was 0.8 MPa and the oil flow rate was 3L/min. For the purpose of this study, a small pump was installed in the system separate from that of the engine lubricating oil pump. The oil passage was constructed from the external pump through the crankshaft and connecting rod, to the piston, by modifying the design of those parts.

2.3 OUTLINE OF DUAL PISTON

2.3.1 PISTON STRUCTURE

Figure 2 shows an outline of the piston. The piston was divided into the outer and inner pistons. The top face of the outer piston constituted the combustion chamber against a cylinder head. The inner piston had the function of a piston skirt and a lifter mechanism as well as a lock mechanism. The lifter mechanism had the function to engage with and ride up onto the rear face of the outer piston. The lock mechanism had the function as a key that retained the outer piston.

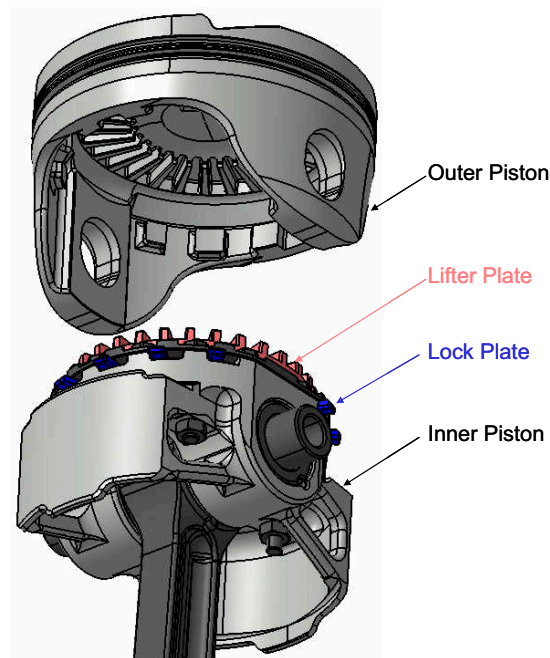


Figure 2 Configuration of piston parts

2.3.2 PISTON SWITCHING OPERATION

The nominal compression ratio could be set to either a low and high compression ratio. At the following, the nominal compression ratio denoted low compression ratio. Figure 3 shows operation chart of the compression ratio switching.

In the switching from low to high compression ratio, after the hydraulic pressure was turned ON, it acted on the pin of lock plate, so that the lock plate rotated out and the outer piston became free (A1). The outer piston rose 3.5mm up by the resultant force of the piston inertia force and the cylinder pressure force (A2). And the maintaining hydraulic pressure made the lifter plate rotated in (A3). The state of the high compression ratio was kept as the outer piston stepped on the lifter plate.

Conversely, in the switching from high to low compression ratio, the lifter plate rotated out (B1) after the hydraulic pressure was turned OFF, the spring acted on the pin of lifter plate. The outer piston was lowered in 3.5mm over the inner piston by the resultant force (B2). And the state of the low compression ratio was maintained by rotating the lock plate in (B3).

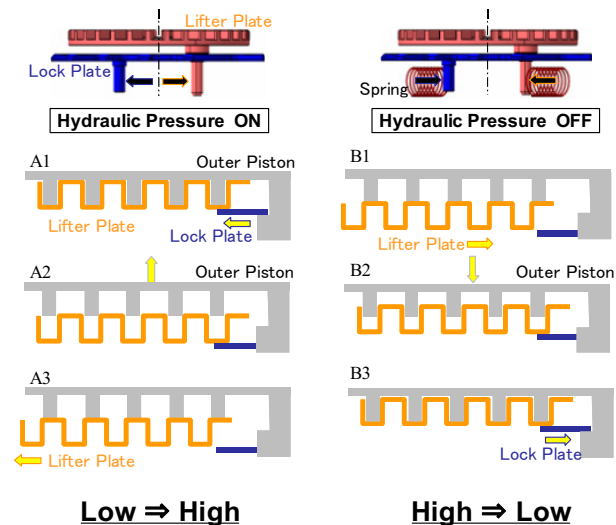


Figure 3 Operation chart of compression ratio switching

2.3.3 OPERATION PRINCIPLE OF VCR SWITCHING

In this section, the principle of the compression ratio switching is described, from the perspective of the force acting to the piston while the completion of the compression ratio switching operation after the hydraulic system was turned ON or OFF. Figure 4 shows a cycle diagram of the piston inertia force, the cylinder pressure force and those resultant forces as which acted to the piston. Additionally, the vibration signals corresponding to the completion of compression ratio switching were illustrated. This was the acceleration output obtained by the knock sensor installed on the engine block.

In the compression ratio switching from low to high, after the lock plate rotated, the resultant force of the piston inertia force and the cylinder pressure force became upward (+ side) so that the outer piston could lift up. As the piston inertia force exceeded the cylinder pressure force, the outer piston traveled up by 3.5mm and the lifter plate rotated, which completed the switching operation. The collision of the outer piston and the piston pin at the completion of the switching was detected as vibration signal. In this case, the switching completion timing was around 335 ~ 340 degCA ATDC.