

Advanced Design of Variable Compression Ratio Engine with Dual Piston Mechanism

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ABSTRACT

A Dual Piston Variable Compression Ratio (VCR) engine has been newly developed. In order to ensure the strength of the Dual Piston, the design guidelines were established. There are two advantages of this design. One is the compactness and the compatibility with a mass production engine block. Another is less power consumption required during compression ratio switching. However, the durability is a challenge for this design because of the impact load during the switching driven by the inertial force of a reciprocating piston. In order to achieve a durable configuration, it was necessary to consider the dynamics of the stress after impact, from analysis of the impacting process during the switching. The analysis of stress and deformation mode was improved in accuracy by using Computer Aided Engineering (CAE) in the designing process. In addition, the results of stress measurements of the piston in firing engine operation were fed back for further enhancements, and the design guidelines against switching load were established. To verify the durability of the VCR engine manufactured according to these guidelines, the durability tests were performed with continuous switching at 1 Hz. As a result, the test proved the switching durability of over 1×10^6 cycles at 2500 rpm.

1. INTRODUCTION

In views of protecting the global environment, saving resources and achieving better economy, there are increasing demands to improve fuel economy of internal combustion engines. In order to achieve high fuel economy, it is necessary to improve the thermal

efficiency. For an internal combustion engine, higher compression ratio leads to an increase in thermal efficiency. However, an increased compression ratio may cause abnormal combustion such as knocking and an engine is likely to operate at a narrow range of driving conditions. For these reasons, various VCR mechanisms that can change a compression ratio suitable for a certain driving conditions have been proposed [1-5]. Some examples of the proposed mechanisms are shown in Figure 1. After our thorough investigation, a variable piston height type was selected for our research of VCR mechanism.

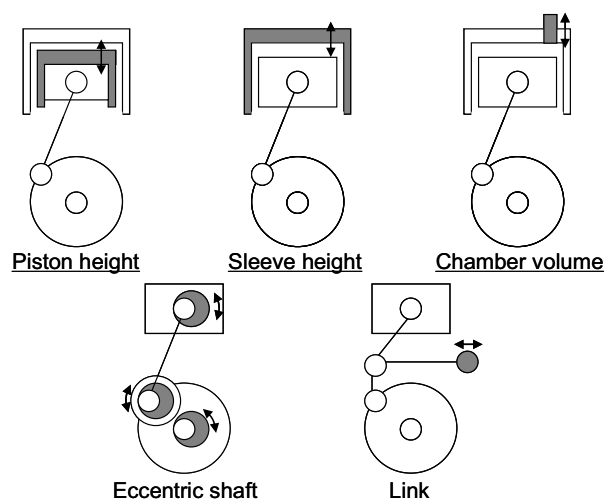


Figure 1 Various VCR configurations [1-5]

This mechanism has two attractive advantages as follows:

1. It has a compact form factor and can be used with the existing mass production engine block, because the switching mechanism is integrated into the piston without major change in the engine design.
2. The consumed power is less, because the inertial force derived from the reciprocating motion of the piston is used to change the piston height for compression ratio switching.

On the other hand, an impact load is applied to the piston on this switching mechanism, because a compression ratio is switched in a short time. For this reason, the durability against the impact load can be a major challenge for the piston design. In this study, a new dual piston height switching mechanism (Dual Piston VCR mechanism) was developed with sufficient durability, while realizing two advantageous characteristics of compactness and low power consumption. In this paper, an outline of this mechanism as well as the results of analyzing the impact process during compression ratio switching was explained. In addition, the design guidelines for the durability against switching load were also established, by reflecting the results of the analysis as well as the result of applying these guidelines.

2. CONFIGURATION OF DUAL PISTON VCR MECHANISM

Figure 2 shows external views of the developed Dual Piston VCR mechanism. Specifications of the Dual Piston are given in Table 1. This compact VCR mechanism was almost in the same size as a mass production piston so as to be used with the existing mass production engine block.

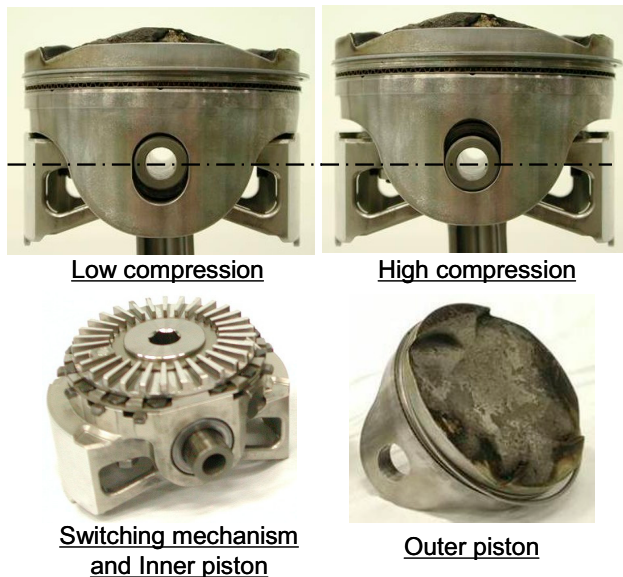


Figure 2 Dual Piston VCR mechanism

Table 1 Piston specifications

	Dual Piston	Mass production piston
Bore (mm)	86	86
Height (mm)	Low61.4/High64.9	51.5
Variable piston height (mm)	0/3.5 (two stage)	—
Material	Aluminium alloy (Outer and Inner piston)	←
Oil pressure for switching (MPa)	0.8	—
Electricity consumption (W)	250	—
Maximum switching speed (Hz)	1	—
Switching response	less than 5 cycles	—

Figure 3 shows the main components of VCR mechanism. The assembly consists of an outer piston, an inner piston, a piston pin and switching mechanism. The outer piston was simply constituted with a combustion chamber, piston ring grooves and piston pin bosses, because the switching mechanism and a piston skirt were compactly incorporated into the inner piston. Compression ratio could be switched between two positions: low and high compression. When a full four-stroke engine process was counted as one cycle, the switching was completed within five cycles after turning on the switching signal. The aluminum alloy was used for the piston material as used in mass production pistons.

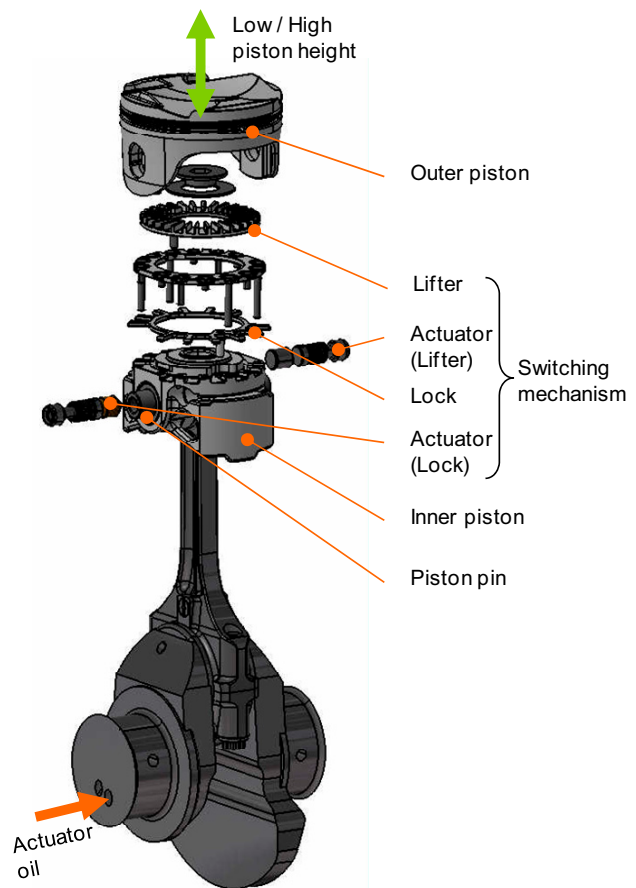


Figure 3 Dual Piston VCR configuration

Figure 4 shows an outline of the compression ratio switching operation in this Dual Piston VCR. Switching a compression ratio was achieved by raising and lowering the outer piston relative to the inner piston. Vertical motion of the outer piston was driven by inertial force of the reciprocating motion of the piston, and hence no additional power was required to move the outer piston vertically. However, during compression ratio switching, the outer piston impacted on the piston pin and the lifter. The impact regions of the outer piston were the piston pin boss on switching from low to high compression ratio, while the back surface of the combustion chamber, on switching from high to low compression ratio. The outer

piston was secured in the low or high compression ratio position by the lock and the lifter of the switching mechanism. These parts were operated by two hydraulic actuators and springs positioned parallel to the piston pin. Engine oil was used as its hydraulics and it was provided by an actuator oil pump system through actuator oil passages. The actuator oil passages were constructed separately from lubrication oil passages in a crankshaft, a connecting rod, and inside the piston pin. Also, seals were provided in each of these parts to minimize oil leaks and maintain low friction between these parts. Thereby the required power for the actuator oil pump during the switching operation was minimized [6].

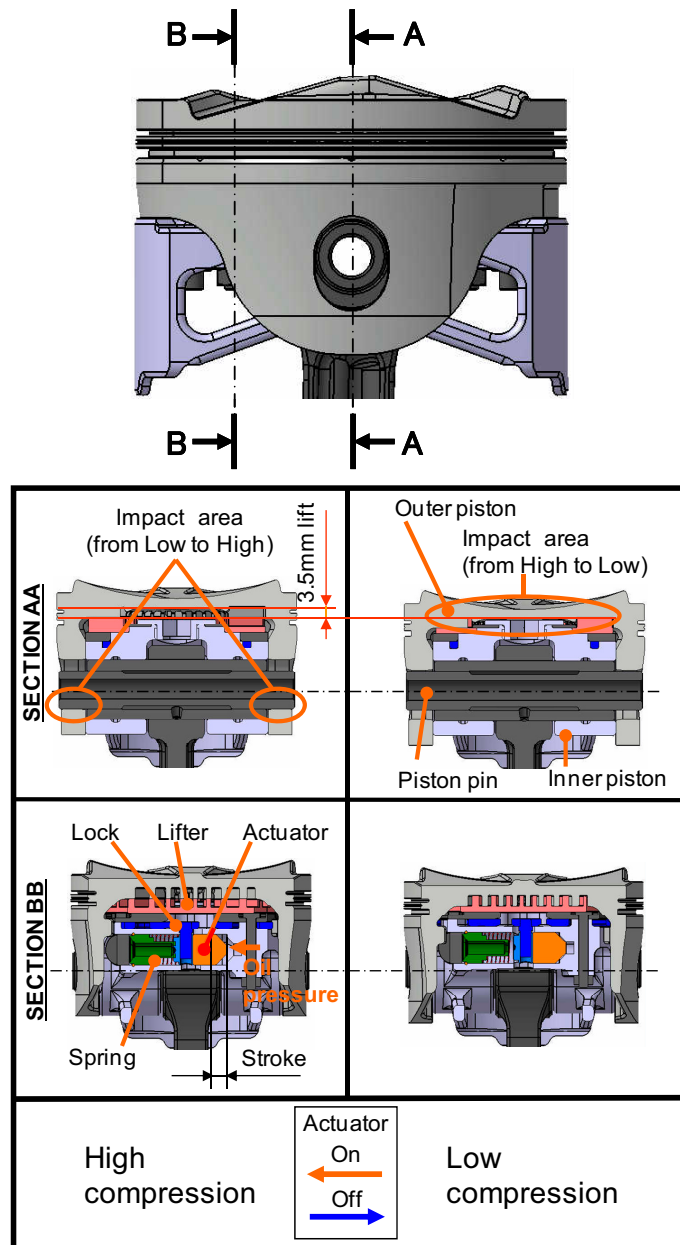


Figure 4 Dual Piston VCR operation