

A Study of a Multiple-link Continuously Variable Valve Event and Lift (VVEL) System

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ABSTRACT

A new variable valve event and lift (VVEL) system has been developed by applying a multiple-link mechanism. This VVEL system can continuously vary the valve event angle and lift over a wide range from an exceptional small event angle and small lift and to a large event angle and large lift. This capability offers the potential to improve fuel economy, power output, emissions and other parameters of engine performance. The valve lift characteristics obtained with the VVEL system consist of a synthesis of the oscillatory motion characteristics of the multiple-link mechanism and the oscillating cam profile. With the multiple-link mechanism, the angular velocity of the oscillating cams varies during valve lift, but the valve lift characteristics incorporate both gentle ramp sections and sharp lift sections, the same as a conventional engine. This paper describes the mechanical features of the multiple-link VVEL system and performance levels attained, based on simulation data obtained at the stage of conceptualizing the fundamental principle of the system and at the stage of validating a prototype system.

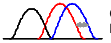
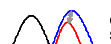
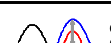
INTRODUCTION

Passenger vehicle engines today are required to satisfy conflicting demands for driving pleasure and environmental performance. Moreover, contributions to achieving an optimal balance of fuel economy, clean emissions and power output have become extremely important in recent years. Variable valve actuation (VVA) has long been a subject of research because of the valvetrain's large impact on engine performance in the course of controlling the gas exchange process.[1] However, in the past there was ample room for improving engine performance by changing the valvetrain configuration. Variable valve actuation began to be adopted around 20 years ago when the DOHC, four-valve-per-cylinder configuration came into general use as the best valvetrain system available. Initially, the application of VVA was limited, but it has now developed

into a commonly used technology that is incorporated in nearly all gasoline engines today. The degrees of variation freedom were initially limited to the phase of the rotating camshaft, resulting in a variable phase valvetrain. Subsequently, the degrees of variation freedom were expanded as the need to reconcile more diverse engine performance parameters increased. At present, valvetrains that continuously vary valve lift and event angles so as to facilitate intake air mass control under all operating conditions have been implemented in production engines.

A functional comparison of various VVA systems is given in Table 1. It is seen that a valvetrain configuration which combines continuously variable lift and event angle control with variable phase control incorporates all of the variable functionality. Such variable valvetrains, especially new engine concepts that independently control the compression ratio and expansion ratio, have recognized benefits for improving fuel economy further and are expected to be a key technology for future engines.[2-6]

Table1 Functional Comparison of Variable Valve Actuation

		O: Possible x: Impossible				
	Type	Valve Lift Curve	Continuous Control	Phase Control	Event Control	Lift Control
Variable Phase	CVTC ¹⁾	 Cam Shaft Phasing	O	O	x	x
Variable Event & Lift	VVL ²⁾	 Cam Switching	x	Δ	O	O
	VVEL	 Oscillating Cam	O	x	O	O
Variable Phase & Event & Lift	VVEL + CVTC	 Combination	O	O	O	O

1) CVTC: Continuous Variable Timing Control

2) VVL: Variable Valve Lift

This paper describes the functional features of a multiple-link variable valve event and lift (VVEL) system (Fig. 1), as an example of a sophisticated variable valvetrain, based on simulation data obtained during the research stage of the system's fundamental operating principle and in the validation of a prototype system.[7-9]

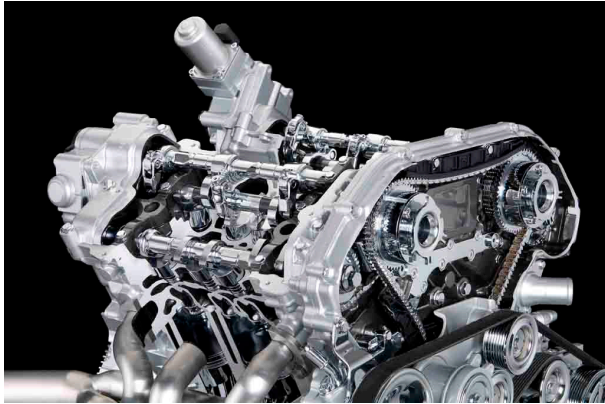


Fig.1 Configuration of VVEL Engine

OUTLINE OF VVEL SYSTEM

VALVE LIFT CHARACTERISTICS

The valve lift characteristics obtained with the VVEL system are outlined in Fig. 2. Valve lift characteristics can be continuously varied from exceptionally small lift and event angles to large lift and event angles characteristic of ultrahigh-performance engines. An ultrasmall event angle with zero lift, i.e., valve deactivation, is also possible. The ramps required for valvetrain operation are nearly identical at each event angle.

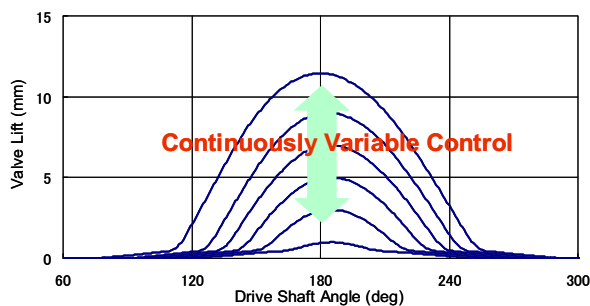


Fig. 2 Valve Lift Characteristics

BASIC CONSTRUCTION

Unlike valvetrain systems with rotating cams, the valve lift curve in the VVEL system is formed by the oscillatory motion of an output cam. The configuration of the VVEL system is shown in Fig. 3.

The VVEL system is a multiple-link variable valvetrain consisting of an output cam and the links that drive it. Valve lift characteristics are defined by the profile of the output cam and its oscillatory motion characteristics, i.e., the oscillatory motion characteristics of the multiple links. Like ordinary rotating cams, the

output cam profile incorporates ramp sections for ensuring quiet, smooth valve operation over the entire range of lift control. The drive shaft is driven by a chain in synchronization with the rotation of the crankshaft. The rotational motion of the input cam provided on the drive shaft is converted to the oscillatory motion of the output cam by means of link A, the rocker arm and link B.

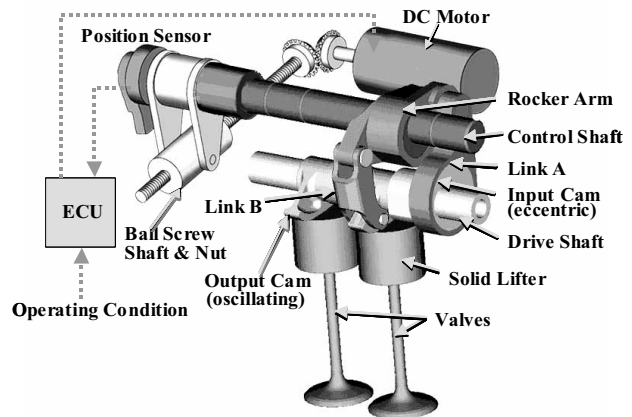


Fig. 3 Configuration of VVEL System

Because the system continues the basic structure of a conventional direct-acting valvetrain, the center of the drive shaft coincides with the center of an ordinary camshaft, and the output cam is positioned coaxially with the drive shaft. Link B drives the output cam for two intake valves so as to simplify the mechanism and improve engine mountability. Compared with ordinary rotating cams, the output cam allows a smaller base circle diameter, due to the lower contact pressure the cam and lifter. This compact configuration allows the VVEL system to be incorporated in existing cylinder heads with minimal modification.

OPERATING PRINCIPLE

Variable valve lift is accomplished by controlling the phase angle of the control shaft with an actuator. This makes it possible to vary the distance between the center of rocker arm oscillation and the center of the drive shaft, thereby changing the oscillatory motion characteristics of the multiple links and of the output cam. Figure 4 illustrates the condition of the links at the time of maximum and minimum valve lift.

The state of maximum valve lift is achieved by reducing the distance between the center of rocker arm oscillation and the drive shaft center. As a result, the output cam begins its oscillatory motion from a position close to the valve lifter, resulting in maximum valve lift. By contrast, the state of minimum valve lift is achieved by increasing the distance between the center of rocker arm oscillation and the drive shaft center. As a result, the output cam begins its oscillatory motion from a position farther from the valve lifter, resulting in minimum valve lift.

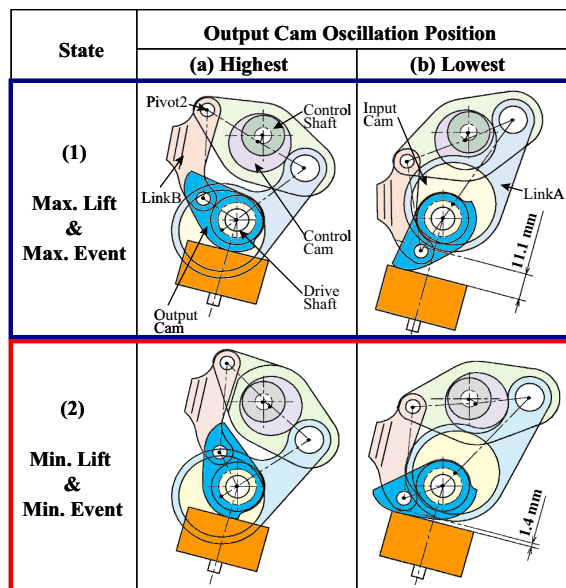


Fig. 4 State Change Operation

Figure 5 shows an example of continuously variable valve lift and event angle control achieved with a non-multiple-link configuration in comparison with the multiple-link system. With the non-multiple-link system, an additional spring is needed to achieve zero clearance in the mechanism. On the other hand, one issue in the multiple-link system is that the oscillation angle of the output cam increases owing to the oscillation of the links even in the base circle phase.

The following sections explain the valve lift characteristics and functional characteristics that have been obtained by developing the multiple-link system.

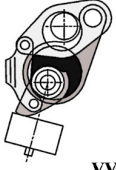
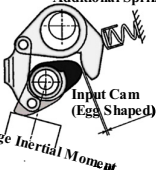
Type		
	VVEL Multiple-Link	Non Multiple-Link Additional Spring Input Cam (Egg Shaped) Large Inertial Moment
Additional Spring	Without	With
Output Cam Oscillating Angle	Large	Small

Fig. 5 Comparison between Multiple-Link and Non Multiple-Link Systems

VALVE LIFT CHARACTERISTICS

COMPOSITION OF VALVE LIFT CURVE

As shown in Fig. 6, the valve lift curve in the VVEL system is formed by the output cam profile and the oscillatory motion characteristics of the multiple-link that drive the output cam. Because the VVEL system continues the basic structure of an existing direct-acting valvetrain, the output cam requires an oscillation angle

of approximately 70° for the ramp and lift sections combined. Moreover, an even larger oscillation characteristic is required because the multiple links oscillate (i.e., lost motion) even during the base circle phase. The VVEL system provides a large multiple-link oscillation angle of approximately 130°, including the variable characteristic range.

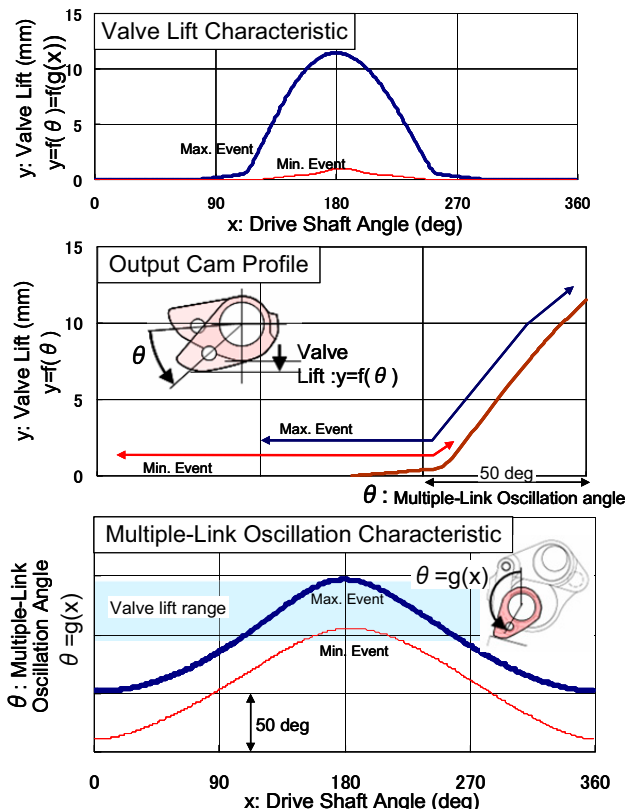


Fig. 6 Composition of Valve Lift curve

The valve lift curve includes the ramp and lift sections and has positive acceleration at the start and end of the lift section. The sharp change in the lift characteristic is identical to that obtained with ordinary rotating cams. The following discussion describes the valve lift characteristics obtained with the VVEL system in more detail. Valve acceleration that characterizes the lift section is defined by the following equation:

$$d^2y/dx^2 = (d\omega/dx)(dy/d\theta) + \omega^2(d^2y/d\theta^2)$$

where y denotes valve lift, x is the drive shaft angle, ω is the oscillatory angular velocity ($d\theta/dx$) of the multiple-link and θ is the multiple-link oscillation angle. The operating characteristics of the output cam and links, representing the constituent elements of the VVEL system, at the time of the maximum event angle are shown in Fig. 7. It is seen from these characteristics that positive acceleration is mainly influenced by the output cam characteristics and negative acceleration by the multiple-link characteristics. This indicates that positive acceleration and negative acceleration, which are important for valve lift, can be set independently and then synthesized, making it possible to adjust the final valve acceleration. Therefore, the output cam velocity ($dy/d\theta$) can be