

# Development of Continuous Variable Valve Event and Lift Control System for SI Engine (VEL)

Yoshihiko Yamada, Kenichi Machida and Tetsuo Yamazaki

Hitachi, Ltd., Automotive Systems

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## ABSTRACT

This paper describes a newly developed variable valve control system called VEL (Variable Valve Event and Lift Control System), which enables continuous control of both valve events (opening duration) and valve lifts, from the lowest lift state below 1mm to the highest lift state over 12mm. VEL has actually been adopted to the new V6 production engine of Nissan since last summer, and contributes not only to fuel economy and low emissions, but also to driving pleasure.

VEL is composed of three subsystems. First is a mechanical valve train system, which converts crankshaft rotation into output cam oscillation via a transmission mechanism. The valves are moved by the output cam oscillation. Second is an electric powered actuator system, which varies valve events and lifts according to driving conditions by controlling the angular positions of a control shaft. Third is the drive control system, consists of the Engine Control Module and the Electric Control Unit to drive the VEL, which controls the actuator system to the optimum valve lifts and events of each engine running conditions.

The basic design of the VEL was decided in consideration of mechanical superiority, that is, high rotational speed limit and low driving friction. In order to realize this, a forced drive mechanism was introduced as the VEL transmission structure, because no additional spring is needed for driving the output cam back to the original position. As a result, both the allowable maximum speed of 7500rpm and the lower driving friction under ordinary driving conditions can be realized.

The electric powered actuator uses a low friction ball-screw element for quick response and lower energy consumption. This simple ball-screw type actuator needs only a 100W motor for its adequate operation with the assistance of a suitable control method.

**THIS PAPER GIVES A GENERAL TECHNICAL EXPLANATION ABOUT VEL, INCLUDING ITS MASS PRODUCTION SPECIFICATIONS.**

## MAIN SECTION

### 2. Introduction

At present, the requirements for saving energy are becoming more and more severe because of the increasing seriousness of global environmental issues. Especially, reducing CO<sup>2</sup> emissions is a highlight. In the same context, reducing other exhaust emissions is also important for a better environment. On the other hand, end-user strongly requires more powerful automobile engines to realize driving comfort. As a key technology to improve these environmental and driving performances, the variable valve control system (called VEL hereafter) has been developed. This system controls valve events and lifts continuously. This paper describes distinguishing features of the VEL system as well as the knowledge and test results obtained through the development of the system until it reaches the mass-production stage.

There are two basic categories of the variable valve control system. One is to make the camshaft phase variable and another is to make the valve event and lift variable. The former has evolved from two-step switching type to continuous variable type and is now being adopted commonly. As for the latter, the switching type has already been put into actual use. However, the continuous variable type, which provides large improvements in fuel economy, exhaust emissions and engine output, has disadvantages of complex mechanism, difficult control and increase of cost. Therefore, not many of this type have been put into production.

The following are the aims of development of VEL considering ease of mass production:

- (1) Structure which ease installation to existing engines
- (2) Wide variable range of valve event and lift
- (3) High reliability of mechanism to enable high engine speed
- (4) Realization of ultra small lift with high accuracy

- (5) Quick control response
- (6) Low driving loss and low electric power consumption for control

### 3. VEL system

VEL is composed of three subsystems as illustrated in Figure 3.1. The first subsystem is a mechanical valve train system, which opens and closes the valves. The second is an actuator system, which varies valve events and lifts by controlling the attitude of the valve train system. The third is a drive control system, which controls the abovementioned systems.

Mechanical valve train system converts the rotational motion of the crankshaft into oscillation motion of the output cam to drive the valves via link mechanism. The structure of this system is shown in Figure 3. The drive shaft corresponds to conventional camshafts, synchronized with the crankshaft and rotates at half the speed of it. The input cam (driving eccentric cam) is fixed to this drive shaft.

Located above the drive shaft are the control shaft, which is formed with eccentric control cam, and the rocker arm, which oscillates on the pivot of the eccentric control cam.

The input cam is connected with one end of the rocker arm with the link-A, which converts eccentric motion to oscillating motion. The other end of the rocker arm is connected to the output cam with the link-B, which oscillates the output cam. The aforementioned drive shaft goes through the output cam, which drives the valve lifter, using the drive shaft as a pivot.

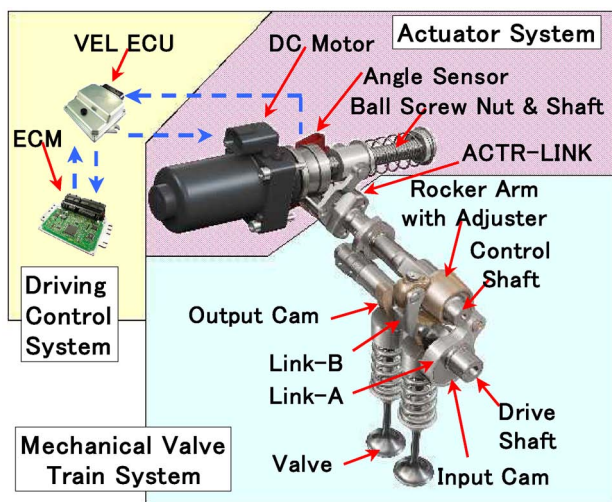


Fig.3 Structure of VEL System

The actuator is located at the end of the cylinder head and is of an electric operated type having a DC motor. This actuator twists the control shaft using a ball-screw as a reduction gear and links in the actuator. It also contains an angle sensor to detect the angle of the control shaft. The drive control subsystem consists of the engine control module (abbreviated as ECM hereafter) and the electric control unit to drive the VEL (VEL-ECU).

The ECM calculates the target angle of VEL based on vehicle and engine information, and transmits the target angle to the VEL-ECU through the CAN communication system.

The VEL-ECU controls the VEL actuator by conducting feedback control using the VEL target angle and the information from the VEL control shaft angle sensor.

Both the ECM and VEL-ECU conduct various kinds of diagnoses on input and output systems of VEL and take fail-safe actions according to the diagnosis results.

### 4. Mechanical valve train system

#### 4.1 Principle of variable mechanism

Figure 4.1 illustrates the principle of variable valve event and lift of the VEL.

Figure 4.1-(1) shows the case where the direction of eccentric cam of the control shaft is controlled to the drive shaft side and the oscillation pivot of the rocker arm is moved close to the drive shaft. As a result, the attitude of this entire link mechanism changes and the oscillation range of the output cam shifts downward, which means that this mechanism provides greater valve event and lift.

On the contrary, Figure 4.1- (2) shows the case where the oscillation pivot of the rocker arm is controlled to move away from the drive shaft and the oscillation range of the output cam shifts upward. This movement increases the range of idle stroke and thereby decreases the valve event and lift.

All the parts of VEL between the input cam and the output cam are tightly connected with links and are driven coercively. The parts that oscillate or reciprocate change the direction of movements when the output cam reaches the lowest point. Then, these parts are forced to return because of the link connection. Therefore, no return springs (to reverse the movement of parts) are required. Owing to this advantage, it is not necessary to strengthen the valve springs, because all of the inertia mass that the return springs are required to push back are the valves and lifters only, which is the same condition as conventional valve train systems.

| Stat                     | Output Cam Oscillation Position |            |
|--------------------------|---------------------------------|------------|
|                          | (a) Highest                     | (b) Lowest |
| (1) Max Lift & Max Event |                                 |            |
| LIFT = 12.5mm            |                                 |            |
| (2) Min Lift & Min Event |                                 |            |
| LIFT = 0.7mm             |                                 |            |

Figure 4.1 Principle of variable mechanism of VEL system

4.2 Valve lift characteristics

Figure 4.2 shows the valve lift characteristics of VEL. The VEL was designed so that it would have a very wide range of continuous change in valve event-lift from ultra small of 0.7mm-100degCA to large 12.5mm-292degCA. The ratio of valve lift to event, which is important for engine performance, is equivalent to that of conventional engines.

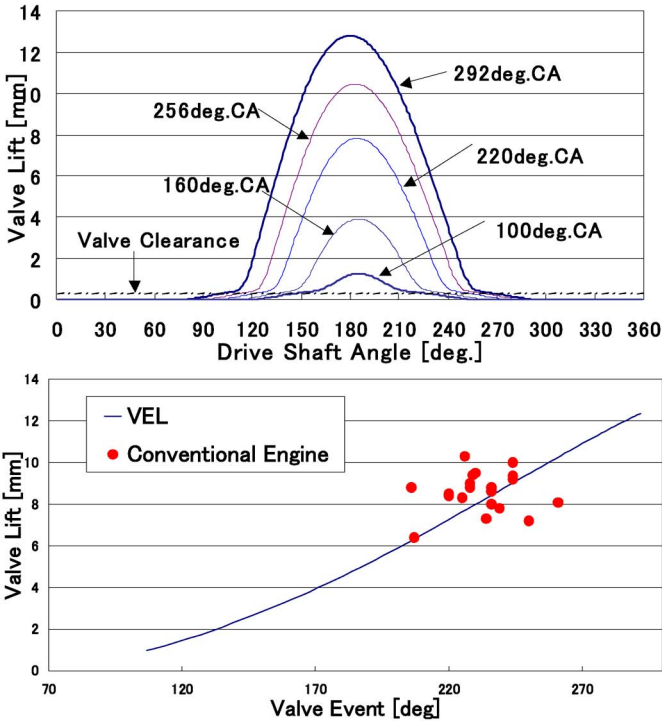


Figure 4.2- Valve event and lift characteristics

4.3 Easy installation to existing engines

VEL realized the ease of installation without a big change of the existing cylinder heads layout by placing the oscillation cam coaxially with the drive shaft, and placing the links, which connects the input cam and the output cam between the dead-space of the cylinders. (See Figure 4.3.1, Figure4.3.2).

VEL does not have an independent cylinder by cylinder structure but has a one-body structure to cover all cylinders, which is the same structure as ordinary camshafts (see Figure 4.3.2).

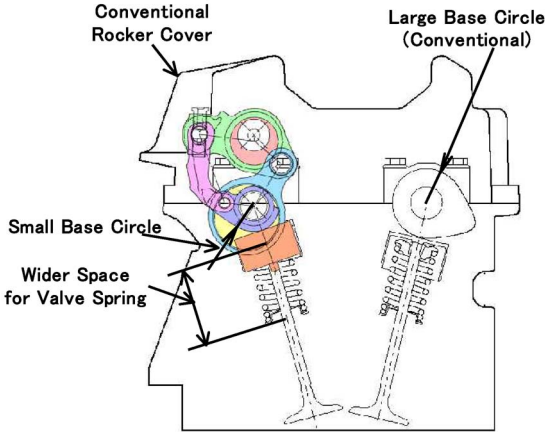


Figure 4.3.1 The Installation Figure of The VEL on The Cylinder Head

Another feature of the VEL is that the same diameter as existing camshaft journal can be maintained, although the double structure of the output cam and the drive shaft is inevitable. The output cam has the advantage that a large radius of curvature can be applied to the oscillating cam. This contributes to reducing contact pressure between cam and the valve lifter, and making the base circle diameter small. This makes it further possible to secure ample space for the valve spring, which is required for increasing the valve lift.



Figure 4.3.2 VEL Assembly

4.4 Design of linkage geometry

Since the VEL is composed of multiple links, there are many design parameters. A special calculation program for linkage design was developed to satisfy various requirements for variable range, valve lift characteristics, size of the system, valve motion characteristics, noise, friction and durability. This calculation program has a two-step structure. The first program is a geometric calculation program to decide the basic geometry and the second is a dynamic structure analysis program to calculate the movements at high engine speeds, frictions, etc. These two programs were utilized according to the purposes.

Analysis parameters and a design flow chart are listed below. Table 4.1 shows the input and output items of the analysis program.

Table 4.1 Input and output items of analysis program.

|                 | Kinematic | Dynamic |
|-----------------|-----------|---------|
| Geometry        | ⊙         | ○       |
| Cam             | ⊙         | ○       |
| Mass Properties | △         | ○       |
| Stiffness       | ×         | ○       |
| Clearance       | ○         | ○       |
| Friction        | ○         | ○       |

- ⊙ : Input & output
- : Input only
- △ : Only inertia mass of valve train is considered
- ×

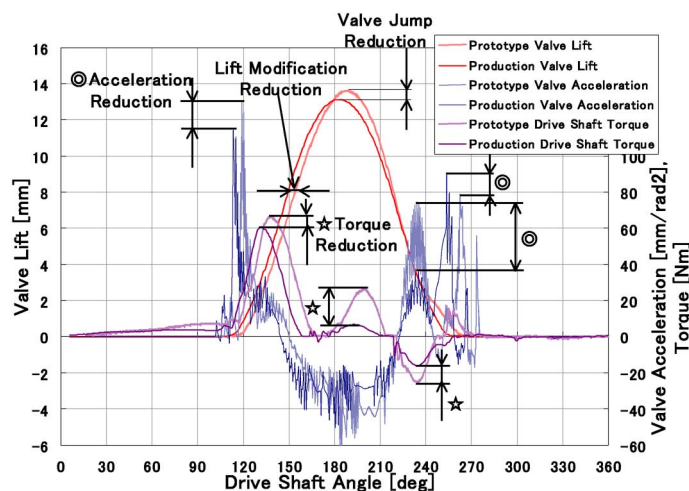
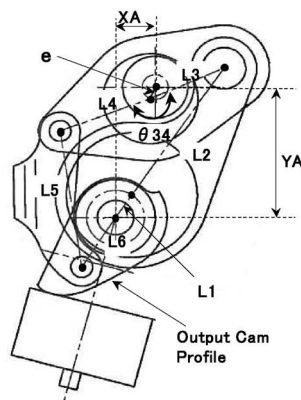


Figure 4.4.3 Analysis of lift curve with imp

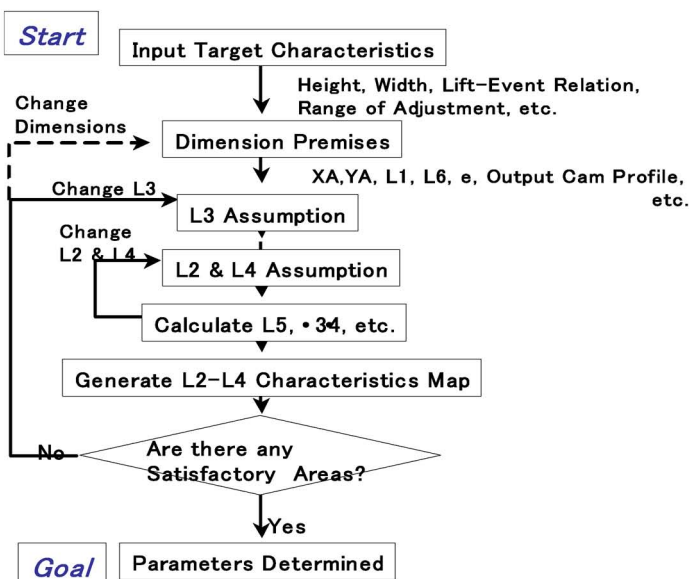


Figure 4.4.1 - Design flow chart

Below Figure 4.4.2 illustrates an example of improved linkage.

With improved linkage, it was made possible to realize reduction in jump and bounce and driving torque.

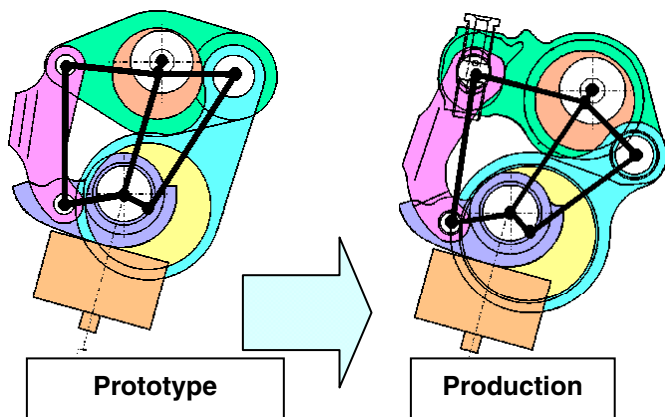


Figure 4.4.2 Example of improved linkage

## 4.5 Technology to cope with high engine speed

### 4.5.1 Stability on the ramp

One of the most important features of function required to valve train at high engine speeds is the stability on the ramp. In the case of VEL, it is possible to set the big ramp at low lift and at high lift stably, and enables to mount on the solid valve lifter, which requires large valve clearance. Almost stable ramp speed at various valve lift were attained because the change of the angular acceleration (in the ramp section) of the oscillating cam at the time of opening and closing of the valve in various valve event and lift are small, as a VEL features shown in Figure 4.5.1. In addition, the suppression of negative acceleration at peak achieved by the cam profile optimization and positive acceleration on valve closing by the link characteristics has provided excellent valve motion characteristics. It is needless to say that this attribute of VEL contributes to lowering the operation noise as well.

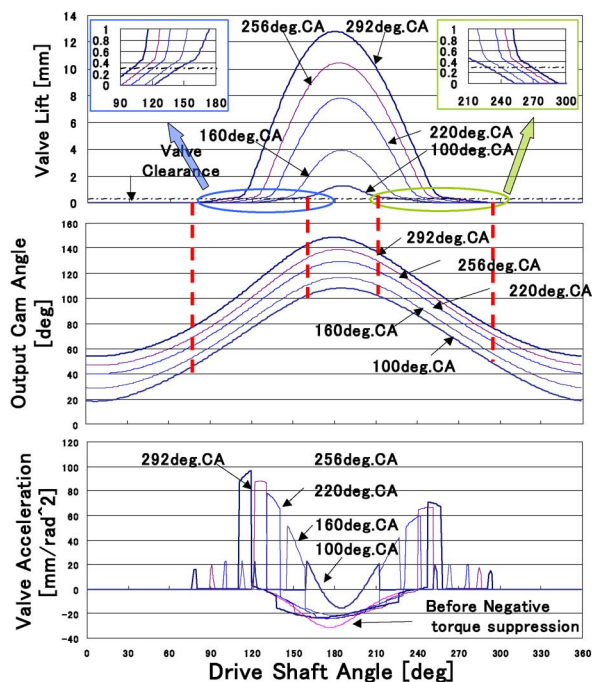


Figure 4.5.1 Valve lift, Valve acceleration, Valve velocity after improvement in Link Geometry