

Development of Variable Valve Timing System Controlled by Electric Motor

Masayoshi Hattori, Takashi Inoue and Zenichiro Mashiki

Toyota Motor Corporation

Akihiko Takenaka, Haruyuki Urushihata and Seiji Morino

Denso Corporation

Takayuki Inohara

Nippon Soken, Inc.

Copyright © 2008 SAE International

ABSTRACT

To meet the requirements for lower fuel consumption and emissions as well as higher performances, a "Variable Valve Timing – intelligent by Electric motor (VVT-iE)" system has been newly developed. The system has been firstly adopted to the intake valve train of the Toyota's new 4.6 and 5.0 liter V8 SI engine series. The VVT-iE is composed of a cam phasing mechanism connected to the intake camshaft and brushless motor integrated with its intelligent driver. The motor-actuated system is completely free from operating limitation caused from hydraulic conditions. This enjoys an advantage for reducing cold HC. The system also presents further reduction in fuel consumption.

INTRODUCTION

To prevent global warming and air pollution motor vehicles are now required to further reduce the amounts of CO₂ and contaminant emissions. Simultaneously vehicle manufacturers are required to improve the performance and appeal of their products. For these demands, engines must optimally combine low fuel consumption and emissions with performance improvements. The role of the engine valve system is significant in meeting these requirements. Consequently, valve systems have been improved in various ways.

An 'intelligent' via electric motor variable valve timing system (hereafter referred to as "VVT – iE") has been developed in place of hydraulically driven variable valve timing systems. The objectives of the development of the VVT – iE is to achieve compatibility among fuel economy, reduced exhaust gas emissions, and improved performance. This paper introduces the development of the VVT – iE, which have been applied to the Toyota New V8 series installed in Lexus LS 460 and LS 600h.

DEVELOPMENT OF VVT-IE

1.OBJECTIVES OF DEVELOPMENT

Table 1 summarizes the current mass produced variable valve control systems currently produced on a larger scale. They are broadly classified into the valve systems in which valve lift is varied and those in which the cam phase is changed. The valve lift type includes cam profile switching and continuously variable types, and has long been commercialized.^{1, 2, 3} In contrast, most of the cam phase types are now continuously variable, hydraulically driven systems. It is conceivable that a change from a hydraulically driven system to an electric motor-driven system contributes to fuel economy, low-temperature emission improvements, performance improvements, and commercial value for hybrid vehicles (HV). The reason for this is that the electric motor-driven system can control the cam phase without being affected by the engine running conditions which offers the following advantages over a hydraulic system:

- (a) Retarding the valve-closing timing of the intake cam to make use of the Atkinson cycle effects improves fuel economy.
- (b) Advancement of the cam phase beginning immediately after engine start promotes atomization of fuel and improves low-temperature emission.
- (c) Cam phase at starting can be freely selected, therefore the working angle of the cam shaft retarded at starting can be expanded. This improves power.
- (d) Advancement of the cam phase during cranking enables improved comfort for HV to be achieved.

To realize these effects, the following development objectives of the VVT – iE were set:

- (1) Capable of holding the cam phase between the most retarded and most advanced positions even after engine stop, and starting at that position.
- (2) Capable of functioning regardless of the running conditions (at low temperatures or low hydraulic pressure)
- (3) Capable of changing the cam phase during engine cranking even at low temperatures

Table 1 Assessment of Variable Valve Control Systems

Type	Description	Power	Fuel Economy	Cold Emissions	Commercial Value for HV
Cam Phase	Cam Phasing (Hydraulic) ⁽⁴⁾ (Brake Type) ⁽⁵⁾	○	○	—	×
	Cam Phasing (Electric)	○	○	○	○
Valve Lift	Cam Profile Switching I (Hydraulic) ⁽¹⁾	⊙	—	—	×
	Cam Profile Switching II (Hydraulic) ⁽²⁾	○	○	—	×
	Lost Motion (Electric) ⁽³⁾	⊙	○	—	×

⊙ Best ○ Better — Base × Worse

The operation principle is shown in Figure 2. When the motor rotational speed is faster than the camshaft rotational speed, the cam phase is advanced. When the cam phase has reached the target value, the motor rotational speed and camshaft rotational speed are returned to the same rate to hold the cam phase. Conversely, the reduction of the motor speed causes the cam phase to be retarded. The advancing (retarding) rate is proportional to the motor increasing (decreasing) rate.

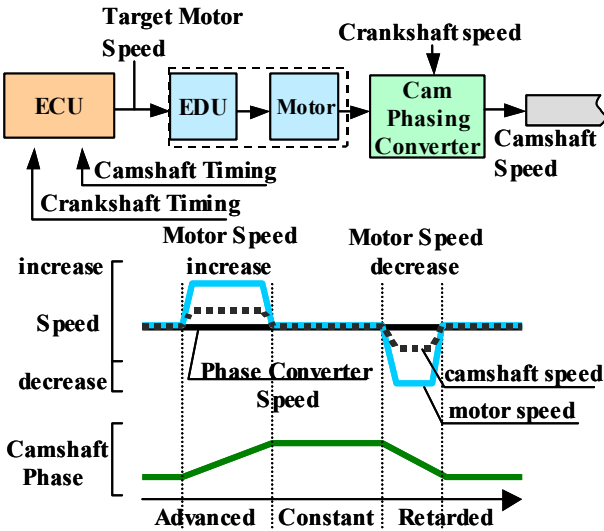


Fig.2 VVT-iE Control Concept

3. SYSTEM CONFIGURATION OF VVT – iE

3.1 System Configuration

Figure 1 shows the system configuration of the VVT – iE developed this time. The VVT – iE consists of the “cam phase converter” mounted on the intake camshaft and a brushless “electric motor” installed in the engine chain case. The “electronic drive unit (EDU)” is integrated with the electric motor.

The EDU drives the motor in response to the command from the engine ECU. The role of the cam phase converter is to convert the motor rotational input into the advance and retard of the cam phase.

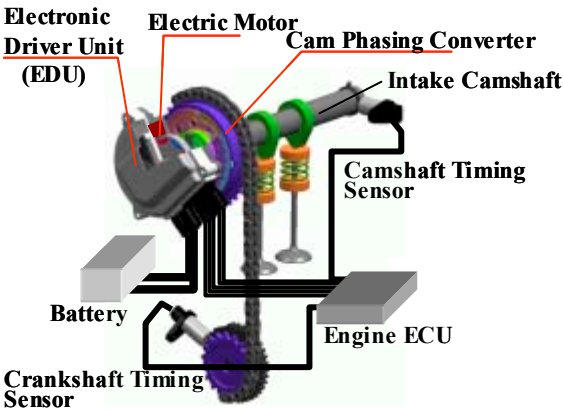


Fig.1 VVT-iE system

3.2 Cam Phase Converter

The role of the cam phase converter is to advance or retard the cam phase according to the motor speed. Figure 3 shows the construction of the cam phase converter. The converter is required to

- ① Establish the optimum gear reduction ratio in which the cam phase can be advanced or retarded using as compact a motor as possible.
- ② Be capable of overcoming cam torque to hold the cam phase during engine stop.

To meet these requirements, the cam phase converter consists of the “reduction mechanism” and “link mechanism” sections. The following describes the features of the reduction mechanism and link mechanism sections.

- ① Reduction mechanism: This section has adopted a compact cycloid gear reducer that can be installed on the co-axis. A reduction ratio of about 100 times was used because of the optimum balance between the size of the motor and the response of the cam phasing speed.