

Application of Engine Load Estimation Method Using Crank Angular Velocity Variation to Spark Advance Control

Ryosuke Ibata, Hirotaka Kawatsu, Tetsuya Kaneko, and Kenji Nishida
Honda R&D Co., Ltd.

ABSTRACT

The technology to estimate engine load using the amplitude of crankshaft angular velocity variation during a cycle, which is referred to as " $\Delta\omega$ (delta omega)", in a four-stroke single-cylinder gasoline engine has been established in our former studies. This study was aimed to apply this technology to the spark advance control system for small motorcycles. The cyclic variation of the $\Delta\omega$ signal, which affects engine load detection accuracy, was a crucial issue when developing the system. To solve this issue, filtering functions that can cope with various running conditions were incorporated into the computation process that estimates engine loads from $\Delta\omega$ signals. In addition, the system made it possible to classify engine load into two levels without a throttle sensor currently used. We have thus successfully developed the new spark advance system that is controlled in accordance with the engine speed and load.

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INTRODUCTION

A large number of small motorcycles are used widely around the world, and the improvement of the fuel economy is one of the important issues to be solved from the global environmental viewpoint. One of the basic techniques for fuel economy improvement is the spark advance control that functions in accordance with the engine load. Generally, the engine load is detected by a throttle sensor. In small motorcycles, two types of throttle sensors are commonly used. One of the types is a potentiometer, which continuously detects throttle angle. Another is a throttle switch, which classifies throttle opening into two levels. The potentiometer is mainly applied to motorcycles equipped with a fuel injection system. In this type, the spark timing is controlled in accordance with the engine speed and throttle angle on the basis of three-dimensional control map stored in the ECU. The throttle switch is applied to some motorcycles equipped with a carburetor. In this type, the spark timing is controlled in accordance with the throttle opening by switching two kinds of two-dimensional control maps in which the relationship between the engine speed and the spark timing is stored. However, regarding small motorcycles with affordable prices using a carburetor, a large number of models are not equipped with a throttle sensor.

It has been known that the single-cylinder four-stroke engine has the typical pattern of variations in crankshaft angular velocity during a cycle consisting of intake, compression, expansion and exhaust strokes (1). In our former studies, the technology estimating engine load with this amplitude of

variation has been already established (we call it " $\Delta\omega$ method") (2). The amplitude ($\Delta\omega$) is calculated on the basis of signals from the crank position sensor which is commonly equipped in conventional engines.

In this project, we aimed to realize an alternative system to the conventional system using a throttle switch. In the alternative system, engine loads are classified into two levels using $\Delta\omega$ method. First of all, we worked out a basic logic using $\Delta\omega$ method. However, when the load-level classification using $\Delta\omega$ was tested on the marketed motorcycle, it was made clear as an issue that the spark timing was unstable due to hunting of engine load-level classification resulting from cyclic variations of $\Delta\omega$ signals. To cope with this issue, we applied a new filtering process in the execution process to classify the load-level depending on $\Delta\omega$ and the issue was resolved. Consequently, the spark advance control system using $\Delta\omega$ method enabled to have the same level of load-level classification capability as the conventional system. We have thus successfully developed a simple spark advance control system without using a throttle switch.

CONVENTIONAL SPARK ADVANCE CONTROL

This section outlines a conventional spark advance control system. Such a system classifies engine load into two levels using output signals from the throttle switch, and controls the spark timing accordingly.



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Figure 1. Experimental motorcycle

Experimental Motorcycle

Figure 1 shows the experimental motorcycle. Table 1 shows the major specifications of the experimental engine. The experimental motorcycle is a marketed small scooter equipped with a four-stroke, single-cylinder 110cm³ engine conforming to India's Bharat Stage-III emission standards (3). The fuel is supplied by a carburetor.

Table 1. Specifications of the experimental engine

Item	Specification
Engine type	Four-stroke single-cylinder
Cooling system	Air-cooled
Bore × Stroke	50.0 mm × 55.6 mm
Engine displacement	109.2 cm ³
Compression ratio	9.5
Spark supply system	Full-transistor
Fuel supply system	Carburetor
Transmission type	Continuously Variable Transmission (CVT)
Maximum brake power output	5.6 kW at 7500 rpm
Maximum brake torque	8.57 Nm at 5500 rpm
Curb weight	108 kg

Load-level Classification by Throttle Switch

Figure 2 shows the cross-sectional view of the piston-valve-type carburetor with the throttle switch. The throttle switch is attached to the side of the carburetor cylinder that retains the piston valve. The push rod is depressed at the specific piston position and the switching signal is transmitted.

Figure 3 shows a throttle switch motion during throttle opening and closing operations. The throttle switch outputs are generated based on the throttle opening regardless the engine speed.

Basic Logic of Spark Advance Control

Figure 4 shows a flowchart of a conventional spark advance control using a throttle switch. In the control flow, the engine speed is calculated, the engine load is classified by the throttle switch, the load-level signal is transmitted, and the spark timing map is selected according to the classified load. When the load is classified as "Low", the advancing map is selected correspondingly. On the other hand, when the load is

classified as "High", the retarding map is selected. Finally, the spark timing matching the engine speed is picked up from the selected spark-timing map.

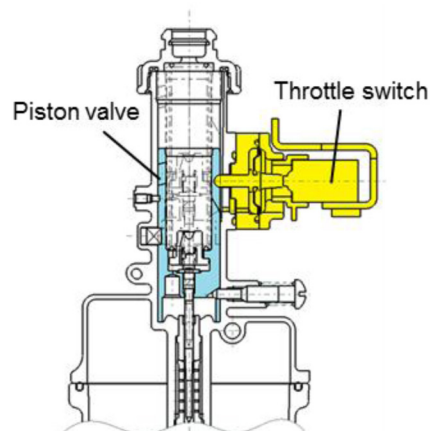


Figure 2. Carburetor with throttle switch system

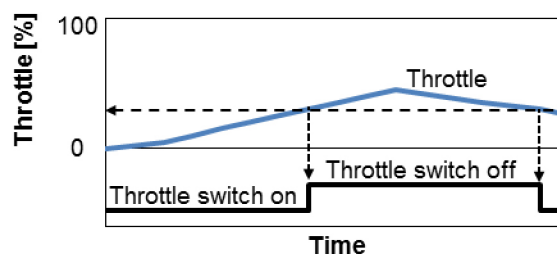


Figure 3. Throttle switch motion

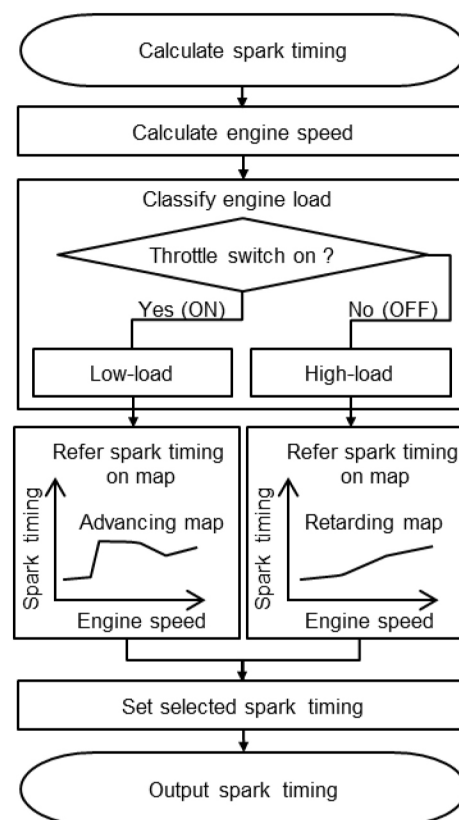


Figure 4. Flowchart of conventional spark advance control

We investigated a new logic to replace the throttle switch method with $\Delta\omega$ method for the process of load-level classification.

SPARK ADVANCE CONTROL USING $\Delta\omega$ METHOD

Basic Principles of Engine Load Estimation Using $\Delta\omega$

In this section, the system structure and the principles of $\Delta\omega$ method are explained, with reference to the previous paper (2).

Structure of System

$\Delta\omega$ is calculated on the basis of the pulse signals from the crank position sensor, which is a standard device in current engines.

Figure 5 shows the structure of the crank position detecting system. The alternator rotor is fixed on one end of the crankshaft, with a reluctor on the outer circumference. The pulses occur when the front end, or the rear end, of the reluctor passes the magnetic pick up during one revolution of the crankshaft.

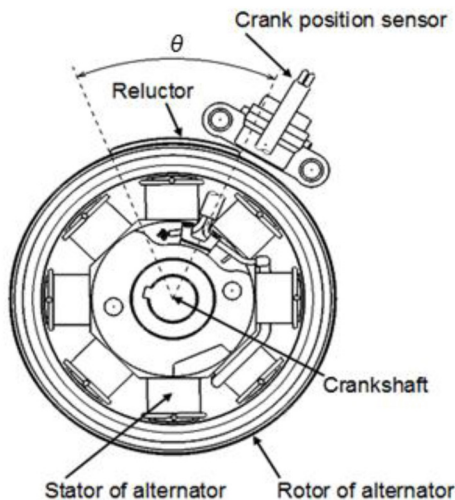


Figure 5. Crank position detecting system (2)

Figure 6 shows the waveform of crankshaft angular velocity, pulse signals, and reluctor position under the operating condition with the constant speed and load. It indicates that the crankshaft angular velocity variation measured by the rotary encoder varies crossing over the engine speed of around 3000 rpm. The crankshaft angular velocity is calculated on board as $\omega = \theta/\tau$, where τ denotes the duration between the two pulse signals, P_1 and P_2 , given from the crank position sensor before Top Dead Center (TDC), and θ is the reluctor phase angle. Thus, two angular velocities are obtained, ω_1 before the compression TDC and ω_2 before the exhaust TDC. Based on ω_1 and ω_2 , the amplitude of crankshaft angular velocity variation $\Delta\omega$ is determined. The $\Delta\omega$ of the preceding cycle is used to estimate engine load for each cycle.

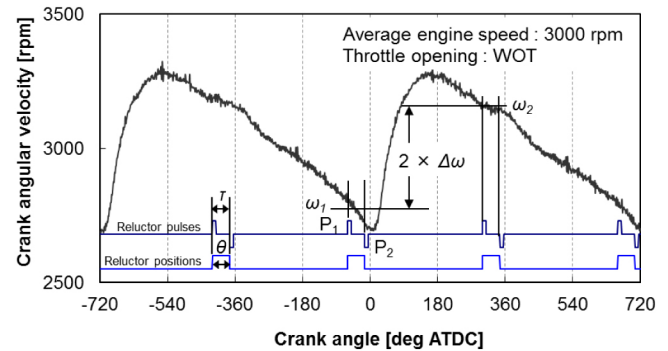


Figure 6. Waveform of crank angular velocity and reluctor positions (2)

Relationship Between $\Delta\omega$ and IMEP

It has been clarified from experiments that $\Delta\omega$ and the net indicated mean effective pressure ($IMEP_{net}$) are highly correlated. Moreover, it has been known from the theoretical analysis that $\Delta\omega$ changes proportionally to the $IMEP_{net}$ and the engine displacement, and counter-proportionally to the engine speed N_e as the following Equation (1) indicates (2).

$$\Delta\omega \propto \frac{V_s \times IMEP_{net}}{I \times N_e} \quad (1)$$

V_s : Engine displacement.

$IMEP_{net}$: Net indicated mean effective pressure, derived from the cylinder work delivered to the piston over the entire four-stroke cycle.

I : Inertia moment of crankshaft system.

N_e : Engine speed, the mean value of crankshaft angular velocity during a four-stroke cycle.

Figure 7 shows the relationship between the $\Delta\omega$ and the $IMEP_{net} / N_e$ at each engine speed, when operating with a wide open throttle. The plotted data are an average of approximately 500 cycles. From Figure 7, it is proven that $\Delta\omega$ changes proportionally to $IMEP_{net}$ and counter-proportionally to N_e .

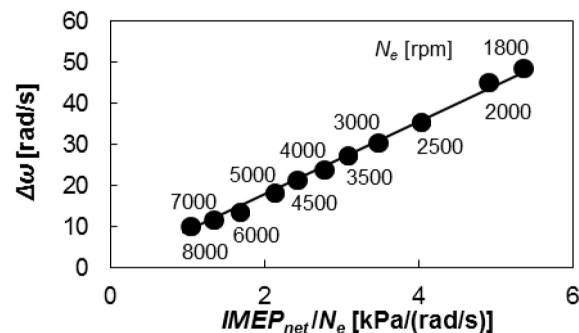


Figure 7. Relation between $\Delta\omega$ and $IMEP_{net} / N_e$ (2)