

Development of an ECU Integrated Throttle Body System Module for a Compact Fuel Injection System Used in Small Motorcycles and Scooters

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ABSTRACT

Concerns about environmental conservation continue to grow, increasing the demand for the reduction of exhaust emissions and enhancing fuel economy for small motorcycles. Therefore, electronic control fuel injection systems, which can finely control an air-fuel ratio, are being utilized. This time, the ECU integrated throttle body system for the electronic control fuel injection system, which is compact and low-cost, was developed for a small displacement engine. Features of this system include combining two modules. The modules are the throttle body module with several bore sizes in series and the ECU module with an electronic control unit, sensors, and an idling-air-control device. As a result, the complex wiring and piping were minimized, miniaturization was achieved, and a system that can be applied to single cylinder engines from 50 cm³ to 250 cm³ was achieved.

1. Introduction

Concerns about environmental issues have increased the demand for the reduction of exhaust emissions and increased fuel economy for small motorcycles. For example, Level 5 emission limits as shown in Table 1 are scheduled to take effect from 2003 in Thailand, one of the major markets for small motorcycles. These limits are predicted to become even stricter in the future. For this reason, electronically controlled fuel injection systems (hereafter referred to as “FI systems”), which can accurately control the air-fuel ratio, are

increasingly being utilized to effectively reduce exhaust emissions and improve fuel economy. However, most FI systems thus far have only been mounted on large motorcycles with multi-cylinder engines^{(1),(2)}. This raised the issues of higher costs and the size being too large for mounting on small motorcycles⁽³⁾. This study aimed to consolidate functions into a unit the size of a conventional carburetor and reduce both the size and cost by integrating the throttle body, various sensors and the engine electronic control unit (hereafter referred to as “ECU”) as a system module.

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2. Aim of Integrating the Throttle Body and ECU into a Single Module

In conventional FI systems for large motorcycles, the ECU is generally mounted on the chassis. In addition, the sensors needed to detect the information for control are positioned independently as separate units. Figure 1 shows an example of this layout. Therefore, many wire harnesses were required to connect these sensors with the ECU. As a result, these systems became quite complex, and application to small motorcycles was difficult. Integrating the throttle body, which controls the air intake volume, and the ECU module, which controls the engine operating status, eliminated the need for these wire harnesses. The module size was also reduced to the size of a conventional carburetor.

3. Test Engine Overview

An example of applying a European specification 4-stroke engine with a displacement of 125 cm³ as the test engine is described below. The main specifications are shown in Table 2.

4. System Overview

Figure 2 shows the configuration of the ECU integrated throttle body system module. Splitting the structure into two parts, the throttle body and the ECU module, as shown in Fig. 3, made it possible to change the throttle body to the appropriate bore size to support engines with different displacements. This created a FI system configuration with a general-purpose and a high flexibility for application. The

Table 1 Current emission limits for motorcycles

	CO (g/km)	HC (g/km)	NOx (g/km)
Euro-3(<150cm ³)	2.0	0.8	0.15
Thailand Level 5	3.5	1.8	

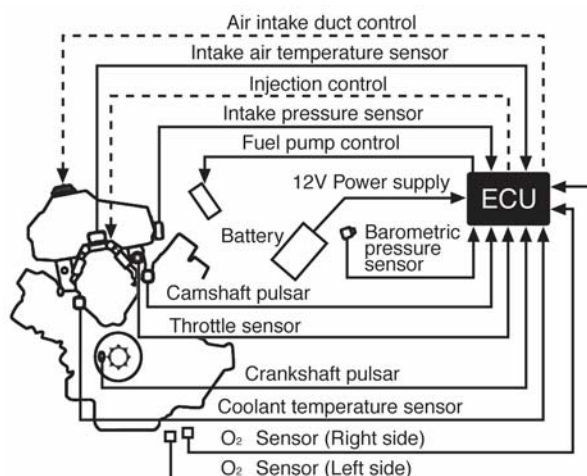


Fig. 1 VFR800FI system

Table 2 Test engine specifications

Items	Specifications
Bore × stroke (mm)	52.4 × 57.8
Displacement (cm ³)	124.6
Compression ratio	11.0
Valve system	OHC 2 valves
Max power (kW/r/min)	9.66/9000
Max torque (Nm/r/min)	11.4/7500

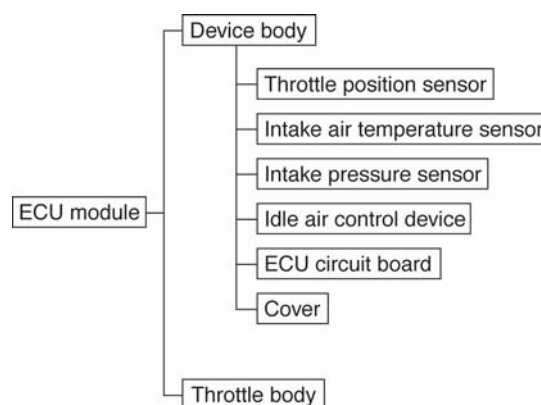


Fig. 2 ECU module components

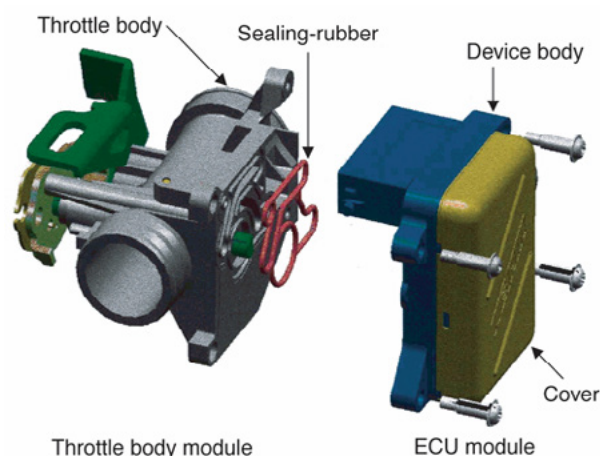


Fig. 3 ECU integrated throttle body system module

throttle body and the ECU module, which incorporates various sensors, are joined by four screws as shown in Fig. 3. In addition, grooves forming idle air passages are provided on the fitting plane on the throttle body side as shown in Fig. 4. These grooves are sealed between the ECU and throttle body with sealing-rubber. The ECU module is comprised of a plastic housing (hereafter referred to as "device body"), the ECU circuit board, and a cover. The device body incorporates various sensors, and the ECU circuit board is connected directly to the input-output terminals of these sensors. After the cover is set on the device body, the inside is filled with potting resin to secure and waterproof the sensors, circuit board and other parts.

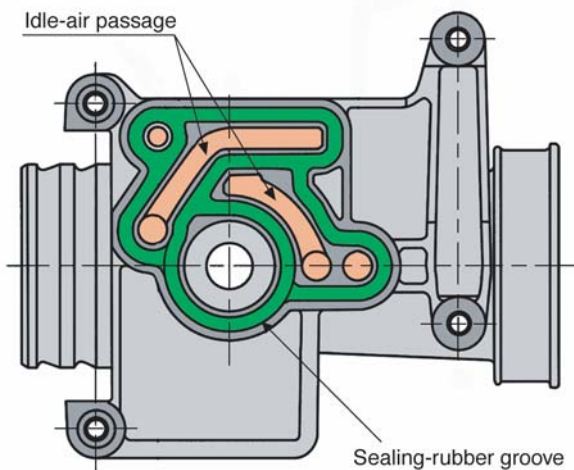


Fig. 4 Throttle body module fitting plane

4.1. Sensor Layout

This throttle body system module contains three sensors inside the device body. Figure 5 shows the sensor arrangements.

- (1) Intake air temperature (Ta) sensor: The sensing element at the tip of the sensor is positioned, protruding from the inner surface of the intake air passage upstream from the throttle valve to allow measurement of the intake air temperature. A compact size is achieved by connecting the sensor terminals directly to the ECU circuit board.
- (2) Throttle position sensor (TPS): This sensor is located at the end of the throttle shaft as shown in Fig. 6, and directly detects the throttle opening. The throttle shaft and the sensor rotor are joined via a spring that presses them in the direction of rotation in order to eliminate working hysteresis caused by the joint clearance. This TPS is fitted directly into the device body, and the external seal is secured by potting.
- (3) Intake pressure (Pb) sensor: The sensor element is mounted directly on the ECU circuit board, and is connected to the communicating hole provided downstream from the throttle valve of the throttle body.

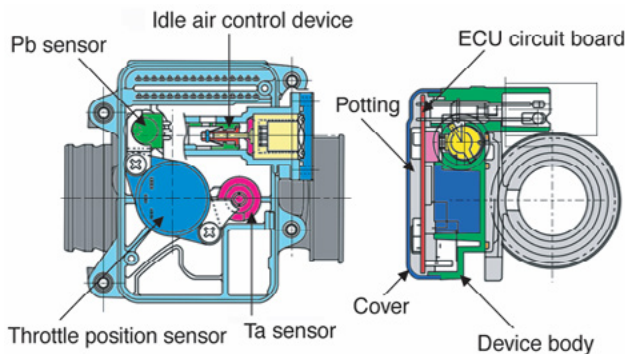


Fig. 5 ECU module components

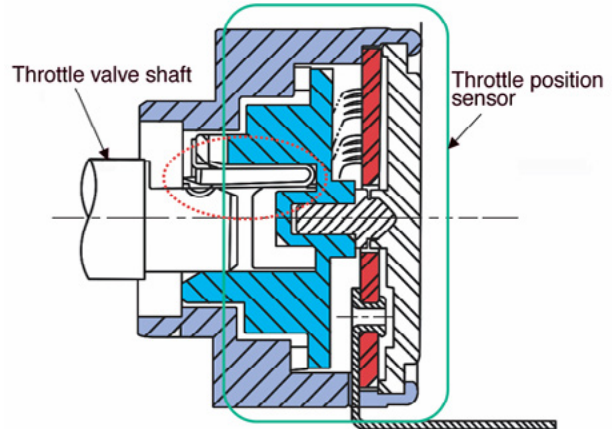


Fig. 6 Structure of throttle position sensor

4.2. ECU Circuit Board

The ECU circuit board utilized by this system was designed specially for single-cylinder engines. That is to say, designing a fuel injector drive circuit and an ignition circuit for a single cylinder made it possible to reduce the size and locate the ECU circuit board on the side of the throttle body. A 16-bit CPU was used as the controller. In addition, large elements such as the condenser in the power supply are positioned in the gaps between the various sensors inside the device body. This helped keep the overall width the same dimension as a conventional carburetor. The ECU circuit board has a 3-layer design with circuits on each of the four sides to reduce the area for each element circuit. In addition, the wire harness connector which accounted for a large space in the conventional ECU was changed to a 32-pin connector with a pin pitch of 2.6 mm, thus reducing the size to approximately half the conventional one as shown in Fig. 7. This pin pitch reduction was made possible by using an adhesive gel sheet for the connector waterproof structure. The number of pins was set at 32 to support the addition of future functions such as an immobilizer.

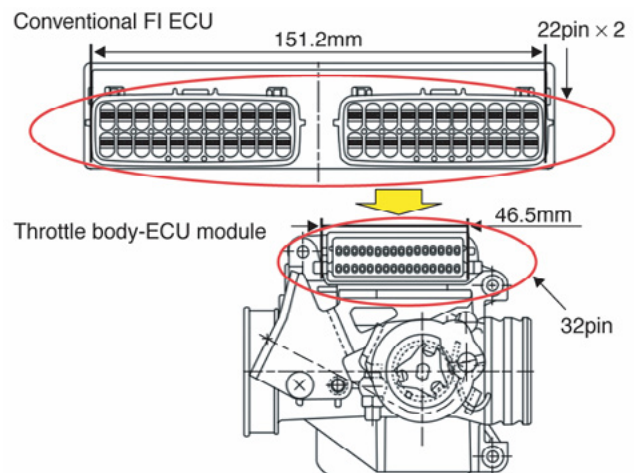


Fig. 7 Comparison of ECU size

4.3. Idle Speed Control Device

Engines for small motorcycles must control the intake air volume in smaller increments than large motorcycles. In addition, fine control capability is also required to support even stricter emissions limits. At the same time a small size is important to allow this system to be used. In order to meet these demands, this system employed a slide-valve-type air-control valve (hereafter referred to as “SACV”) driven by a stepping motor. As shown in Fig. 8, the conventional direct-drive type needed a stepping motor with a diameter of 20 mm to ensure sufficient operating torque against the intake pressure. However, the developed SACV uses a slide type valve structure, which made it possible to reduce the stepping motor size to a diameter of 14 mm. There were concerns that using a SACV with a slide structure would produce hysteresis in the air volume due to the reciprocating action, but this was dealt with by eliminating the clearance in the valve thrust direction. Figure 9 shows the SACV idle-air volume characteristics. This graph shows that there is extremely little hysteresis in the idle air volume when the valve opens and closes, which indicates adequate control performance.

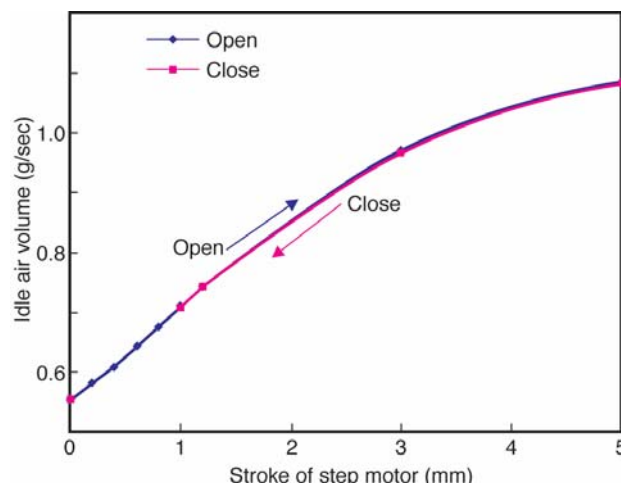


Fig. 9 Characteristics of idle-air volume

5. Mounting on an Actual Motorcycle

Figure 10 shows the overall layout of the test motorcycle. A plastic fuel tank is located in the center of the test motorcycle chassis, and a return-less type in-tank fuel pump unit is mounted inside this fuel tank. Fuel is sent from the pump at a pressure of 300 kPa through a high pressure fuel hose to the fuel injector mounted to the intake manifold. The throttle body system module is mounted to the intake manifold, which extends to the rear from the cylinder head via a rubber insulator. The unit swing type engine mount used in the test motorcycle is subject not only to its own vibration, but also the running vibrations from the road surface. Most

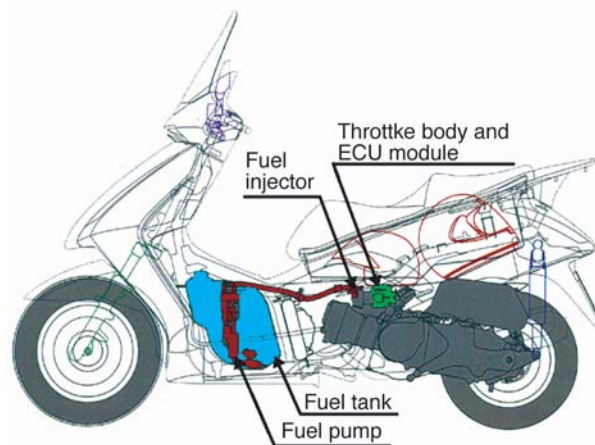


Fig. 10 Location of ECU integrated throttle body system module

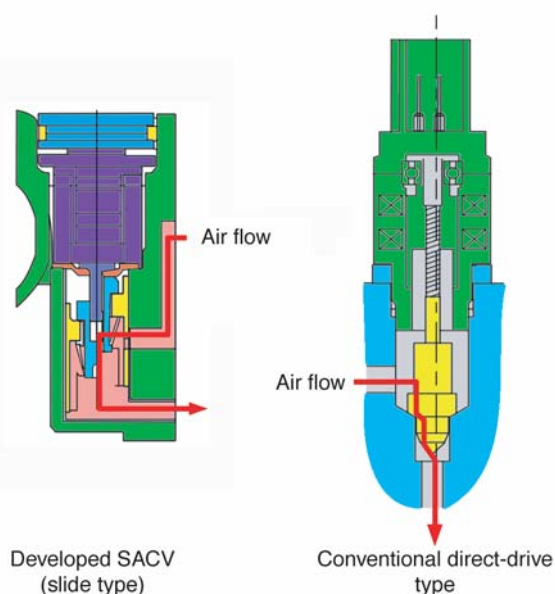


Fig. 8 Comparison of idle-air control valve

ECU thus far had been rubber-mounted to the frame body, and none had been mounted directly to the engine.

Figure 11 shows the engine vibration acceleration. This ECU module achieves high reliability under continuous high vibrations by securing the ECU circuit board, the sensors and the SACV stepping motor inside the device body with potting resin. In addition, the issue of heat was raised as a potential problem from mounting on the engine. Figure 12 shows the measurement data for temperature around the throttle body during running. The ECU reached its maximum temperature when the engine was returned to the idling state after full throttle operation. Therefore, a heat resistant plastic insulator was inserted between the engine and the intake manifold as a countermeasure to ensure ECU module heat resistance. Heat generation from the SACV stepping motor also caused the ECU temperature to rise, but the effects of this heat generation were canceled by stopping power to the SACV motor after the engine warmed up.

The test motorcycle employed an O_2 sensor and a 3-way catalyst as countermeasures for reducing emissions in order to support stricter emissions limits.

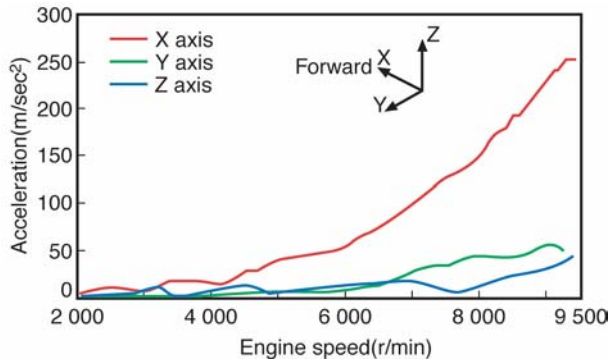


Fig. 11 Vibration acceleration on throttle body during no-load condition

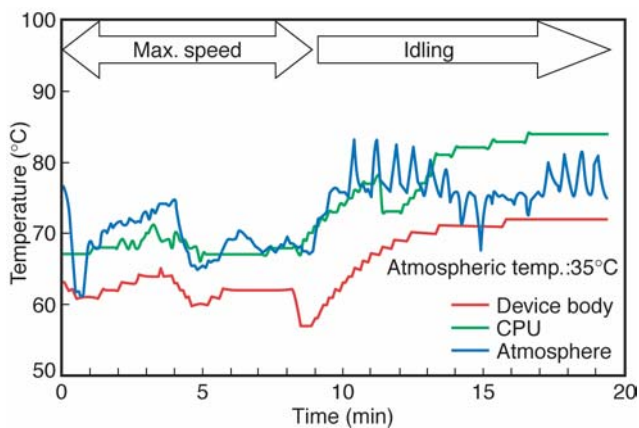


Fig. 12 Temperature rise characteristics (V max. to idle)

6. FI System Control

6.1. Control Outline

The developed FI system controls the fuel injection volume, injection timing and ignition timing based on the signals from the TPS and Pb sensors located inside the ECU module and the crank position sensor, which detects the angle of rotation. Compensation is also performed according to the coolant temperature, the intake air temperature and the atmospheric pressure to control the fuel injection volume, injection timing and ignition timing to the optimum values with respect to changes in environmental conditions.

6.2. Fuel Injection Control

The fuel injection volume control method consists of switching between two different injection volume maps according to the throttle opening and the engine speed.

- (1) Under low load conditions minute changes in the throttle opening are detected by the engine intake pressure and it uses the intake pressure injection volume map determined by the engine intake pressure and the engine speed.
- (2) Under high load conditions it uses the throttle opening injection volume map determined by the throttle opening and the engine speed.

6.3. Ignition Timing Control

The ignition timing is controlled to achieve the optimum ignition timing using a map determined by the throttle opening and the engine speed.

6.4. O₂ Feedback Control

In order to efficiently utilize the performance of the 3-way catalyst mounted inside the exhaust muffler, a feedback system using an O₂ sensor is employed to control the air-fuel ratio to the stoichiometric ratio.

6.5. Control of Idle Speed Control Device

The SACV controls the intake air volume according to each operating condition of starting up, warming up and idling. As shown in Fig.13, when starting up, the intake air volume is increased to improve the start-up performance by opening the idle air control valve according to the engine coolant temperature. Then, as the engine coolant temperature rises, the valve opening is adjusted to control the intake air volume to the optimum value.

After the engine coolant temperature reaches the set value, the intake air volume is controlled using engine speed feedback control to maintain a constant idling speed. This feedback control eliminates the need for maintenance to cope with changes in the idling speed over time, which formerly required adjustment.

7. Results of Employing the New FI System

A test motorcycle using the new FI system achieved the following results compared to a model using a conventional carburetor, the introduction of secondary air to the exhaust port, and an exhaust catalyst system.

- (1) Exhaust emissions: CO and HC emissions were reduced by approximately 50% as shown in Fig. 14.
- (2) Fuel economy: Fuel economy was improved by approximately 10% compared to the conventional model as shown in Fig. 15.
- (3) Cold start-up and warm-up performance: The new FI system and air control device achieved excellent engine start-up and warm-up performance as shown in Fig. 16.

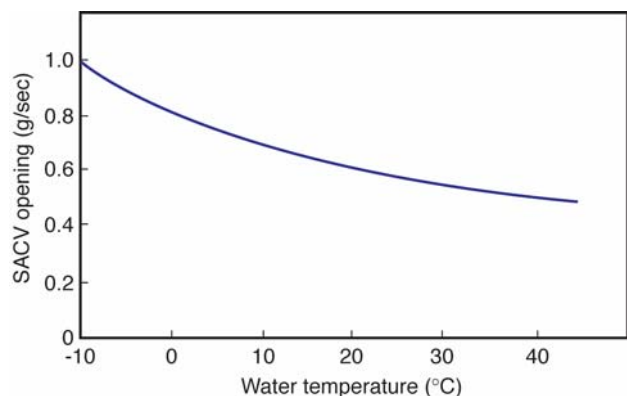


Fig. 13 SACV opening characteristics

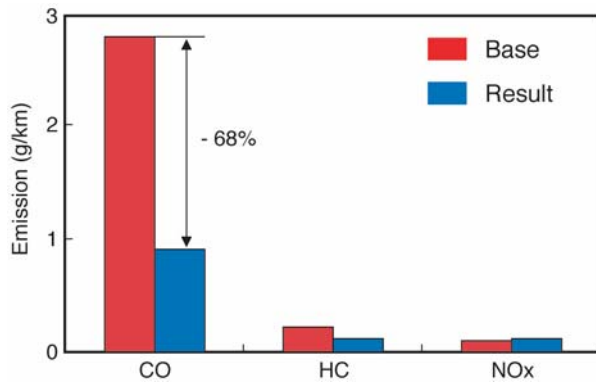


Fig. 14 Test results of ECE40 mode emission

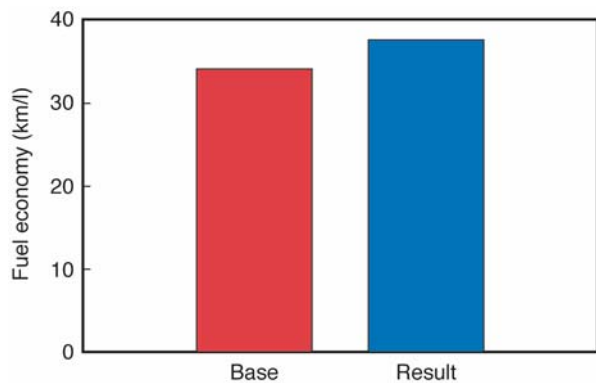


Fig. 15 Test results of fuel economy by ECE40 mode

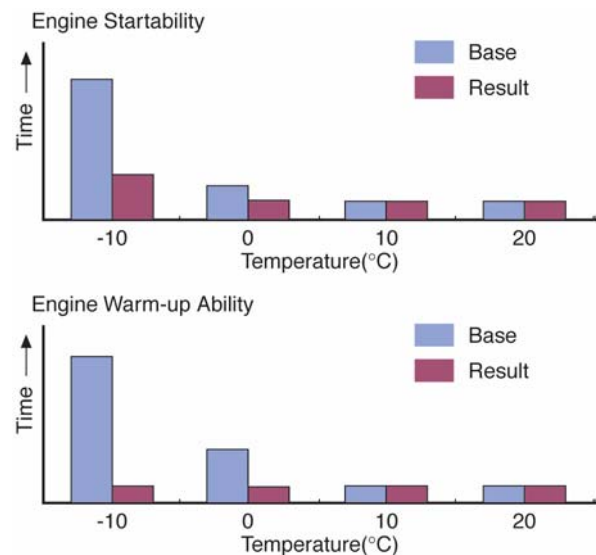


Fig. 16 Result of engine startability and warm-up ability

8. Summary

Development of this ECU integrated throttle body system module realized the following results.

- (1) Integration into a module made it possible to eliminate the wire harnesses for the sensors, ECU and other parts

that have become quite complex in recent years, and allowed the ECU module size to be reduced to the same size of a conventional carburetor. In addition, the system cost was also approximately the same as a conventional carburetor system.

- (2) CO and HC emissions were reduced to approximately half that of conventional carburetor systems, and fuel economy was improved by approximately 10%.
- (3) The newly developed compact SACV assembled into the module achieved stable and excellent start-up and warm-up performance.

The use of these technologies made it possible to employ a FI system to small motorcycles, which account for the majority of the market, without substantial changes to the layout. This is expected to accelerate the application of FI systems to small motorcycles, thus further improving emission purifying and fuel economy.

References

- (1) Horiike, S., et al.: Exhaust emission reduction technology for the VFR800FI, HONDA R&D Technical Review, Vol. 10 (1998)
- (2) Horiike, S., et al.: Exhaust emission reduction for the VFR800FI, International Motorcycle Conference "Safety, Environment and Future II", p. 459-475 (1998)
- (3) Akamatsu, S., et al.: Research of an Emission Reduction System for Small Motorcycles, International Motorcycle Conference: Safety, Environment and Future III, p. 291-309 (1998)

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