

Control Device of Electronically Controlled Fuel Injection System for Small Motorcycle Air-cooled Engine

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ABSTRACT

In general, when an on board battery is at low power, the electric power generated from an alternator by a kick-starter operation is consumed by all the electrical loads, including the battery. This causes a voltage drop. To eliminate the power shortage, an installed relay circuit opens all electric loads other than the fuel injection system. This allows the fuel injection system to use all the electric power generated by the kick-starter. An electric power control system was incorporated into the ECU. The control system permits the starting of an engine by using the kick-starter even when the battery is completely discharged. Also, by suitable sensing of the engine oil temperature, the control device permits an efficient compensation of fuel injection quantity and ignition timing even in an air-cooled engine.

1. Introduction

Due to increasing global environmental issues in recent years, the emission regulations of small motorcycles have been becoming more stringent than ever in various countries in the world. In Europe, currently the Euro-2 emission control is enforced, and even more stringent, the Euro-3 emission control is due in 2006. In Asia, which is the main

market of small motorcycles, China will follow similar to Euro-2 from 2004 and similar to Euro-3 from 2006. In Thailand, the 5th regulations, which are more stringent, will be applied from 2004. The motorcycle exhaust gas emission controls of principal countries or areas are shown in Table 1. Even for small motorcycles, the same level of emission control as for large motorcycles is being required. For emission controls in large motorcycles, the system using fuel

Table 1 Motorcycle emission control in various countries

Country	Regulations	Period	Exhaust Emission (g/km)		
			CO	THC	NOx
Europe	Euro-2	2003 —	5.5	1.2	0.30
	Euro-3	2006 —	2.0	0.8	0.15
China	Current	— 2004	13.0	3.0	0.30
	Future	2004 —	5.5	1.2	0.30
Thailand	4th level	— 2003	4.5	3.0	
	5th level	2004 —	3.5	2.0	
Japan	Current	— 2006	13.0	2.0	0.30
	Future	2007 —	2.0	0.5	0.15

125cm³ - class motorcycles

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injection (hereinafter referred to as FI) and combining the feedback control incorporating an oxygen sensor and a three-way catalyst is widely applied. Meanwhile in small motorcycles, the system using a carburetor and combining air induction and a catalyst is mainly applied. To make small motorcycles conform to more stringent emission regulations in the future, a fuel supply system that permits more accurate control of the air-fuel ratio is required and for that purpose an FI system is most appropriate at the moment⁽¹⁾. We therefore researched an electronically controlled FI system that is applicable to small motorcycles using a natural air-cooled four-stroke single cylinder 125 cm³-class engines.

The electric power control at kick-starting of a small motorcycle with an air-cooled engine, the appropriate control of the air-fuel ratio, and their effectiveness are described in this paper.

2. Outlines of Test Engine

The air-cooled four-stroke single cylinder 125 cm³-class engine, which is applied to many commuter motorcycles in Southeast Asian countries, is chosen for the test engine. The major specifications are shown in Table 2. The small motorcycle with a test engine mounted is shown in Fig. 1.

3. Issues in Application of a Fuel Injection to a Small Motorcycle

Application of an FI system to motorcycles started when component parts for automobile applications were applied to large motorcycles⁽²⁾. Therefore, the high cost was an obstacle

Table 2 Major specifications of test engine

Item	Specifications
Engine type	Air cooled 4-stroke single-cylinder
Bore × Stroke	52.4 × 57.9 mm
Displacement	124.8 cm ³
Compression ratio	9.3
Valve train	SOHC 2 valves
Valve diameter	IN 24, EX 21 mm
Clutch type	Automatic centrifugal
Transmission	4-speed constant mesh
Max. output	6.75 kW/7 500 r/min.
Max. torque	9.74 Nm/5 500 r/min.



Fig. 1 Overview of small motorcycle with test engine mounted

when considering application to small motorcycles. In recent years, the low-cost FI system, using the modularizing technique with the ECU attached to the throttle body, has been developed and applied to small scooters for export to Europe⁽³⁾. There are two major issues mentioned hereafter when applying the above-mentioned system to a small motorcycle using an air-cooled engine.

(1) Simultaneous use of the electric starter and the kick-starter

Usually, when an electric starter is the only starting system for an engine using an FI system, if the battery is completely discharged, not only will the starter motor not work, but also the fuel pump will not function, hence no fuel is supplied and the engine cannot be started. However, in an engine that has a kick-starter and a carburetor, even when the battery is completely discharged, the air-fuel mixture is automatically supplied into the combustion chamber when cranked by the kick-starter. At the same time, AC generator (hereinafter referred to as ACG) starts to supply energy to the ignition system, thus allowing the engine to start. In a small motorcycle, therefore, the engine should be able to start by the kick-starter when the battery is discharged even when an FI system is applied instead of a carburetor.

(2) Choosing a measurement position for engine oil temperature is necessary for system control

Most motorcycles using fuel injection have water-cooled engines, and the fuel injection is controlled based on the water temperature. In natural air-cooled engines, the air temperature after cooling the engine is unstable and difficult to measure. We therefore decided to measure the engine oil temperature. The engine oil for lubrication is distributed to various areas of the engine including the transmission gearbox, and the temperature differs depending on the position. It is therefore necessary to choose an appropriate measurement position for fuel injection control.

4. Outlines of the Fuel Injection System for Air-cooled Engines

4.1. Fuel Injection Control

Figure 2 shows the configuration of the fuel injection quantity control system applied to the test engine. The module unit integrating the throttle body, which controls the intake air volume, and the ECU, which controls the operating conditions of the engine, is incorporated. This module is of the same size as a conventional carburetor for small motorcycles. Figure 3 shows the overview and configuration. Incorporated into the module are the throttle sensor, the intake manifold pressure sensor, and the intake air temperature sensor. The engine oil temperature sensor for control of fuel injection is attached at the oil return passage in the cylinder. The oil temperature sensor sends temperature information to the ECU. The ECU controls the fuel injection quantity, injection timing and ignition timing. For the fuel supply, the power saving fuel pump is installed in the fuel tank, and feeds the pressured fuel to the injector. The fuel pressure is set at 250 kPa. Figure 4 shows the layout of fuel system components.

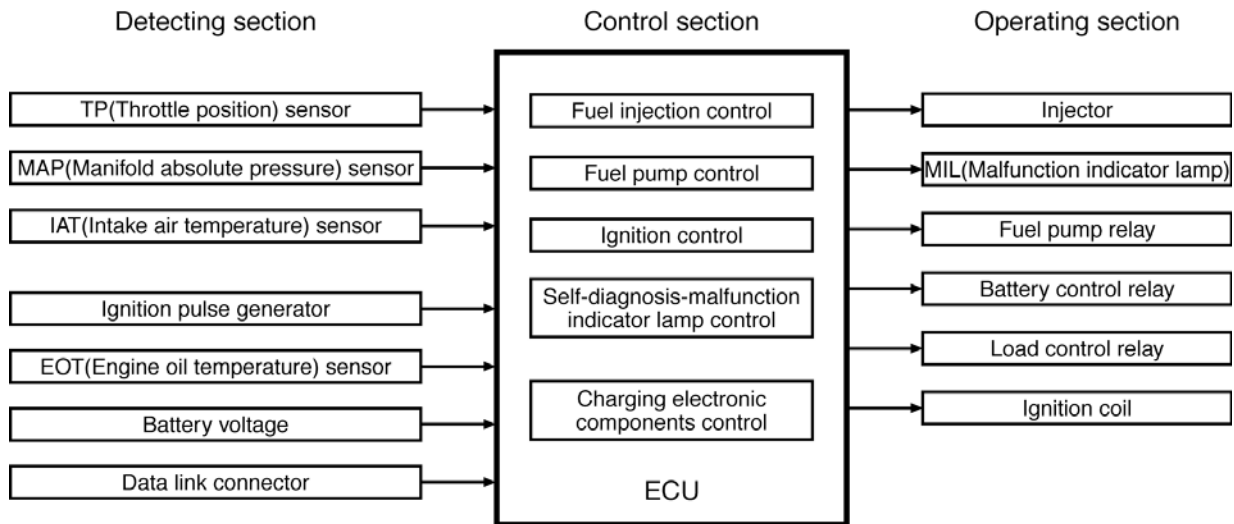


Fig. 2 Configuration diagram of fuel injection volume control system

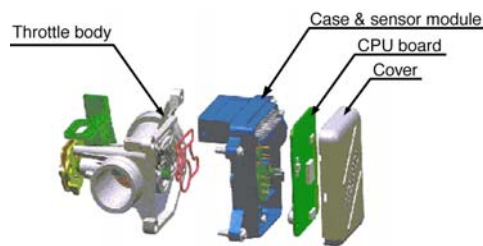


Fig. 3 Overview of module and components

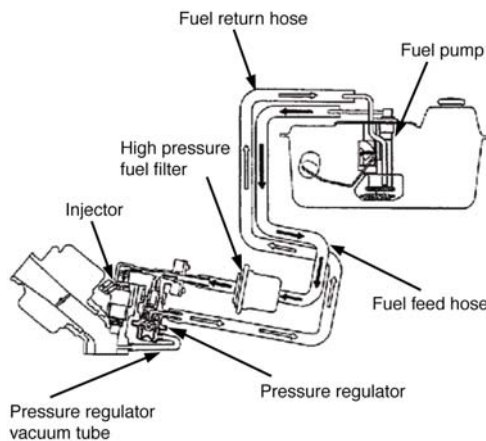


Fig. 4 Layout of fuel supply system

4.2. Electric Power Supply Circuit

An ACG is installed for the electric power supply. The power output of the ACG is increased to supply adequate power for the fuel injection system. As shown in Fig. 5, for the electric power supply circuit, a condenser is added in the regulator unit to store energy from the ACG. The relay, (called the battery control relay, load control relay) controlled from the ECU, cuts off the battery and electric loads from the ACG.

5. Fuel Injection System

5.1. Control of Electric Power Supply on Kick Starting

Usually when starting an engine with an FI system, as well as supplying fuel by operating the ECU, fuel pump and injector with electric power stored in the battery, the electric power is supplied to the ignition coil for sparks. In order to start the engine when the battery is discharged and unable to supply energy to operate the FI system, the electric power generated by the ACG by kick-starting has to be supplied to the ECU, fuel pump, injector and ignition coil. As shown by Fig. 6, however, in the conventional system, the electric power generated by kick-starting is consumed by charging of the battery and other electric loads, causing a voltage drop and not allowing the ECU to function.

To cope with that issue, the ECU in this system starts functioning when the ignition switch is turned on, and detects the battery voltage. The ECU can function when the battery voltage is between six and nine volts, but judges the battery voltage is too low to operate the fuel supply system and the ignition system. The ECU splits the battery and electric loads other than the FI system from the ACG using the relay as shown in Fig. 7. The flowchart of controls is shown in Fig. 8.

When the ECU is activated by the electric power from the ACG, as the battery voltage is less than six volts, just like the above-mentioned conditions, the relay splits the battery and electric loads from the ACG. The voltage lowers and the ECU stops functioning if a large current occurred momentarily in the ignition coil or in the injector of the FI system. The condenser in the regulator stores electric charges to prevent such a voltage drop. Thus the power supply control system mentioned above ensured the starting of the engine by kick-starter, as well as an engine equipped with a carburetor, even when the battery malfunctions, as shown in Fig. 9. After the engine has started or when the battery is in normal condition, the relay is maintained so that power generated by the ACG is supplied to the battery and all electric loads.

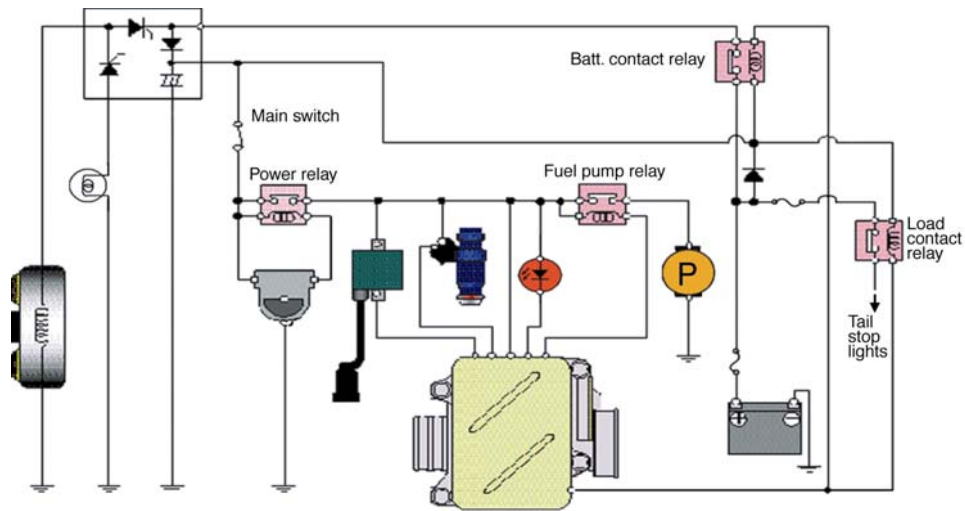


Fig. 5 Power source circuit at normal operation with full charged battery

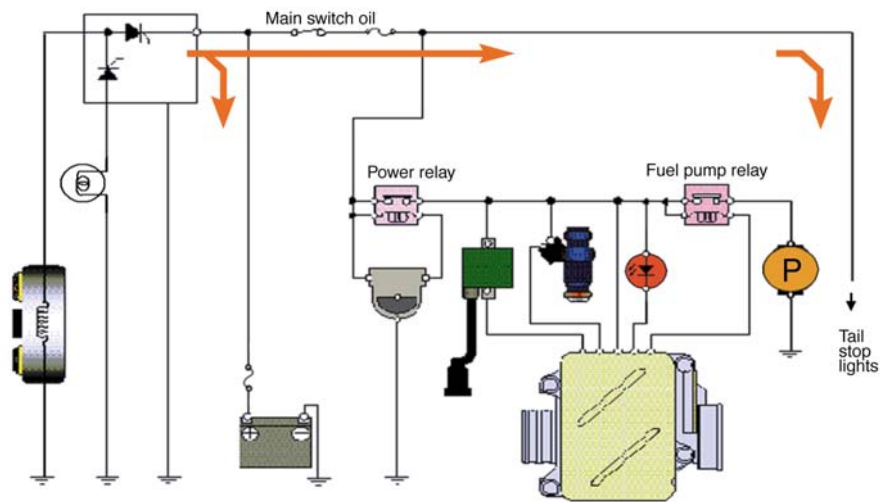


Fig. 6 Usual circuit

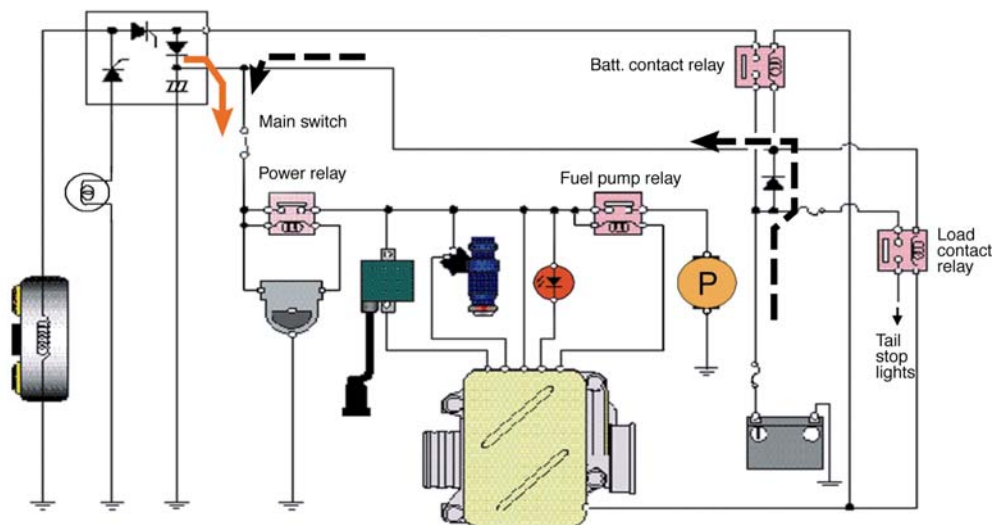


Fig. 7 Cut off of electrical load at kick starting under battery down

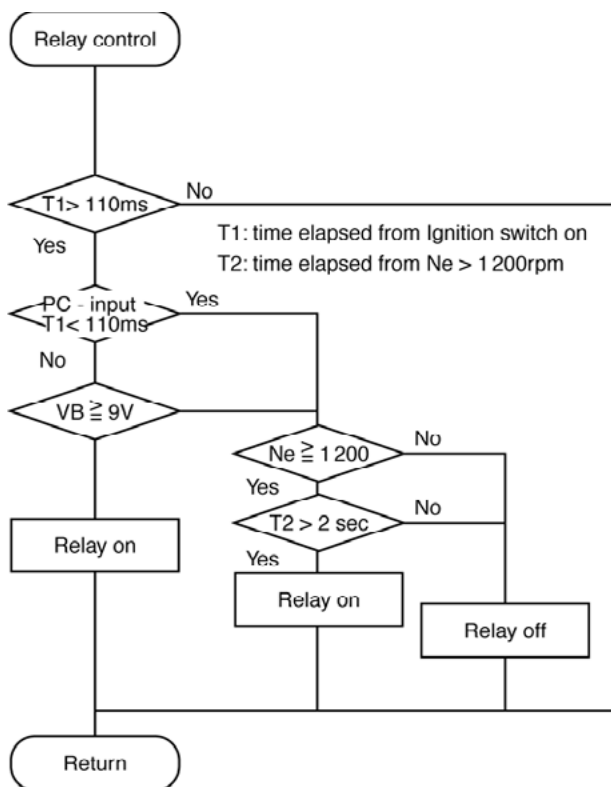


Fig. 8 Flow chart

5.2. Fuel Injection Control by Oil Temperature

To allow the ECU to control the air-fuel ratio and the ignition timing appropriately, an output from a sensor is required to understand the engine's warmed-up condition. In case of a liquid-cooled engine, the coolant temperature detected at the exit of the water jacket is used for that purpose. The thermostat regulates the circulating flow rate of the engine coolant to maintain the temperature at the prescribed level. Figure 10 shows an example of such a coolant temperature sensor for a liquid-cooled engine. In case of a natural air-cooled engine, the cooling medium is the air, and it is difficult to measure the air temperature after cooling the engine. Therefore, the engine oil temperature was used to learn the status of the engine warming-up. The engine oil passages of the test engine are shown in Fig. 11. The oil discharged from the oil pump is split between the crankshaft and the cylinder head. The oil supplied to the cylinder head lubricates the camshaft and valves via the cylinder, contacts the cylinder head, then the oil is collected into the passage in the cylinder, and returns to the oil pan. Considering that the oil circulates while absorbing heat from the cylinder and the area close to the combustion chamber, it is said that the engine oil in the air-cooled engine has the same circulation passage as the coolant of a liquid-cooled engine. We therefore consider that the oil temperature in the return passage to the oil pan represents the engine's warmed-up condition, just like the coolant temperature in a liquid-cooled engine. The correlation between the oil temperature and engine's warmed-up condition was confirmed through actual measurements. Figure 12 shows the rise in oil temperature while operating the engine in the exhaust gas emission measurement mode of Thailand.

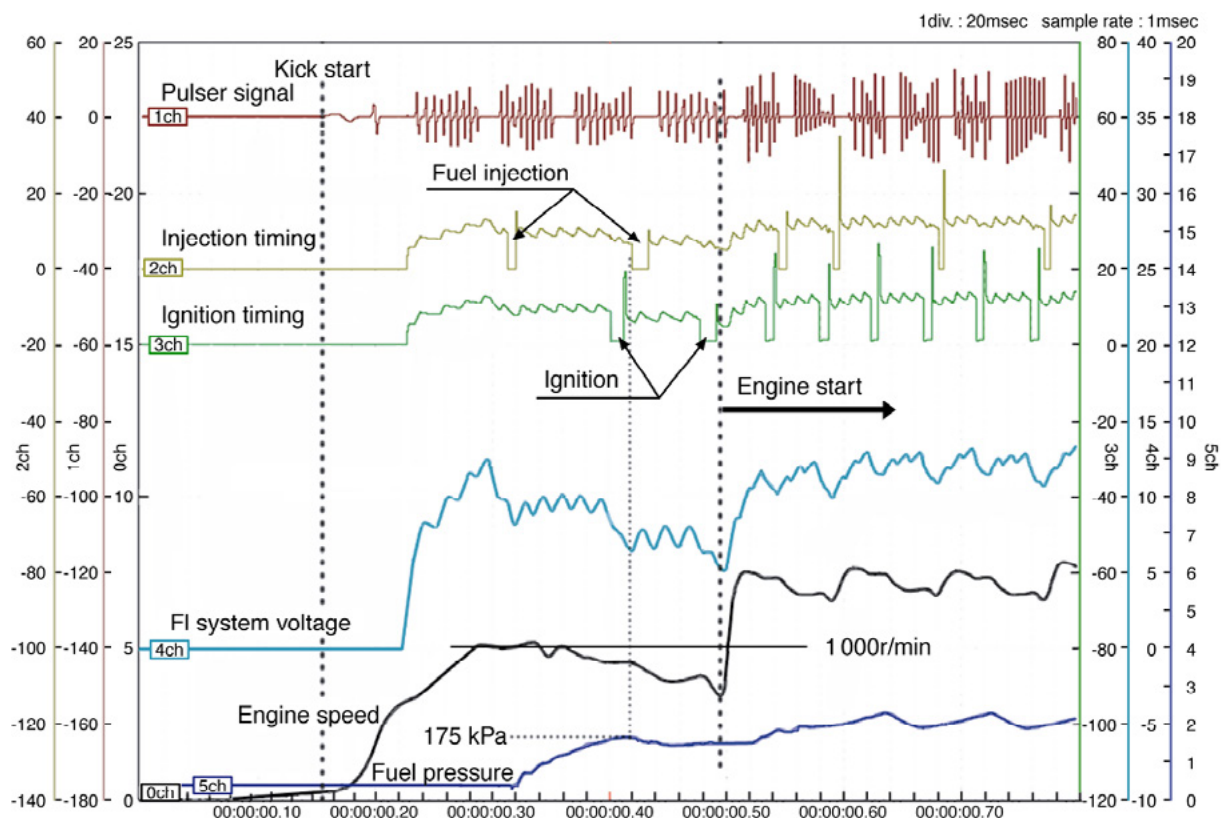


Fig. 9 Measurement data at engine start

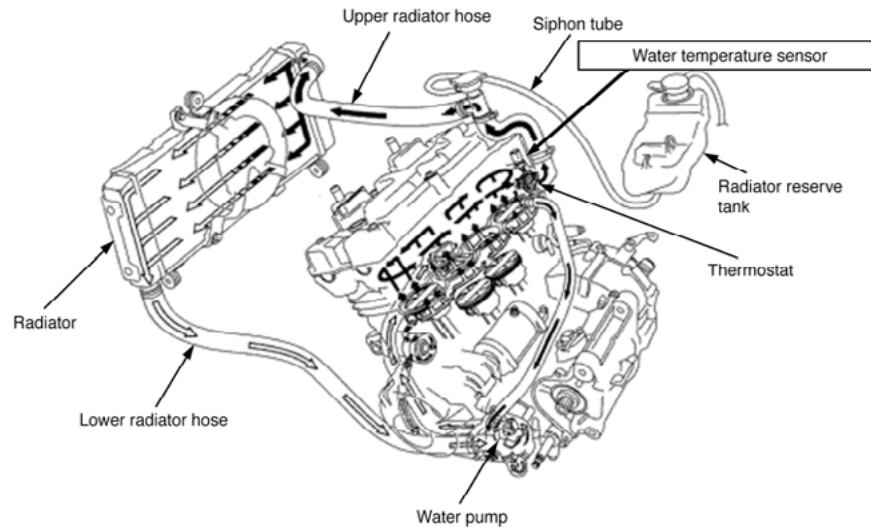


Fig. 10 Water temperature sensor of water cooled engine

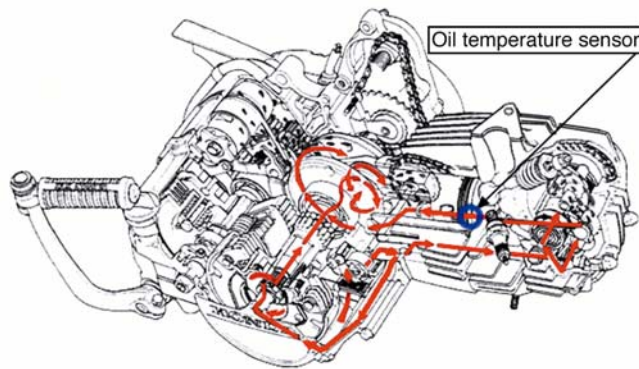


Fig. 11 Layout of oil supply system

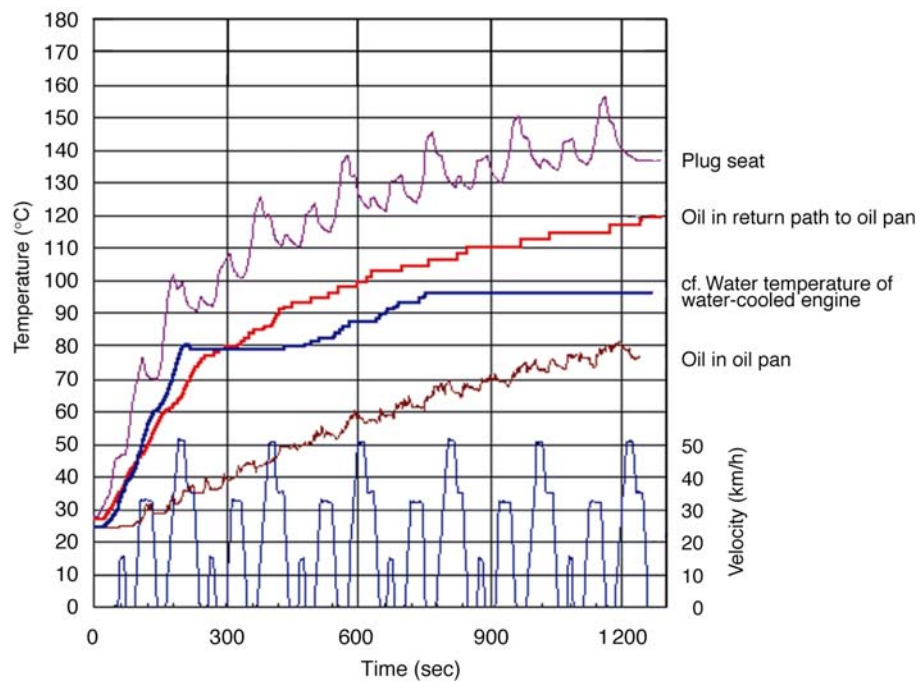


Fig. 12 Rise of temperature in exhaust emission measurement mode of Thailand

In the case of cold starting at an ambient temperature of 25 °C, it takes about 200 seconds to warm up the engine. The oil temperature in the oil pan rises slowly, showing no changes just after starting the engine. The temperature rises approximately 10 °C 200 seconds after starting the engine. Therefore, it is difficult to monitor the engine's warmed-up condition by measuring such small temperature changes. The oil temperature in the oil pan has low correlation with the temperature near the combustion chamber because the engine is fully warmed up 200 seconds after starting. Compared to that, the oil temperature measured at the return passage to the oil pan rises quickly and extensively, by approximately 35 °C, 200 seconds after starting the engine. This results from the oil being directly subjected to high temperatures when passing through the cylinder and cylinder head which creates a high correlation with the temperature near the combustion chamber. Therefore, we have decided to install an oil temperature sensor at the oil return passage in the cylinder, and use the sensor output for the fuel injection control. The output from the engine oil temperature sensor permits control of fuel injection depending on the engine's warmed-up conditions.

5.2.1. Actual control by oil temperature

The test engine is mounted behind the front wheel of the test motorcycle with the cylinder head in a flat position. When driving in rain or running through puddles, the water splashed by the front wheel comes directly onto the engine and cools it. The water temperature is close to the ambient air temperature, which is much lower than the engine temperature. As water is much more heat-conductive than air, the temperature of the entire engine lowers considerably. In natural air-cooled engines having no temperature compensation device such as a thermostat in a liquid-cooled engine, even after once warmed up, the engine may be cooled down to the pre-warm up condition in a wet condition. This results in low temperatures around the combustion chamber, and requires compensation of the fuel injection volume. The newly developed control system for fuel injection is very effective under such conditions as mentioned above.

6. Effectiveness of Fuel Injection System

By the accurate control of the air-fuel ratio, the exhaust gas emission of the test motorcycle using the FI system has been reduced to such a level that corresponds to 40% of the 4th emission control of Thailand. Figure 13 shows this achievement level. These are results from using only air induction, without using the oxygen concentration feedback control or catalyst. Even when the battery is completely discharged, the engine can be started by the kick-starter. Figure 14 shows the startability of the engine.

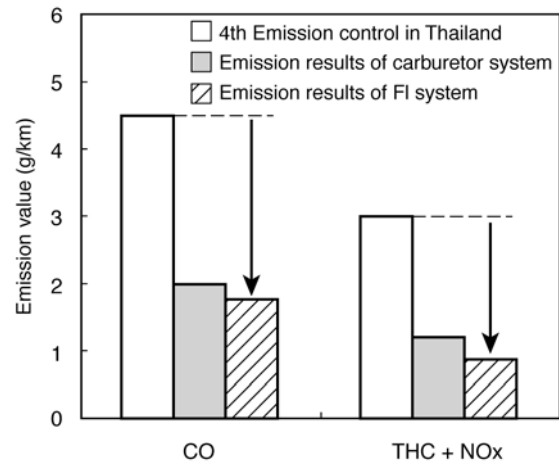


Fig. 13 Results of exhaust gas emission

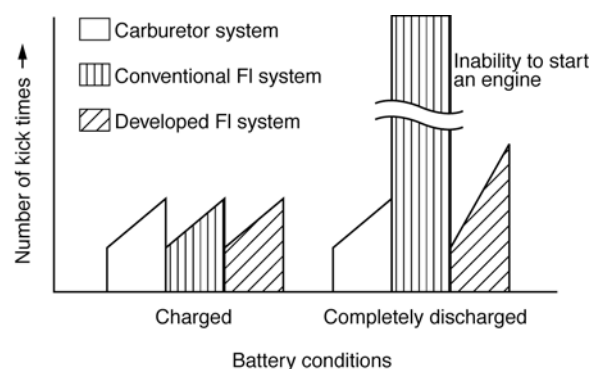


Fig. 14 Startability

7. Conclusion

- (1) An electronically controlled FI system that permits the starting of the engine by the kick-starter even when the battery is completely discharged has been realized.
- (2) By incorporating engine oil temperature detection, the system permits the compensation of fuel injection quantity and ignition timing even in an air-cooled engine.
- (3) This electronic control system allows for the application of an FI system to a small, air-cooled engine without the need for major modification to the engine configuration.

This new technology will contribute to the further reduction of exhaust gas emissions for small motorcycles widely used in Asian countries.

References

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