

Development of Electric System for Four-stroke Engine Trials Motorcycle “RTL250F”

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ABSTRACT

In order to reduce vehicle mass, a kick-start system without battery was selected for a trials competition motorcycle with four-stroke engine. The integrated throttle body developed for small motorcycles contains the ECU (Engine Control Unit), which is the main component of the fuel injection system. The power used to start the fuel injection control system is generated by the AC generator when the kick-starter is operated. A new control system was adopted for trials motorcycle, taking into consideration drivability requirements for slight and rapid throttle operation. This control system performs calculations twice for each combustion stroke and has a logic to control the fuel injection quantity and timing. Therefore, the above control system adds many enhancements to the drivability of trials motorcycle. Furthermore, users can set data inside the ECU as required.

1. Introduction

The concern of environmental issues has grown; accordingly, emissions regulations for motorcycles have become increasingly severe. To reduce emissions from commercial motorcycles, two-stroke engines are giving way to four-stroke engines and electronically controlled fuel injection systems are being increasingly used instead of carburetors. Even in the motorcycle race world, emissions regulations are being tightened, and the use of two-stroke engines tends to be prohibited by race regulations in each category. In world trials championships, the use of motorcycles

fitted with two-stroke engines was scheduled to be completely banned from 2006 due to changes in the FIM regulations (subsequently, the regulations were amended to allow two-stroke engines to be used until the end of 2008). The RTL250F and RTL250F-W were fitted with four-stroke engines from the 2005 model, prior to the amendment of the regulations. To realize the same drivability as that achieved with a two-stroke engine, an electronically controlled fuel injection system (PGM-FI system)⁽¹⁾ was adopted. This paper describes the control of the fuel injection system, which functions as part of a battery-less system.

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Fig. 1 External view of RTL250F

2. Outline of Functions

2.1. Outline of the RTL250F

Figure 1 shows an external view of the RTL250F⁽²⁾. To ensure that the RTL250F has the same competitive performance as the two-stroke RTL250R, the various parts of the machine were made more lightweight, the center of gravity was lowered, and the mass of the machine was concentrated.

The engine was based on that of the commercial Motocrosser CRF250R, but changes were made to several parts to lower the center of gravity of the machine and make it more compact. The maximum output of the engine was controlled to 14 kW against 31 kW for the CRF250R. Also, the torque characteristics were made flat and priority was given to increasing the torque at low speeds. Because power output was increased in the range of partial throttle opening at low engine speeds, even though the full throttle torque was less than that of a two-stroke engine, a torque feeling that was at least the same as that of the two-stroke engine was obtained.

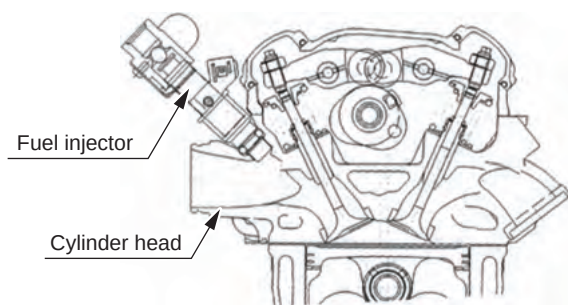


Fig. 2 Fuel injector directly installed in cylinder head

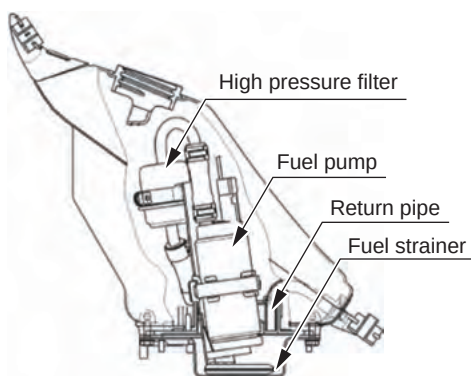


Fig. 3 Fuel tank assembly

To raise the throttle response of the PGM-FI system, the injector was mounted directly on the cylinder head (Fig. 2), while to ensure a stable supply fuel even during intense vehicle body motion when running in trials, the fuel pump was mounted inside the fuel tank (Fig. 3). The throttle body, which was based on the ECU-integrated type for small motorcycles, was changed to an air adjustment screw type that permits the user to adjust the idling speed. In addition, a decompression cam was used and the kick ratio was modified to realize smooth start-ability.

In contrast to the Japanese model of the RTL250F, which is intended exclusively for competitive use, the European model can run on public roads. The European model conforms to Euro-2 emissions regulations through use of a four-stroke engine and a PGM-FI system.

2.2. Outline of the RTL250F-W

The RTL250F-W was developed based on the RTL250F, with the goal of winning the World Championship for Trial. Although the basic design of the engine and the body is the same as that of the RTL250F, the materials used for many parts have been changed to reduce mass, the engine specifications have been changed to provide enhanced torque at low engine speed, and the road grip performance on slippery roads has been enhanced. Like the RTL250F, the ECU is integrated with the throttle body, and additionally has a built-in data logger based on the ECU for the RC211V four-stroke road racer. The built-in data logger enables the operating condition of the engine to be observed as data, and also enables the ECU to be set in a short period of time. The RTL250F-W displayed high competitive performance during the 2005 World Championship for Trial, and took both second and third place.

3. Battery-less System

The RTL250F electrical system consists of an AC generator, pulse generator, regulator rectifier, capacitor, fuel pump, fan motor, fan motor relay, bank angle sensor, water temperature sensor, ignition coil, fuel injector, ECU, and engine stop switch. The ECU contains an intake negative pressure (PB) sensor, air intake temperature (Ta) sensor, and throttle position sensor (TPS). The electrical system of the European model also includes a headlight, tail and stop lights, turn signal lights, a speedometer, horn, and light switches as safety equipment to enable the motorcycle to be ridden on public roads. The circuit diagram is shown in Fig. 4.

Normally, an engine that has a fuel injection control system is started by operation of the ECU, fuel pump, injector, and ignition coil using electrical energy stored in the battery. However, in the case of a battery-less system, these operations must be performed using electrical power generated by the AC generator when the crankshaft of engine is rotated by kick-starting. The AC generator for the RTL250F has a diameter of 147 mm, which is the largest generator used on a 250 cm³ displacement motorcycle. This is to ensure that the generator provides the large moment of inertia demanded by a trials motorcycle. A 3-phase generator is used to provide adequate electrical power at low engine speeds. It produces an output current of 7.5 A at a rotational speed of 1 000 r/min (Fig. 5). The electrical power generated by the AC generator is rectified and regulated to 14.4 VDC by means of a three-phase full-wave commutator type regulator rectifier, smoothed by a capacitor, and then supplied to each electrical load. The regulator rectifier and the capacitor are mounted on a bracket above the crankcase near the AC generator in order to reduce electric power

loss. The fan motor relay and the bank angle sensor are also mounted on this bracket, thus helping to concentrate the mass (Fig. 6).

To permit kick-starting using a battery-less system, the ECU controls the flow of current so that when the machine is being kick-started, electrical power is supplied only to the ECU, fuel pump, injector and ignition coil, and not to the fan motor or other electrical loads, such as the safety equipment in the case of the European model (Fig. 7). After the engine has started and has been allowed

to idle for a certain period, electric power is supplied to the fan motor and other electrical loads such as the safety equipment (Fig. 8).

By using an AC generator that generates a high output at low engine speeds, as well as electrical load control by the ECU and a decompression cam, the engine can start within three cranking operations, as shown in Fig. 9.

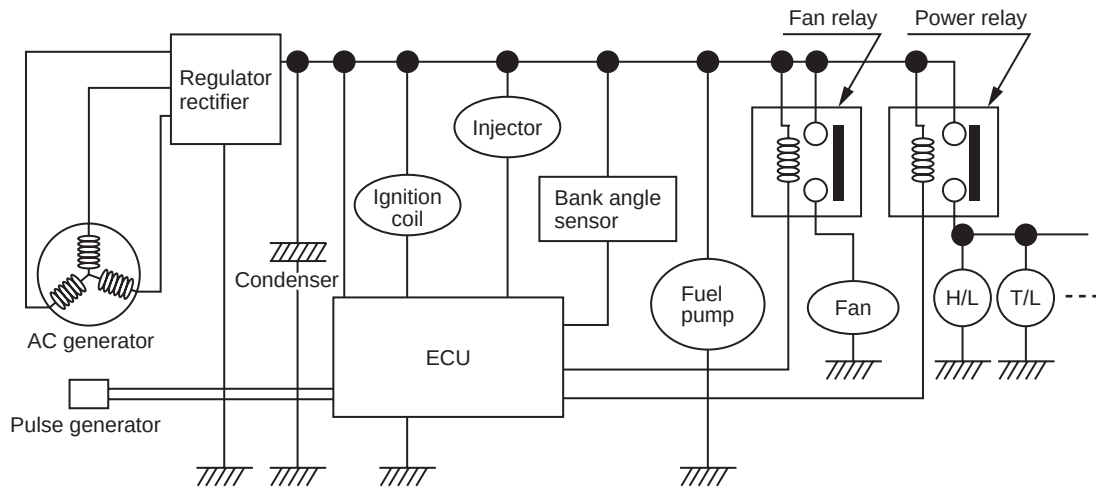


Fig. 4 Circuit of electric system

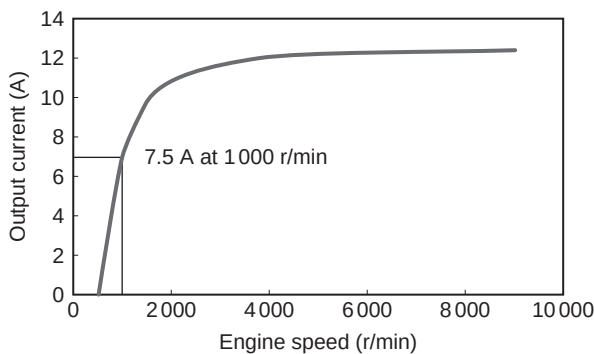


Fig. 5 AC generator characteristics

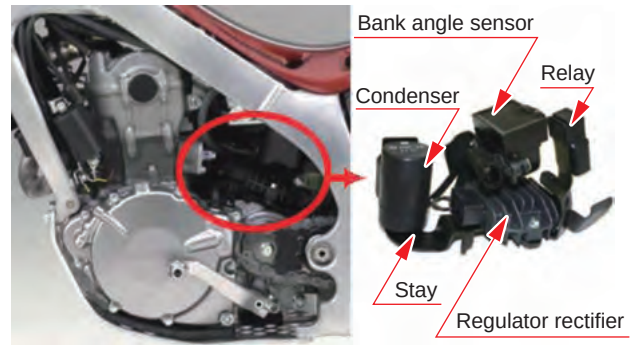


Fig. 6 External view of electrical equipments

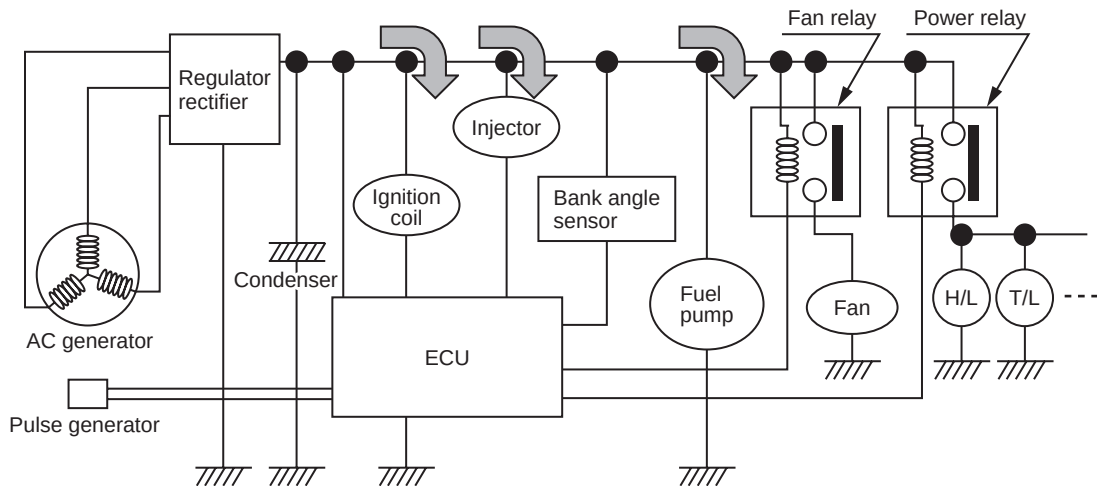


Fig. 7 Electric current mode at kick starting

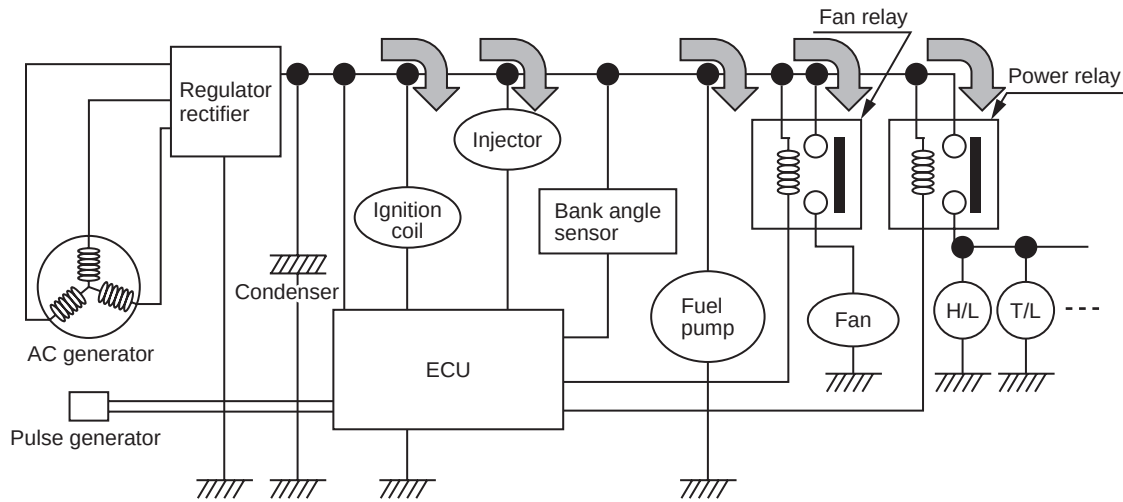


Fig. 8 Electric current mode after engine started

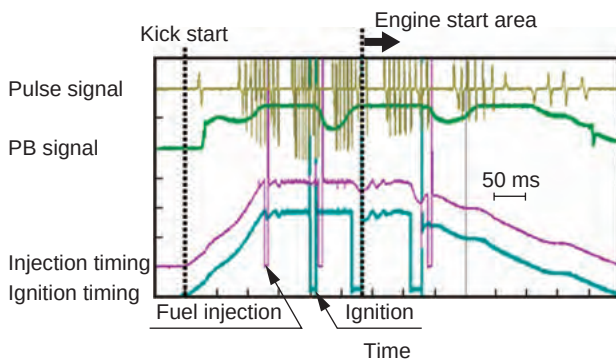


Fig. 9 Measurement data of engine startability at kick start

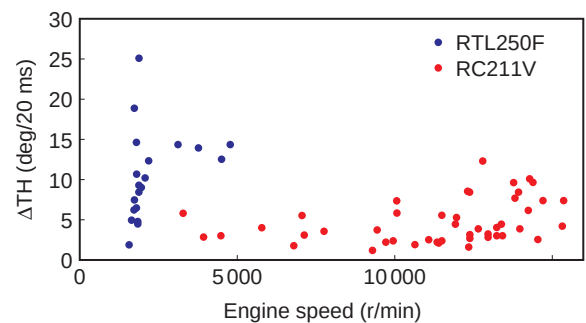


Fig. 10 Comparison data of throttle opening speed

4. PGM-FI System

The PGM-FI system determines the optimum fuel injection quantity, fuel injection timing, and ignition timing based on the following data: the crank angle input to the ECU, engine speed calculated from the crank angle, throttle opening, negative pressure of the intake pipe, intake air temperature, and cooling water temperature. It then operates the injector and energizes the ignition coil. In contrast to the use of a carburetor, fuel injection control enables the air-fuel ratio to be perfectly controlled under various conditions. In the case of the RTL250F, a test was also carried out on a carburetor specification engine. The air-fuel ratio changed remarkably when the body was subjected to violent motion during trials running. The engine stall occurred when the throttle was rapidly opened at low engine speeds, or when the motorcycle was braking downhill. Also, when the throttle was rapidly opened, engine hesitation occurred due to a delay in following the negative pressure of the intake pipe. These phenomena were solved as a result of the adoption of the PGM-FI system and also modification of the layout of the fuel pump.

In trials competitions, particular importance is placed on the response to rapid opening of the throttle at low engine speeds. The data concerning the throttle opening per unit time (ΔTH) of a trials competition and one lap of a circuit run using the RC211V four-stroke road racer were compared. As a result, it can be seen that in a trials competition the throttle is frequently opened rapidly at low engine speeds (Fig. 10). For this reason, in the case of the RTL250F, the throttle response to rapid opening was enhanced by calibrating the fuel injection twice for each 720 degrees of

crankshaft rotation angle.

In the case of conventional fuel injection control, calibrating was performed once at the timing to be optimum combustion during one 720-degree cycle of the crankshaft, consisting of the intake, compression, combustion, and exhaust strokes, and fuel injection was performed immediately after calibration. With this method, it is possible to adequately control the air-fuel ratio by setting the calibration timing and fuel injection amount for each engine speed and each throttle opening during constant speed running. However, during transient operation, particularly at low engine speeds with long stroke time, the fuel injection quantity is not calculated when the throttle is operated at the end of calibration. As a result, lower throttle response is induced at rapid throttle opening and smolder of spark plug is induced at rapid throttle closing. Figure 11 shows the timing chart at rapid throttle opening in the case of conventional calibration, and Fig. 12 shows the timing chart at rapid throttle closing. With the new control method, the number of calibrations of the fuel injection quantity during one cycle was increased to two. Fuel injection is timed to start so that fuel injection ends during the intake stroke after the end of the first calibration that begins during the exhaust stroke. In addition, a method of correcting the fuel injection amount by performing the second calibration during the intake stroke while fuel injection is beginning (hereinafter referred to as "2-calibration injection control") was devised. As a result of this method, it was possible to optimize not only the air-fuel ratio during constant engine speed, but also the fuel injection amount and the fuel injection timing when the throttle is opened or closed rapidly at low engine speeds. Figure 13 shows the timing chart for when the throttle is opened rapidly during 2-calibration

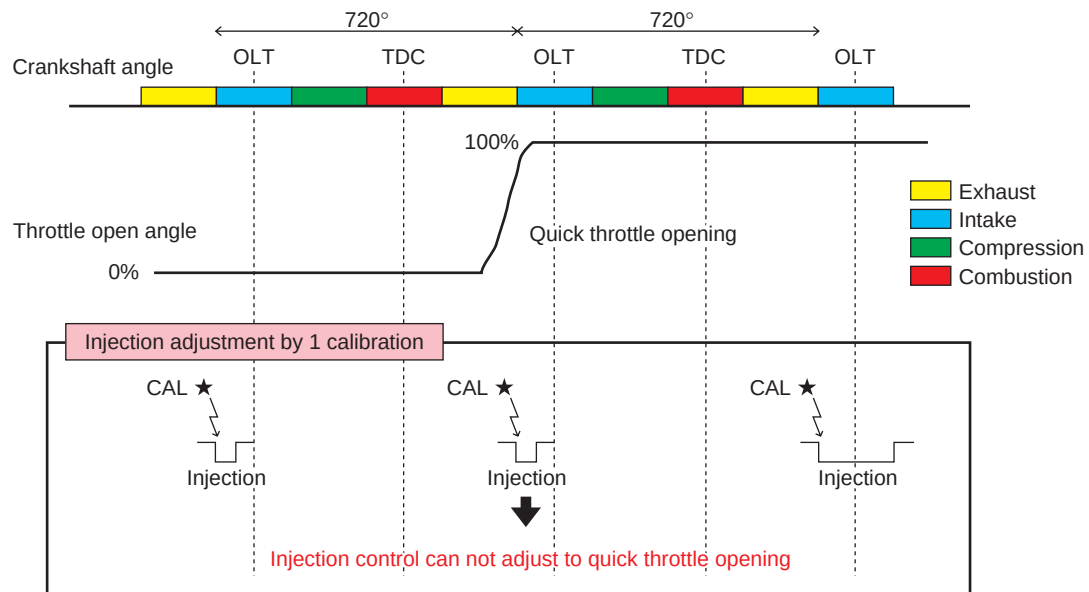


Fig. 11 Injection timing chart by 1 calibration when throttle opened

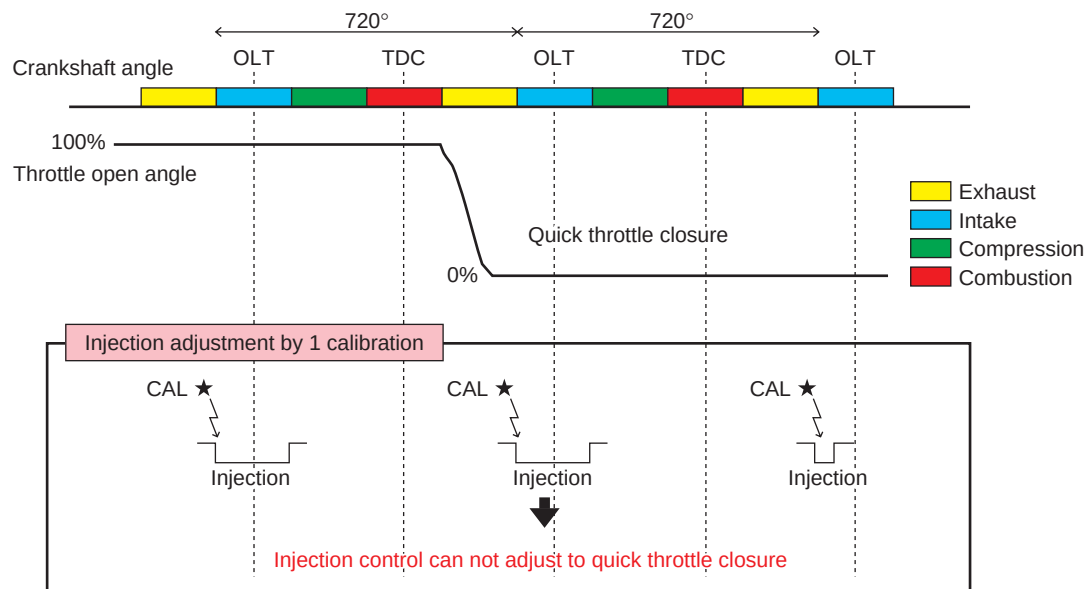


Fig. 12 Injection timing chart by 1 calibration when throttle close

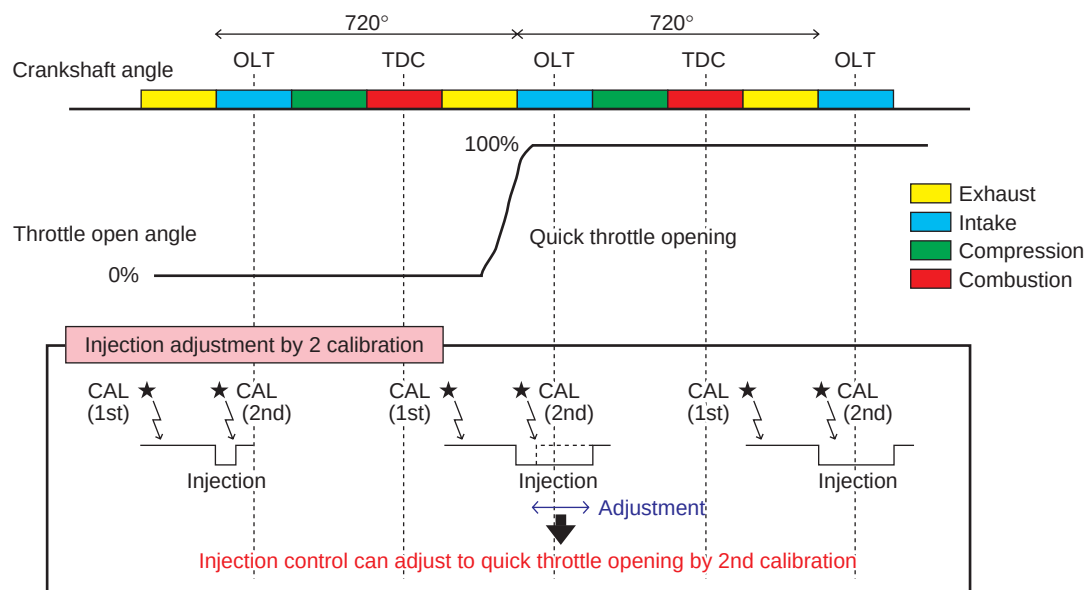


Fig. 13 Injection timing chart by 2 calibrations when throttle opened

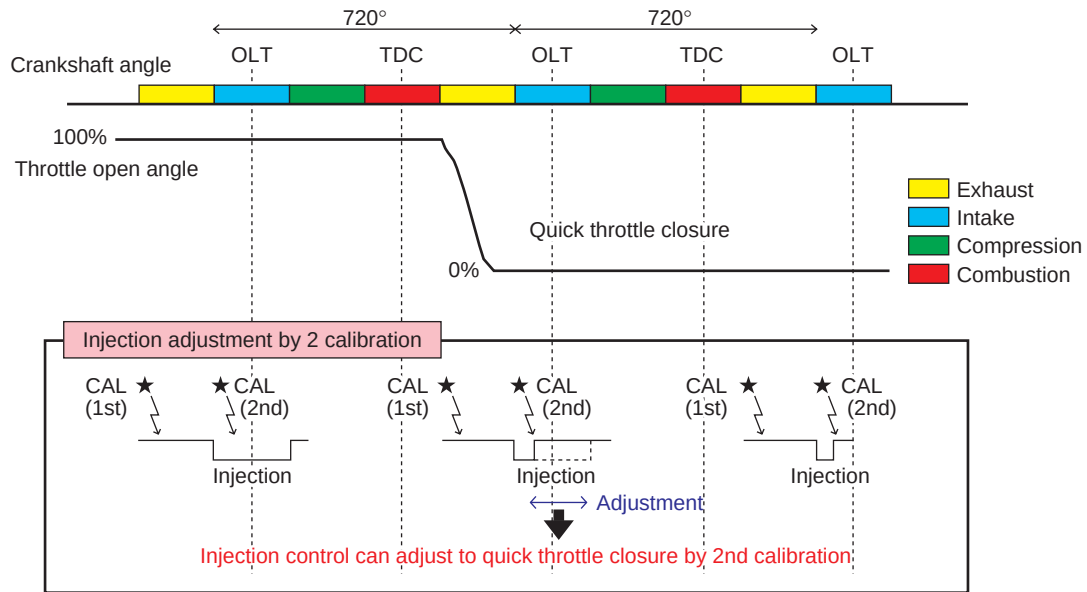


Fig. 14 Injection timing chart by 2 calibrations when throttle closed

injection control, and Fig. 14 shows the timing chart for when the throttle is closed rapidly.

With a two-stroke engine, the combustion pressure rises greatly from the beginning of opening of the throttle, so generally the throttle response is better than that of a four-stroke engine. In the case of the RTL250F, importance was placed on ensuring that the response to rapid opening of the throttle was of the same order as that of a two-stroke engine. This was done to enable a rider used to a two-stroke motorcycle to make a smooth changeover to a four-stroke engine. As a result of using 2-calibration injection control, the resulting rise in combustion pressure when the throttle was opened rapidly was comparable to that of a two-stroke engine. Figure 15 shows the results of a comparison of the combustion pressure data of the RTL250R, which is a two-stroke engine, and the RTL250F. It can be seen that the throttle response is in no way inferior to that of the two-stroke engine. Figure 16 shows the results of a comparison of the output characteristics of the RTL250R (two-stroke) and that of the RTL250F (four-stroke).

In addition, a system that could be controlled even using an ECU with a low processing speed was developed by performing 2-calibration injection control only at low engine speeds and changing

over to conventional single calibration at high engine speeds, where the calibration interval is short.

5. ECU Setting Tool

In trials competitions, races are carried out under a variety of road surface conditions, ranging from asphalt with good grip performance to river beds that have poor grip performance, and in highland regions beyond an altitude of 1 000 m. Also, users range from beginners to world championship class riders, and they have a correspondingly wide range of skill. An ECU setting tool that enables the user to change the ECU setting was developed for the RTL250F. The user can change the fuel injection amount and ignition timing within a certain range by means of a tool on a personal computer. The setting data created by the user using the ECU setting tool is stored in the EEPROM inside the ECU by serial

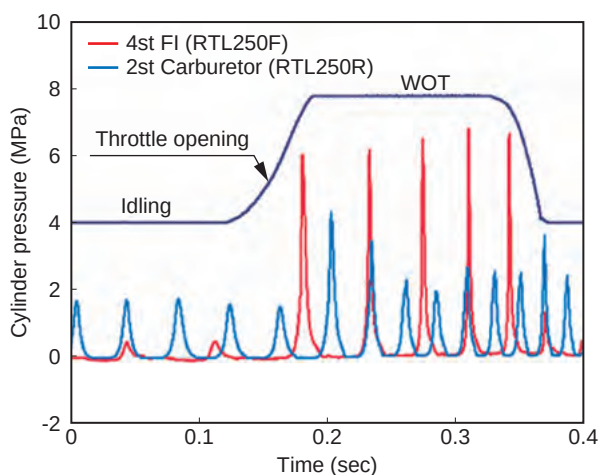


Fig. 15 Comparison data of cylinder pressure

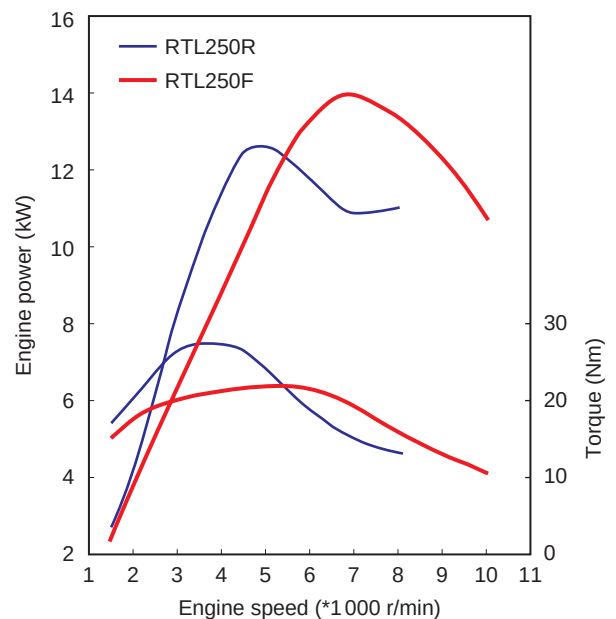


Fig. 16 Engine performance curve

communication. The ECU adds this setting data to, or subtracts it from, the fuel injection amount and ignition timing data in the flash memory, and determines the final fuel injection amount and the ignition timing. As a result, the user can find settings for various road surface conditions, altitudes and user skills. Figure 17 shows an outline of the setting tool.

6. ECU for Factory Racer

To perform the accurate and rapid ECU settings demanded by a factory racer, an ECU with a built-in data logger was developed based on the ECU for the RC211V. Compared to the ECU for the RTL250F, this ECU has a data logger function for collecting data in the flash memory, a CAN communication function for performing various measurements and driving the meters. In addition, a Bluetooth communication function for communicating

with the ECU, fan motor drive circuit, fuel pump drive circuit, multi-channel A/D input circuit, pulse input circuit, general purpose motor drive circuit, and solenoid drive circuit were added. The 32 bit CPU can cope with the increased processing required by the addition of the data logger function. There is a flash memory, in addition to an EEPROM. The flash memory can store the data (logging data) collected by the data logger function, and the EEPROM can store multiple sets of setting data. Figure 18 shows the block diagram of the ECU, and Fig. 19 shows a comparison with the ECU for the RTL250F. The device body, intake negative pressure (PB) sensor, and the throttle position sensor (TPS) are the same as those used on the ECU for the RTL250F, and the idle air control device is the same as that used on the ECU for a small motorcycle. Circuits were added along with the increasingly sophisticated functions, and the circuit board is a 6-layer 0.8 mm thick 2-stage construction flex-rigid circuit board instead of the previous 4-layer 1.6 mm thick glass-epoxy printed circuit board.

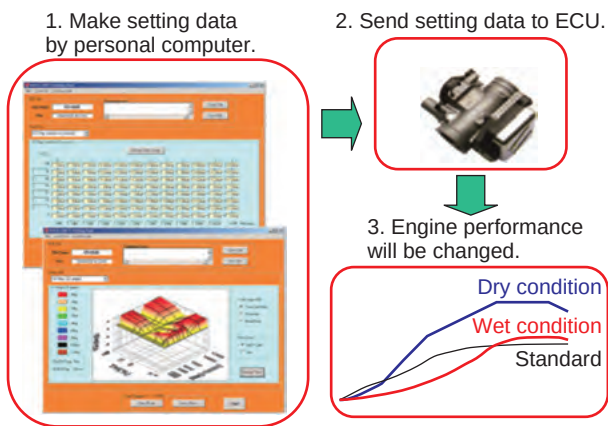


Fig. 17 ECU setting tool

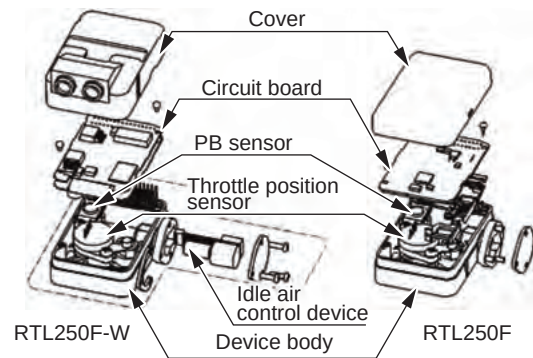


Fig. 19 ECU for factory racer

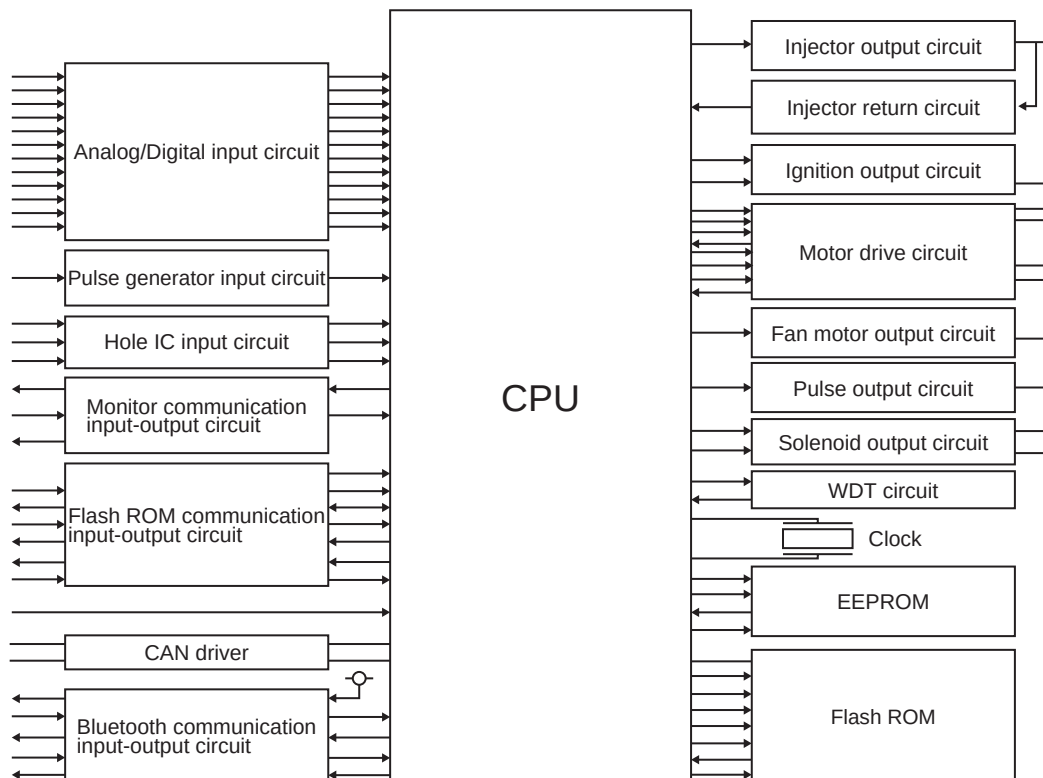


Fig. 18 ECU input-output block diagram for factory racer

The input/output circuit uses the same custom IC as that of the ECU for small motorcycles, resulting in a mere 20% volume increase and 30% mass increase. The conventional press-molded cover has been replaced by a pre-cut aluminum one, enabling the mass increase to be kept to a minimum despite the complicated shape needed by the flash memory communication connector and the Bluetooth communication connector. To obtain the optimum intake air temperature, the intake air temperature (Ta) sensor has been moved from inside the ECU to inside the air cleaner box.

The data logger function enables the collection of various data, including crank angle, engine speed, throttle opening, temperature of each part, fuel injection amount, ignition timing, and countershaft rotational speed. The collected logging data is sent to a personal computer by wireless communication using the Bluetooth communication function, and then subjected to data analysis. Based on the analyzed data, the optimum fuel injection amount and ignition timing are set, the mechanic staff creates the setting data, and the setting data is sent to the ECU by means of the Bluetooth communication function. As a result, it is possible to set the fuel injection control system in a short period of time. Figure 20 shows samples of logging data.

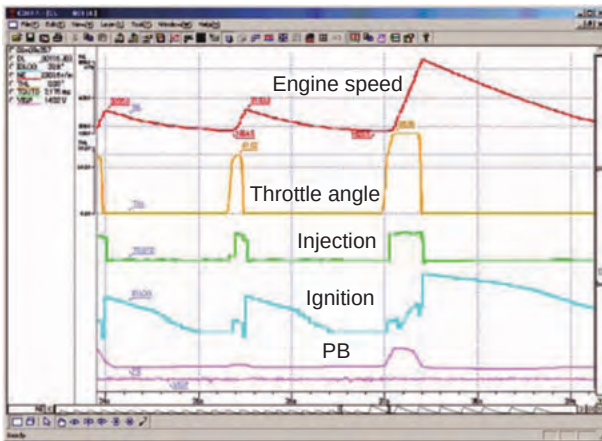


Fig. 20 Logging data sample

7. Conclusion

An electrical system that has the following features was developed for a four-stroke engine trials motorcycle.

- (1) A battery-less system that enables the motorcycle to be kick-started was developed.
- (2) The use of 2-calibration injection control enabled the fuel injection amount to be adjusted optimally in response to rapid throttle operation.
- (3) With the commercial RTL250F, a function that enables the user to freely set the fuel injection control system using a personal computer was achieved. In the case of the RTL250F-W factory racer, the built-in data logger of the ECU enables the fuel injection control system to be set in a short period of time.

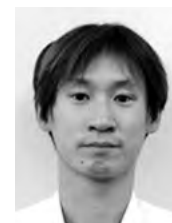
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