

Development of Integrated Fuel Injection System for Small Sized Motorcycles

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ABSTRACT

Demands for reducing exhaust emission and enhancing fuel economy have been increasing in accordance with growing concerns regarding global environmental issues. An electronically controlled fuel injection system which precisely controls the air-fuel ratio has been adopted to effectively meet the demands. Technologies for miniaturizing and achieving a high-efficiency system have been established for fuel injectors, the fuel pump and ECU (Electrical Control Unit). For the fuel injector, a spray form and magnetic circuit was optimized through computer simulation. As the result, a fuel injector with good installation ability for engine displacements ranging from 50 cm³ to 900 cm³ was realized. For the fuel pump, the maximized motor efficiency along with an optimized pump rotor shape reduced current consumption by 25%. For the ECU, the development of a circuit-integrated custom IC and the standardization of a housing achieved a compact, light, inexpensive design.

1. Introduction

Following the lead of industrialized countries, governments in the ASEAN region are implementing regulations calling for enhanced motorcycle fuel efficiency and reduced emissions. Since most of the world's motorcycles are used in the ASEAN region as a vital form of transportation, it is only natural that these motorcycles have a significant impact on global environmental issues. Electronically controlled fuel injection system (hereafter fuel injection) is a very effective means of addressing environmental concerns without compromising the performance and function of the motorcycle. Honda adopted fuel injection technology⁽¹⁾ for small-sized motorcycles beginning with the 2003 Pantheon (for

the Italian market), followed by the Wave 125i (Thailand) and Dio Z4 (Japan)⁽²⁾. To expand the use of fuel injection in small-displacement motorcycles, it is essential to make a system smaller and more efficient. This will help reduce power consumption and cost. This report introduces technological measures that were taken to make the fuel injection system smaller, lighter and less expensive.

2. Issues in Adopting and Techniques for Achieving Fuel Injection

2.1. Issues in Adopting Fuel Injection

Figure 1 shows the fuel injection system of the 2003 Wave 125i. This motorcycle was launched in Thailand in July of 2003.

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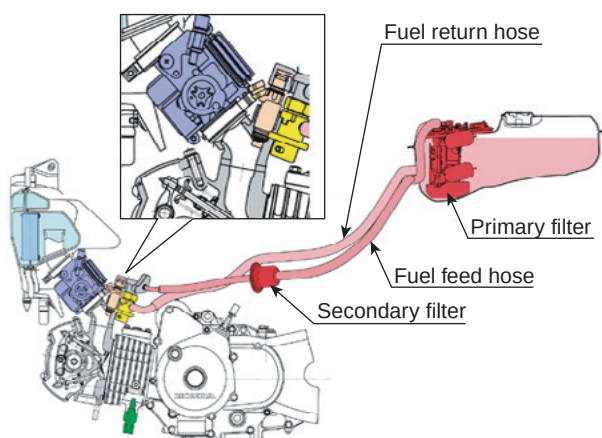


Fig. 1 Fuel supply system of 2003 Wave125i

The fuel injection system has new technologies such as the integration of the ECU with the functions of the throttle body. The system was based on automobile technology but was not optimized for small-sized motorcycles. Therefore it's unsatisfactory in terms of the layout and cost.

2.2. Techniques for Achieving Fuel Injection

The current development focuses on reducing size, weight and cost for the following four items.

- (1) A compact fuel injector^{(3), (4)}
- (2) A highly efficient fuel pump and a fuel feed pump module without a secondary filter⁽⁵⁾
- (3) A small integrated ECU (electrical control unit)⁽⁶⁾
- (4) High pressure fuel hose using small-diameter resin tubes

3. Major Specifications and Outline

Table 1 shows the major specifications of the recently developed 2005 Wave 125i compared to those of the earlier model. Figure 2 and 3 show the fuel supply system and the appearance of the motorcycle, respectively. Figure 4 shows a fuel injection control

diagram. For the fuel supply system, fuel vapor lock was prevented by revising the fuel injector position and changing the fuel supply pressure. This allowed for the elimination of the fuel return hose.

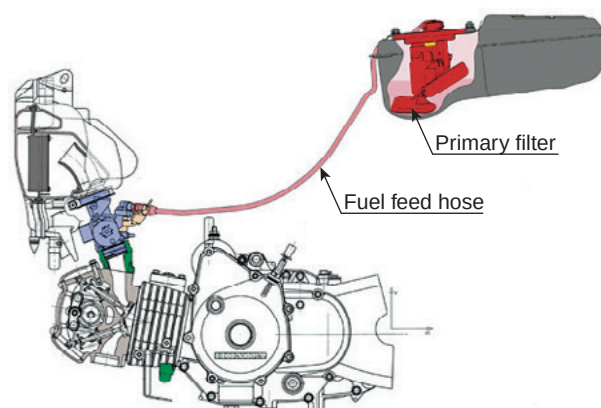


Fig. 2 Fuel supply system of 2005 Wave125i



Fig. 3 2005 Wave125i

Table 1 Major specifications

		2003 Wave125i	2005 Wave125i
Engine	Engine type	Air-cooled 4-stroke SOHC	Air-cooled 4-stroke SOHC
	Bore x Stroke	mm	52.4 x 57.8
	Displacement	cm ³	124.9
	Compression ratio	9.3	9.3
	Throttle body	Keihin GQ20	Keihin GQ22
	Max. output	kW/ r/min	6.75 / 7 500
	Max. torque	Nm/ r/min	9.74 / 5 500
Fuel system	Fuel supply system	In-tank return	In-tank return-less
	Fuel pump	Keihin	Keihin (Carbon commitator)
	Fuel pressure	kPa	250
	Fuel feed hose	FKM (φ6)	Resin (φ2.5)
	Injector	Denso C-3	Keihin type 7
Electric	ECU (Electrical Control Unit)	Keihin (Integrated to throttle body)	Keihin
	Throttle position sensor	Alps	Alps
	Manifold pressure sensor	Fuji	Fuji
	Air Temperature sensor	Shibaura	Shibaura
	Engine temperature sensor	Denso	Matsushita
	Ignition coil	MP06	MP33

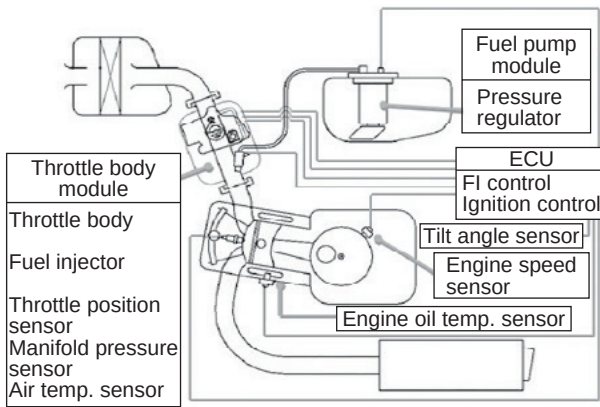


Fig. 4 Schematic of fuel injection system

4. Main Technologies

4.1. Compact Fuel Injector

The current fuel injectors for automobiles are rather large and therefore offer little flexibility for installation on small-sized motorcycles. Achieving engine performance has been a challenge with these systems. This research developed a new compact fuel injector with flexibility for installation on small-sized motorcycle engines^{(3), (4)}. Figure 5 compares its size to that of a current fuel injector. Table 2 provides their performance specifications.

In order to make the fuel injector smaller while keeping its basic performance, the construction of the fuel injector was fundamentally revised based on the simulation results of the magnetic circuits and fuel flow.

- (1) Simplification of the movable valve stopper structure
- (2) Optimization of the magnetic circuit configuration
- (3) Reduction of pressure loss in fuel passage

4.1.1. Simplification of the movable valve stopper structure

Conventionally, two types of movable valve stopper structures are common: As shown in Fig. 6(a), the first uses a non-magnetic parted C-shaped washer to create an air gap between the movable valve and the fixed iron core. The second type, shown in Fig. 6(b), uses a hard chromium plating on the movable valve to create an air gap.

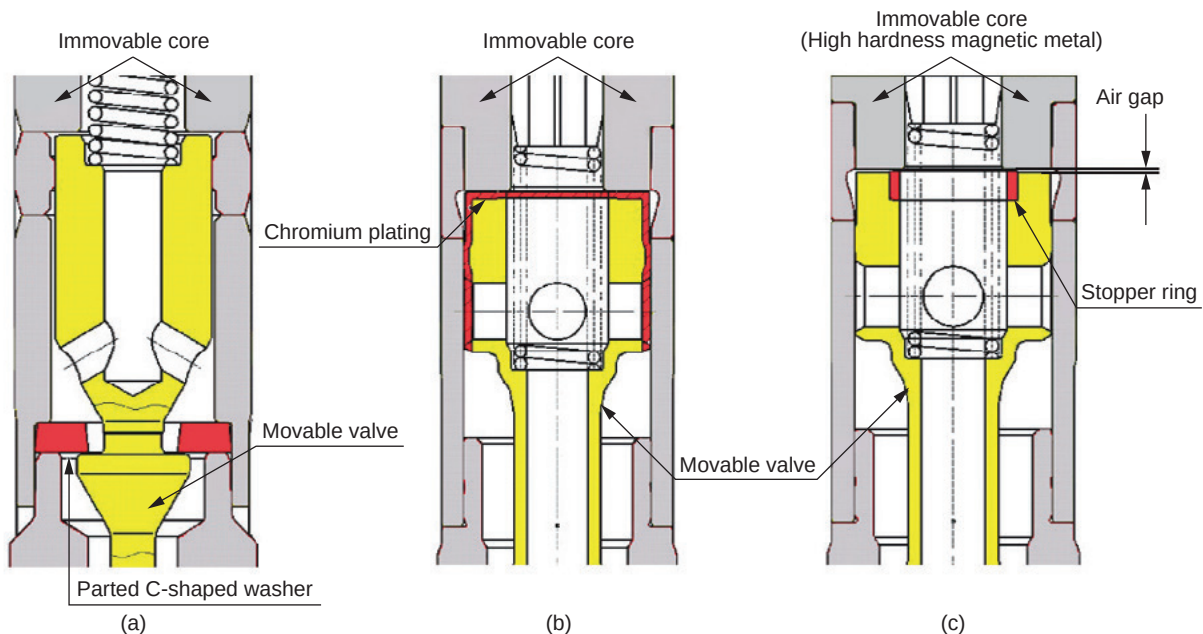


Fig. 6 Simplification of plunger stopper system

Both types are expensive. The type with the parted C-shaped washer consists of many components while the type with the hard chromium plating on the movable valve requires more surface treatment processing.

For this research a new construction was used for the movable valve stopper structure (c).

First, an air gap was formed between the movable valve and fixed iron core. A non-magnetic stopper ring, which acts as the movable valve's stroke stopper, was press-fitted into the movable valve.

In order to reduce the abrasion, a new magnetic material that is harder than the surface hardness of the stopper ring was used for the fixed iron core that touches the stopper ring.

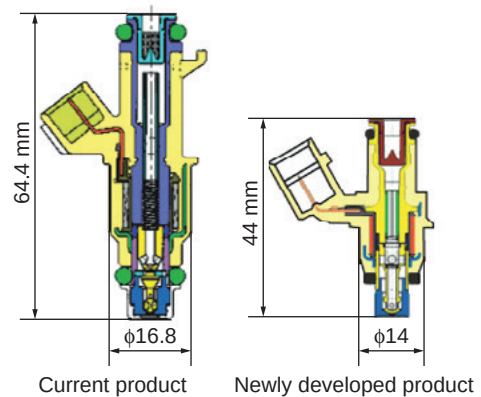


Fig. 5 Comparison of injector size

Table 2 Specifications of injector

	2003 Model	2005 Model
Number of nozzle	4	4
Dynamic flow rate (2 msec)	1.73 mm ³ /st	2.12 mm ³ /st
Static flow rate	90 cm ³ /min	78.8 cm ³ /min
Spray form	1 Jet 12 deg	1 Jet 15 deg
S. M. D	120 μm	72 μm

This resulted in a construction with unprecedented economy and simplicity.

Moreover, its durability is greater than that of the existing C-shaped washer type.

4.1.2. Optimization of the magnetic circuit configuration

An optimally compact design was created for the magnetic circuit through the use of CAE analysis.

The new design balances coil inductance reduction, surplus solenoid attraction force reduction, optimal position settings for the movable valve, restraint of the overall coil bobbin length, etc. to achieve a smaller design without compromising performance.

For example, CAE analysis indicated that the gap between the outside diameter of the fixed iron core side and that of the movable iron core side was too large. As shown in Fig. 7, this resulted in increased flux leakage. Therefore, the outside diameter gap was reduced to enhance efficiency.

4.1.3. Reduction of pressure loss in fuel passage

The configuration of the fuel channel was also revised in order to assure a fuel flow rate applicable to a range of displacements, from small to large, with the more compact design. Specifically, a center fuel channel with low channel resistance was used. The cross-sectional area of each part was designed to be more than three

times the opening area of the seat part when flow was at its maximum. This resulted in a great reduction of pressure loss as compared to existing fuel injectors, as Fig. 8 shows.

4.2. Fuel Feed Pump Module

Motorcycles in the ASEAN region, where there is such a strong need for enhanced fuel efficiency and lower costs, require further reductions in current consumption. Therefore, with a goal of achieving current consumption of less than 1A, a new low-cost fuel pump module was developed⁽⁵⁾.

By focusing on the low-flow range required for small-sized motorcycles, the development of the fuel pump module aimed at achieving the following four requirements:

- (1) Rotor blade angle optimization
- (2) Pump passage gauge optimization
- (3) Pump motor optimization
- (4) Elimination of secondary filter

Figure 9 and Table 3 compare the size and properties of the new and current pumps.

The new fuel pump (c) is about the same size as (b) but has greatly enhanced performance. The new fuel pump was able to satisfy flow requirements while reducing current consumption to the target level of less than 1A.

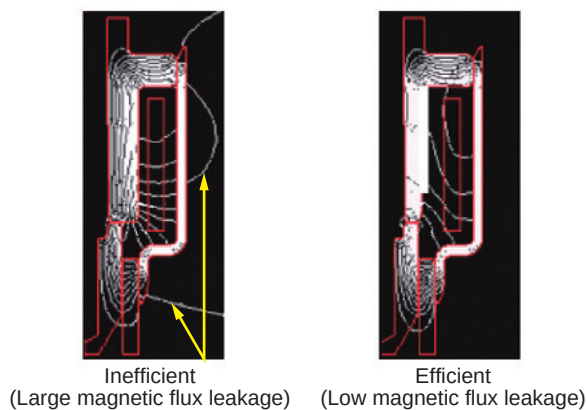


Fig. 7 Optimization of magnetic circuit

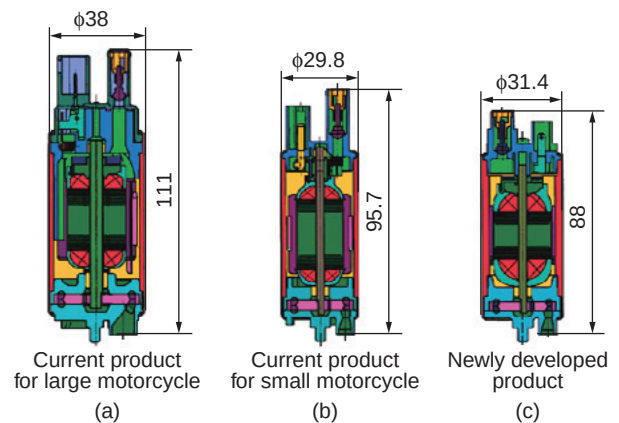


Fig. 9 Comparison of fuel feed pump size

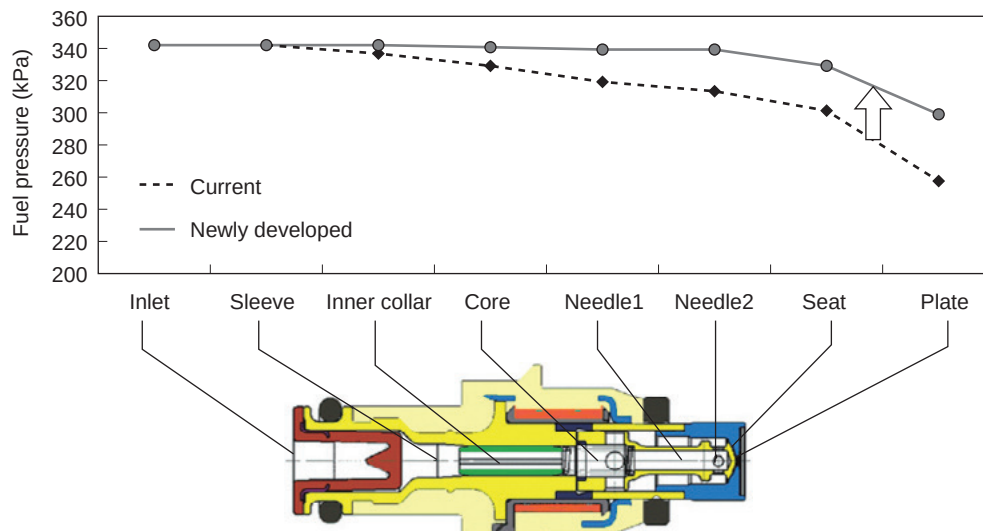


Fig. 8 Pressure loss at various locations

Table 3 Specifications of fuel pump

	2003 Model	2005 Model
Fuel pressure	250 kPa	294 kPa
Flow rate	17.7 L/h	16.5 L/h
Current	1.0 A	0.95 A
Pump type	Turbine	Turbine
Motor type	DC motor	DC motor
Magnet type	Ferrite	Neodymium

4.2.1. Rotor blade angle optimization

Enhancing pump efficiency requires increasing the flow velocity of a fluid's swirl flow.

Setting the rotor blade angle is very important in achieving increased velocity.

Rotors with various blade angles were built and their efficiencies measured, as shown in Fig. 10.

The result was that reducing the rotor blade angle from 60° (the angle of the existing type) to 45° increased pump efficiency by 3%.

4.2.2. Pump passage gauge optimization

The passage area was optimized for the set flow. In the low displacement range, pump efficiency is enhanced because bulkhead resistance declines as a result of reducing the passage cross-sectional area. This is shown in Fig. 11. If the cross-sectional area is reduced too much, the discharge flow rate itself declines, reducing pump efficiency.

The new pump uses a passage cross-sectional area of 11.1 mm² as compared to the 14.0 mm² of the existing pump. The result is that pump efficiency at low flows was increased by 3.5%.

4.2.3. Enhancing pump motor efficiency

To enhance the efficiency of the motor, a Nd-Fe-B bond magnet was used for the magnetic material in place of the ferrite of existing motors. As shown in Fig. 12, residual flux density rose 78% and motor efficiency increased by 7.6% over that of the existing motor.

4.2.4. Elimination of secondary filter

Conventionally, it is typical in fuel pump modules to place a primary filter on the fuel pump's intake side and a secondary filter on the high pressure side. With the new pump module, a high density nonwoven fabric filter was used for the primary filter and a carbon

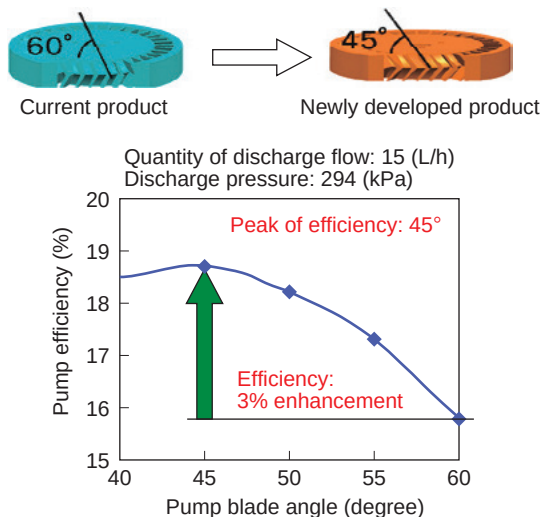


Fig. 10 Optimization of rotor blade angle

commutator was used in the pump motor. This made it possible to eliminate the secondary filter at the high pressure end. Table 4 lists the specifications of the primary filter.

4.3. Small Integrated ECU

Among small-sized motorcycles, the devices required vary depending on model, destination market and other factors. Table 5 shows the major combinations.

Since the combination of Engine Management System (EMS) devices (auxiliaries) varies according to model, the ECU's sensors, switch input circuit and device drive circuit all must be general-purpose and multi-functional. An ECU was developed through this research to accommodate the mutually opposing goals of smaller size, weight and cost with that of advanced and general purpose functionality⁽⁶⁾.

4.3.1. Development of circuit-integrated custom IC

Figure 13 shows the ECU's circuit configuration. In the fuel injection system, functions were built into the custom IC taking

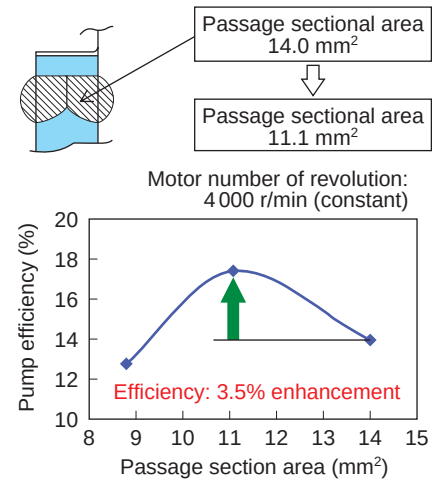


Fig. 11 Optimization of fuel passage design

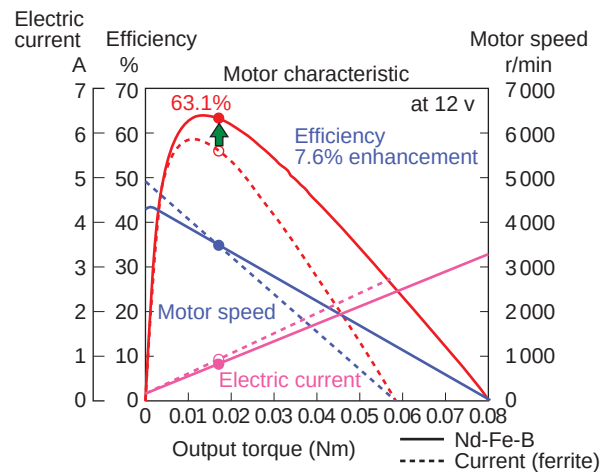


Fig. 12 Developed motor characteristic

Table 4 Specifications of fuel filter

	2003 Model	2005 Model
Filtration area	25 cm ²	65 cm ²
Filtration density	30 μm 90% min	10 μm 95% min
Max. diameter of pass	35 μm	10 μm
Life performance (Pressure loss by 3 grams in dust)	1.2 kPa	0.6 kPa

Table 5 Demands and applications for small motorcycles' ECU

Sensor/Device	Wave 125i (Thailand)	Scooter (Europe)
Throttle position sensor	Yes	Yes
Manifold pressure sensor	Yes	Yes
Air temperature sensor	Yes	Yes
Engine temperature sensor	Yes	Yes
Oxygen sensor	—	Yes
Crank pulse sensor	Yes	Yes
Speed sensor	—	Yes
Side-stand switch	—	Yes
Neutral switch	Yes	Yes
Injector	Yes	Yes
Ignition coil	Yes	Yes
Fuel pump relay	Yes	Yes
Power relay control	—	Yes
Oxygen sensor heater	—	Yes
Exhaust air induction	—	Yes
Positive crankcase ventilation	—	Yes
Fan control	—	Yes
Idle air control valve	—	Yes

into account the combination of sensor devices and added functions that would be needed to address strict exhaust emission regulations. The functions bundled in the custom IC were the basic input and output needed by the fuel injection system, a stepping motor drive circuit, the ECU's internal 5V power source and microcomputer monitoring/reset circuit.

4.3.2. Housing standardization and mounting design

The space in which the ECU can be mounted is limited on a motorcycle for structural reasons. Additionally, since these are electronic components, the environmental conditions of the mounting location must be considered.

To address these concerns, small connectors and other components were employed first in order to easily configure the layout. Furthermore, the connectors were designed to be waterproof and the substrate was filled with resin. This resin filling also helped enhance the vibration resistance of the ECU.

(1) Electronic components

By using surface-mounted electronic components that allow for high-speed automatic mounting, manual labor and process cycle time for this task were reduced. Since lead-free solder is used to connect components, components were selected that have suitable electrode surface treatment and heat resistance properties (Fig. 14).

(2) Connectors

The terminal size was reduced from the current 040 to 025 while still achieving the carrying capacity requirement. This allowed for smaller connectors. Additionally, the technique for affixing the housing to the substrate changed from a screw on type to that of a screwless snap-fit design, thus eliminating the screw-down process.

(3) Substrate

The substrate must have enough area so electronic components, having a load drive current of 1A or greater (such as the solenoid and motor), can release heat. Therefore an ordinary FR-4, through-via 4-layer laminates was used.

4.4. Small-diameter Resin Fuel Hose

To reduce costs, high pressure resin fuel hoses were used in place of rubber.

Existing resin hoses, however, are rigid and cannot bend freely. It was necessary to perform a form molding and bending process in advance for the desired form. Accomplishing this in the complicated form of a motorcycle frame has been a challenge. Moreover, existing hoses were intended for automobiles and their large flows are not appropriate for the low flows required by small-sized motorcycles.

For this research a small-diameter resin hose suitable for low flows was developed that makes it possible to arrange tubing in the complicated forms of motorcycles, without any molding and bending process involved. Detailed specifications are shown in Fig. 15.

4.4.1. Construction

Like existing resin hoses, the new small-diameter resin hose has a three-layer construction, consisting, from the inner layer, of ETFE, PA12 and EPDM. Figure 16 illustrates this construction. The innermost layer of ETFE and the outermost EPDM are protective materials that respectively withstand deteriorated gasoline and provide weather-fastness.

4.4.2. Anti-kinking

CAE-based analysis was performed to judge the flexibility of the small-diameter resin hose. As Fig. 17 shows, while existing resin hoses kink at a bending curve of R25, the new small-diameter hose does not kink even at R8. It was confirmed that the new hose has as much flexibility as existing rubber hoses.

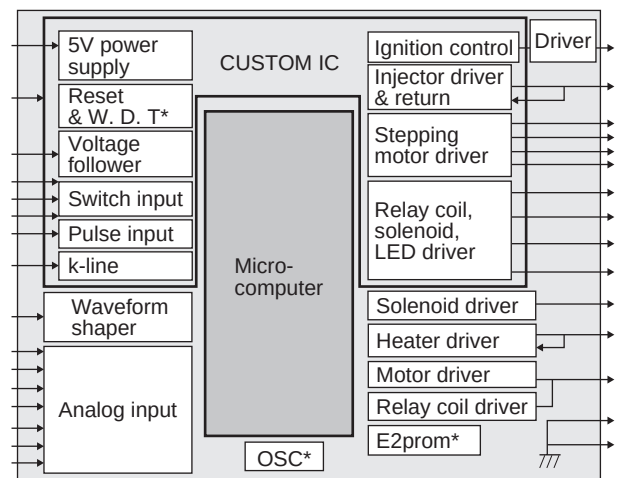


Fig. 13 ECU circuit

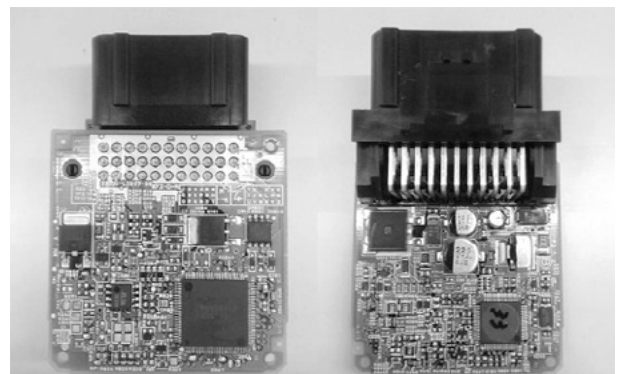


Fig. 14 ECU board for small motorcycle

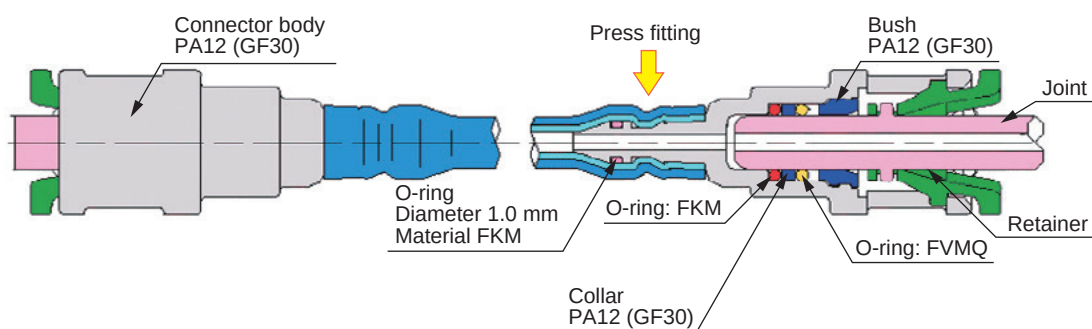


Fig. 15 Thin resin tube

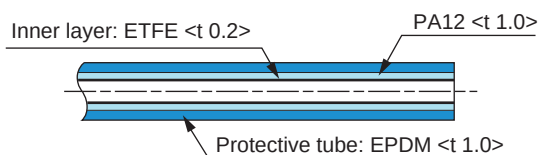


Fig. 16 Thin resin tube

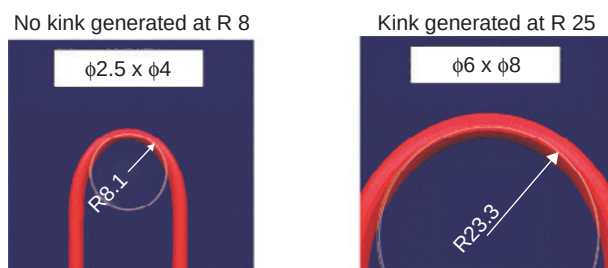


Fig. 17 Comparison of anti-kink

5. Conclusion

For this research, a small and highly efficient fuel injector, fuel pump, ECU and high pressure fuel hose were developed as the functional components of a small-sized motorcycle's fuel injection system. Using these components, a simple and inexpensive fuel injection system was built and used on the 2005 Wave 125i.

- (1) The fuel injector was among the world's smallest, but maintained as much performance as that of an ordinary fuel injector for automobiles.
- (2) By increasing overall efficiency by 25% over Honda's existing fuel pumps for small-sized motorcycles, the new fuel pump achieved a current consumption of less than 1A.
- (3) A custom IC was used for the ECU and the housing was standardized, making the ECU suitable for all small-sized motorcycles.
- (4) The development of a flexible new small-diameter resin hose made it possible to arrange tubing without molding it in the shape of the frame of the small-sized motorcycle.

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