

Development of Inverter Generator Equipped with Fuel Injection Engine

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ABSTRACT

The EU6500is generator, which has an established reputation for realizing the world's top level of compactness and quietness in the 5.5 kVA class, has been employed as the base model in the development of the EU7000is, further increasing the value of the unit as a home back-up generator.

The use of a fuel-injection system able to optimally control engine air-fuel ratio irrespective of external factors has increased fuel efficiency by 22% against the existing model.

The integration of the injector and the throttle body has made it possible to employ the developed generator fuel-injection system while maintaining compactness, and the mounting of the atmospheric pressure and intake air temperature sensors on the circuit board of the generator control unit and the removal or simplification of various other sensors have helped to enable the use of the fuel-injection system with minimal cost increase.

The use of the fuel-injection system has enabled continuous operation of the unit for up to 12 hours without refueling. Modification of the power supply circuit and reduction of the minimum operating voltage of the generator control unit allow starting of the unit using a battery-less recoil starter. The realization of increased inverter efficiency and the optimization of ignition timing have increased maximum output from 6,500 VA to 7,000 VA. This has made it possible to respond to the motor load represented by air conditioners and other pieces of equipment that draw large amounts of power at startup, expanding the range of applications of the unit as a generator.

1. Introduction

The price of gasoline is increasing worldwide simultaneously with the number of planned power outages as a result of power shortages in developing countries and increased outages due to hurricanes and other natural disasters. This situation is producing demand for greater fuel efficiency and extended continuous operation in portable generators.

In addition to its fuel efficiency, Honda's current EU6500is portable generator has been well received due to its compact body, quietness, and reliable generating performance, is employed in a wide variety of applications and relied on as a power source for film shoots and for construction work using precision equipment in addition to functioning as a backup power source during outages⁽¹⁾.

However, taking into consideration responses to the environmental issues that are currently increasing in severity around the world, there are limits to the ability to balance fuel efficiency and emissions reductions using

a carburetor system, which is affected by external factors such as temperature and altitude (air pressure).

In response to this situation, for its latest generator model change Honda developed its first fuel-injection (FI) system for a generator, seeking to realize an enhanced balance between high fuel efficiency and reduced emissions.

In contrast to carburetor systems, FI systems necessitate the use of fuel pumps and a large number of sensors, thereby increasing cost. In addition, considering the use of the generator during a power outage caused by a natural disaster, it is necessary to be able to start these devices when the battery is exhausted. It was also necessary to consider the infiltration of dust into the fuel tank and long-term storability, given the characteristic use modes of generators.

This paper introduces the EU7000is, Honda's new model generator fitted with the unique FI system described above.

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2. Development Goals

The goal was the development of a generator that maintained the world's top level of compactness and quietness for a 5.5 kVA-class unit while realizing enhanced value as a backup power source (extended continuous operation, long-term storability). Figure 1 shows an external view of the EU7000is, and Table 1 shows a comparison of the specifications of the developed and existing models.

According to market surveys, the power generation demanded during an outage is between 2,000 and 3,000 VA (corresponding to 50% of the unit's rated load) in the case of a normal U.S. household. If 12 hours of continuous operation were possible at this load, the unit could be continuously operated throughout the night until morning without refueling, giving it considerable appeal as a home back-up generator.

Realizing this goal would require increasing the volume of the fuel tank as much as possible while maintaining the compactness of the existing model, as well as increasing fuel efficiency by 20%.

The following development goals were set:

1. Goals for generator FI system
 - (1) 20% increase in fuel efficiency
 - (2) Reduction in number of sensors and optimization of devices
 - (3) Start-up using battery-less recoil starter
 - (4) Protection of exhaust gas catalyst when unit stops due to low gasoline levels
2. Targets as backup generator
 - (1) 12-hour continuous operation without refueling
 - (2) Increased maximum AC output
 - (3) Long-term storability and increased maintainability
 - (4) Greater ease of start-up



Fig. 1 Appearance of EU7000is

Table 1 Comparison of specifications

	EU7000is (New model)	EU6500is (Current model)
Engine displacement (cm ³)	389	389
Fuel system	Fuel Injection	Carburetor
Max. AC output (VA)	7000	6500
Rated AC output (VA)	5500	5500
Fuel tank capacity (L)	19.2	16.0
Rated operating noise level (L _{WA} : dB)	91	91
Dimensions (L × W × H: mm)	848 × 700 × 721	850 × 666 × 699
Dry mass (kg)	118.6	118.2

3. Methods of Realization of Targets and Achieved Values

3.1. Generator FI System

3.1.1. 20% increase in fuel efficiency

While realizing a lean air-fuel ratio (A/F) by reducing the ratio of fuel increases an engine's fuel efficiency, if the ratio of fuel is reduced when a carburetor system is used, the fuel ratio is further reduced at low temperatures, when the density of the intake air is high, and combustion becomes unstable.

An FI system able to optimally control A/F irrespective of external conditions such as temperature and altitude (air pressure) through the use of a variety of sensors was therefore employed in the new model generator. In combination with the use of an exhaust gas catalyst, this has realized a good balance between increased fuel efficiency and reduced exhaust emissions.

Figure 2 shows a comparison of fuel consumption between the developed and the current models. Fuel efficiency is 22% higher in the developed model (at 50% of rated load).

3.1.2. Reduction in number of sensors and optimization of devices

The number of sensors employed in the FI system was reduced and sensors were simplified in order to maintain the compactness of the existing model while minimizing

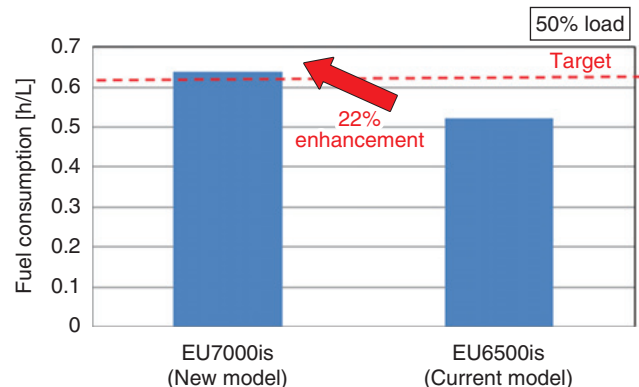


Fig. 2 Fuel consumption

cost increases. Figures 3 and 4⁽²⁾ show diagrams of the configuration of the FI system.

(1) Injector and throttle body

The integration of the injector and the throttle motor with the throttle body enabled fitting of an injector and throttle motor without changing the compact layout of the existing model (Fig. 5).

(2) Generator Control Unit (GCU)

FI control functions were added to the existing GCU employed to control the generator, enabling FI control without the addition of a new FI control unit.

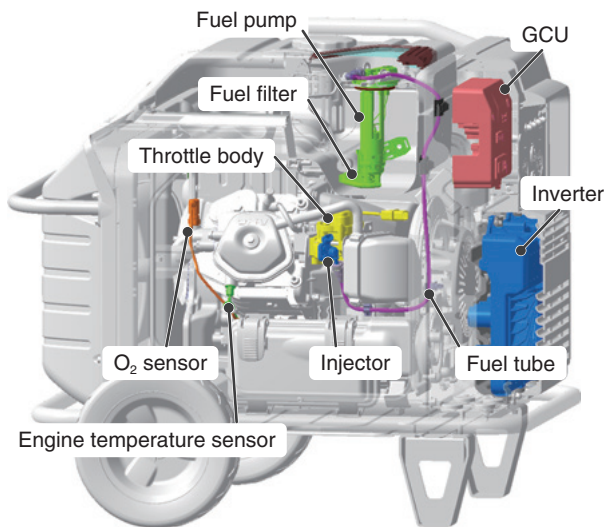


Fig. 3 Fuel injection system

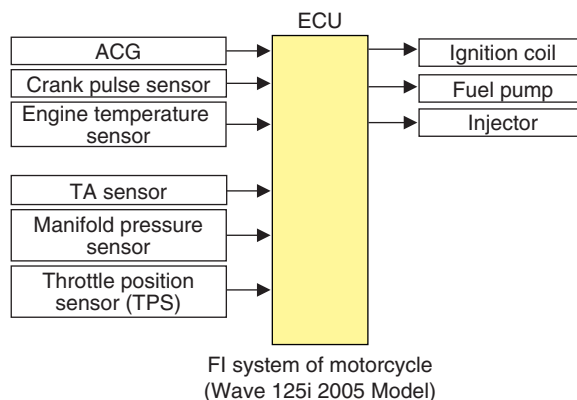
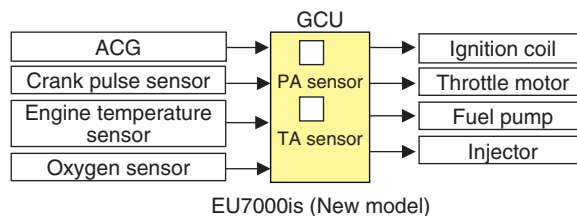


Fig. 4 Schematic diagram of fuel injection system

In response to the increases in power consumption and number of parts from the use of an FI system, a two-level circuit board was employed in the unit, enabling fitting of the FI system with no increase in size compared to the existing model.

(3) Atmospheric pressure sensor and intake air temperature sensor

Direct mounting of the atmospheric pressure sensor (PA sensor) and intake air temperature sensor (TA sensor) on the circuit board of the GCU lowered the cost of the sensors and reduced the need for harnesses (Fig. 6).

The readings of the TA sensor can deviate from the actual engine intake air temperature due to factors such as the heat produced by other components. To avoid the sensor being affected by heat, the layout divided the circuit components into high-temperature and low-temperature sections, and the sensors were positioned in the low-temperature section (Fig. 7).

An air vent was also positioned in the upper section of the control panel, helping to ensure a correlation with the actual intake air temperature through the introduction of external air to the area around the sensors.

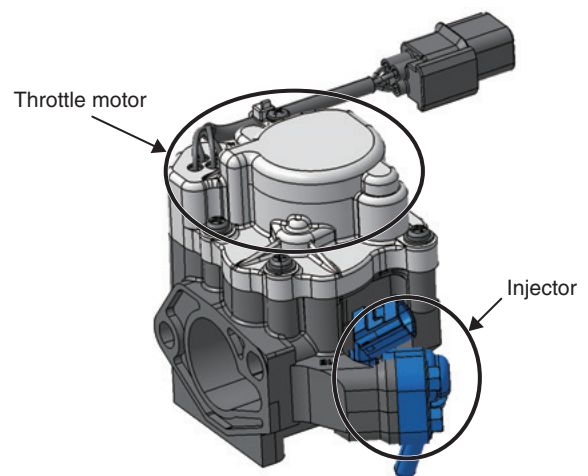


Fig. 5 Throttle body

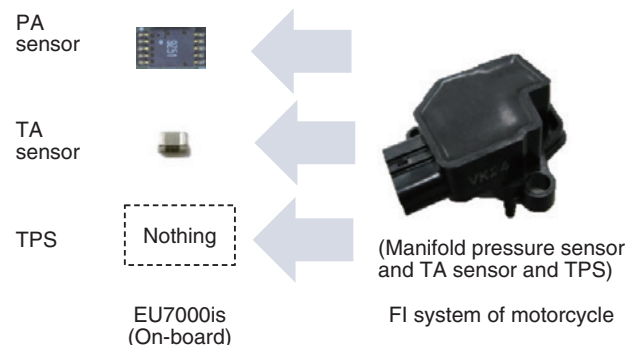


Fig. 6 PA sensor and TA sensor and throttle position sensor

(4) Throttle opening sensor

Because the GCU controls the degree of throttle opening using a stepping motor, in the developed system the output pulse to the motor is counted, helping to ensure the GCU is constantly aware of throttle opening. Recognition of the degree of throttle opening by the GCU has eliminated the need for a throttle-opening sensor while applying throttle-speed control.

(5) Reluctor for detection of engine speed

Control of conventional FI systems is realized by mounting a reluctor able to detect a number of reference positions (e.g. 13 pulses) for each single rotation on the flywheel (F/W) or another part in order to detect engine speed and crank angle.

In the developed generator, the engine speed and crank angle are detected by combining the reference signal for ignition (one pulse per one rotation) as used in the existing model and the alternator output signal (10 pulses per one rotation).

As a result, it is possible to detect the engine speed and crank angle using the F/W of the existing model without the addition of a new reluctor. Figure 8 shows a comparison of the reluctors employed in the developed model and in a conventional FI system.

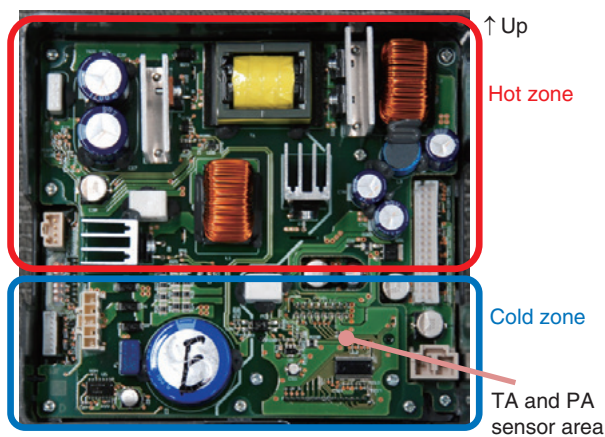


Fig. 7 GCU circuit board

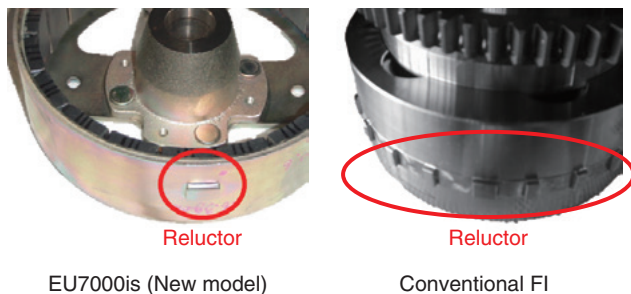


Fig. 8 Reluctor

3.1.3. Start-up using battery-less recoil starter

While the developed generator is normally started using a starter motor, it was also necessary for it to be started when the battery was exhausted. The system configuration enables manual starting using a recoil starter even if the battery is removed.

An FI system uses more power than a carburetor system due to the necessity of driving the fuel pump and injector at start-up. Employing the existing power supply system would result in a shortage of power when the unit was started using a battery-less recoil starter. The power supply circuit was therefore modified to realize the same level of startability using a recoil starter as in the existing model.

The rotational speed for ignition start in the developed model is 200 rpm. Since at lesser speeds it is necessary to start the system up, the minimum operating voltage for the GCU was reduced. Figure 9 shows the power increase characteristic of the unit when started using the battery-less recoil starter. Using power from the alternator coils (ACG), sufficient power can be supplied from 100 rpm.

3.1.4. Protection of exhaust gas catalyst when unit stops due to low gasoline levels

There are occasions on which a generator will be used until the gasoline in the fuel tank runs out. When the gasoline runs low, fuel is intermittently supplied to the injector and a governor automatically controls the throttle to maintain constant speed. This results in significant fluctuations in A/F and engine speed. When this happens, uncombusted gas flows to the exhaust gas catalyst, resulting in unusually high temperatures, as well as in possible declines in catalyst performance.

A method of detecting that the system is running low on gasoline was therefore developed using the existing engine speed control function, enabling response without the addition of a fuel level sensor or other components. This control judges that gasoline is running out when engine speed remains at the minimum level without rising despite the throttle being close to wide open, and rapidly stops the

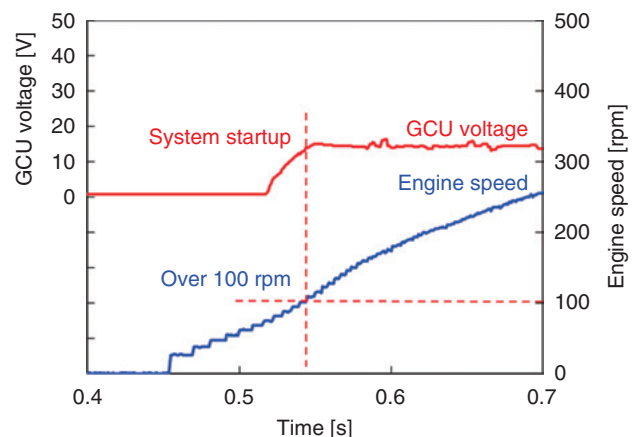


Fig. 9 Power supply at startup

engine, helping to protect the exhaust gas catalyst without increasing cost.

3.2. Backup Generator

3.2.1. Continuous 12-hour operation without refueling

Increasing the volume of the fuel tank by 20% and employing the FI system technology discussed above has increased the period for continuous operation from full tank to low gasoline levels at 50% of rated load by 1.5 times against the existing model, enabling 12 hours of continuous operation without refueling. Figure 10 compares the existing and developed models.

3.2.2. Increased maximum output

The use of the generator FI system in the developed unit eliminated the venturi, an important element in a carburetor system, increasing the engine's maximum output by 3% against the existing model. In addition, the realization of increased inverter efficiency and the optimization of ignition timing increased maximum output from 6,500 VA in the existing model to 7,000 VA in the developed unit. Figure 11 shows the power characteristics of both models at startup.

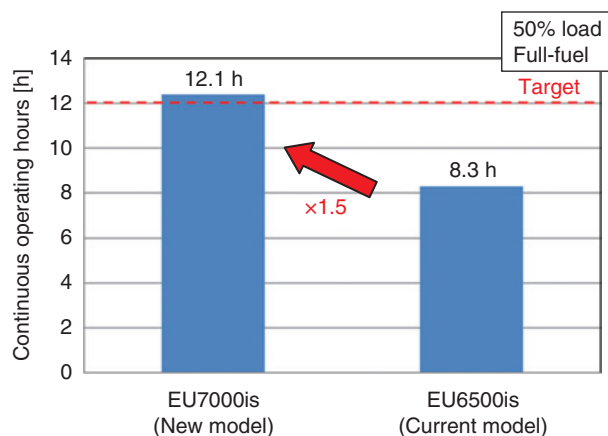


Fig. 10 Continuous operating hours

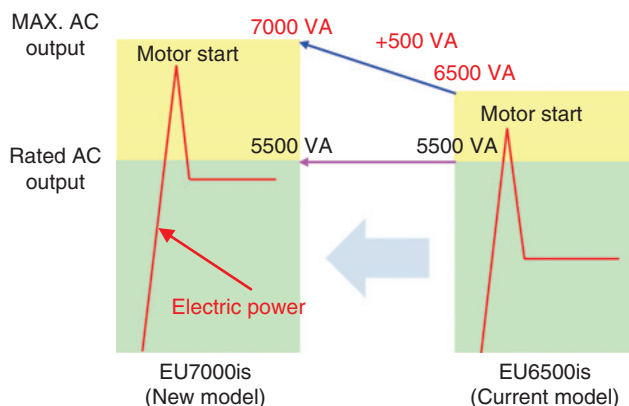


Fig. 11 Maximum power

These enhancements compensate for the motor load represented by air conditioners and other equipment that require large amounts of power at startup, expanding the range of applications of the unit as a generator.

In order to increase power, the magnetic force of the magnets in the alternator coils was increased by modifying the material, and the efficiency of the inverter was increased by redesigning the power module.

Because increased maximum power also increased the maximum amount of heat produced by the inverter, simulations were employed to optimize the shape of the cooling fins and enhance cooling performance.

Figure 12 shows the temperature distribution indicated by the inverter heat simulations. The use of a radiating fin shape disperses the flow of wind, enhancing cooling performance.

3.2.3. Long-term storability and increased maintainability

Backup generators are often stored for extended periods. Due to the configuration of the system, when the generator uses a carburetor system, gasoline comes into contact with the external air, necessitating removal of the fuel from the carburetor float chamber when storing the unit over a long period. With an FI system, however, gasoline makes little contact with the external air and thus tends not to become degraded, eliminating the need to remove the fuel from the FI system (the injector, fuel hose, and other parts) and easing maintenance prior to storage.

In addition, because generators cannot be directly supplied with fuel from a gasoline pump, they are often refueled using stored gasoline from portable gas cans, with a significant amount of dust entering the fuel tank. In response, the fuel pump in the developed unit is positioned at the top of the fuel tank (Fig. 3), and can be removed and reattached, increasing the ease of fuel filter maintenance.

3.2.4. Easier start-up

The use of an FI system eliminated the need for a fuel cock and choke, as used in carburetor systems, simplifying startup.

A push-start system has been employed to further emphasize this benefit. While the existing model is cranked by turning an ignition key, startup has been completely

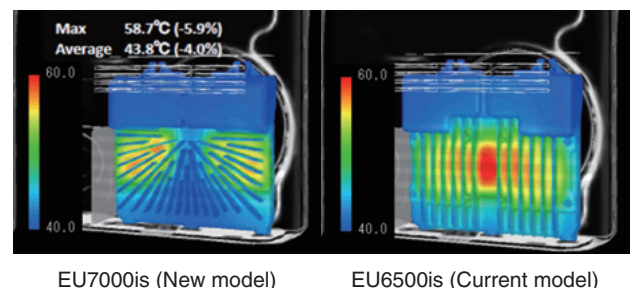
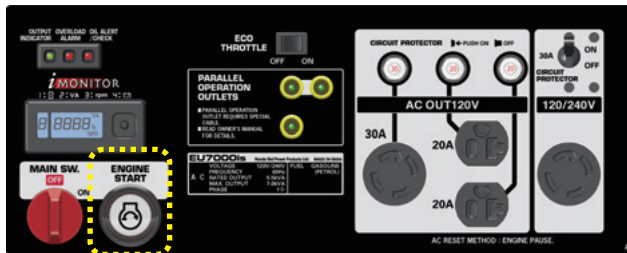


Fig. 12 Simulation result

refurbished in the developed model by the use of push-button cranking (Fig. 13).

Briefly pressing the push-start button automatically operates the starter motor for a maximum of five seconds, with the starter motor ceasing operation when the engine starts. This startup method increases convenience for users in comparison to the existing model, and offers more advanced operability.



Push start button

Fig. 13 Control panel

4. Conclusion

A generator employing an FI system has been developed that realizes increased appeal as a home back-up generator while maintaining the compactness of the previous model.

(1) Development of generator FI system

- The development of a generator FI system increased fuel efficiency by 22%.
- The integration of the injector and the throttle body allowed incorporation of an FI system while maintaining the compactness of the existing model. In addition, the mounting of the PA and TA sensors on the circuit board of the GCU and the removal of the throttle-opening sensor realized the system with minimal cost increase.
- The optimization of the power supply circuit and the reduction of the minimum operating voltage of the GCU allow the unit to be started using a battery-less recoil starter.
- The application of control when the unit is running out of gasoline helps to protect the exhaust gas catalyst.

(2) Development of backup generator functions

- The application of the generator FI system has realized continuous operation for 12 hours without refueling.
- The realization of increased inverter efficiency and the optimization of engine specifications have increased maximum output from 6,500 VA to 7,000 VA.
- The use of an FI system has increased long-term storability, and the ability to remove and reattach the fuel pump from the top of the fuel tank has increased the ease of fuel filter maintenance.
- The use of a push-start method has increased the ease of start-up.

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