

Development of Electronically Controlled Multi-purpose Engine *iGX440*

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ABSTRACT

Honda's *iGX440* general purpose engine utilizes electronic control technology to increase ease of use with high fuel economy and low noise performance.

The engine control system employs an electronic control unit (ECU) enabling more precise engine speed control in response to the numerous different operational requirements of a general purpose engine. This has resulted in an engine displaying power characteristics and operational performance meeting the requirements of users in a variety of different applications.

To increase the environmental friendliness of the engine, exhaust emissions have been reduced below regulation levels and fuel economy has been increased. In addition, the noise level of the engine has been reduced to meet Stage 2 requirements of the EU Directive on Noise Emission by Outdoor Equipment. This has been achieved mainly by reducing the noise generated by the mechanical system.

A precoated steel sheet fuel tank, a cold-forged camshaft, and a thermoplastic resin molded ECU have also been employed in the new engine.

1. Introduction

A vertical cylinder and side valve configuration had previously been used for general purpose engines but the GX general purpose engine series developed in the 1980's adopted an inclined cylinder and OHV configuration, providing both a compact structure and high power output in addition to being highly reliable and durable. Therefore, after sales had begun, the GX engines became the standard within the industry particularly for commercial and industrial applications. However, in recent years, various companies have developed inclined cylinder compact configuration engine line ups that can be installed interchangeably with GX series engines and that have equivalent levels of engine performance. From this background, the *iGX440* has been developed, equipped with electronic control, with the concept of "evolution and increased intelligence," in addition to a further evolution in low fuel

consumption and low noise performance. This engine provides ease of use in which work that previously required users to depend on experience and intuition can now be performed "reliably," "quickly," and "simply." This paper introduces the development of the *iGX440*, the first of the "*iGX*" engine series.

2. Development Goals

Performance and functional requirements of general purpose engines include power output sufficient for the work load, ease of starting and use while working, inexpensive use, and low noise performance. In consideration of the above performance requirements, the development goals of the *iGX* engine were set as "enhancement of ease of use" and "reduction of fuel consumption and noise."

Figure 1 shows an external view of the *iGX440*.

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Fig. 1 External view of iGX440

2.1. Enhancement of Ease of Use

To develop a general purpose engine that is easy for users to use, the following concrete targets were established.

- (1) Ensure stable governor characteristics provided in conjunction with mounting on any type of working equipment.
- (2) Achieve operating conditions under which users can operate easily, by automatically changing the engine speed corresponding to working conditions when mounted on work equipment.

2.2. Reduction of Fuel Consumption and Noise

To develop a general purpose engine that is environmentally friendly from the perspective of exhaust and noise, the following items were defined as concrete goals.

- (1) While meeting EPA Phase 2 exhaust requirements, achieve an increase in fuel economy for EPA mode operation.
- (2) Achieve EU noise directive stage 2 standard compliance for power generation equipment levels [LwA97 dB (operating condition: 3 000 min⁻¹, at 3/4 rated power), which is to be implemented January, 2006.

3. Main Specifications

Table 1 shows the main specifications of the iGX440. The engine has a displacement of 438 cm³, uses an OHC driven by an in oil timing belt, and has two valves. In consideration of engine interchangeability in relation to working equipment, the positioning of auxiliary devices such as the air cleaner and fuel tank are the same as those on the GX engine series. In addition, to provide easier use, an adaptive control type electronic governor system⁽¹⁾ is employed as the governor mechanism and the ECU and throttle control mechanism are placed on top of the carburetor. Figure 2 shows a primary sectional drawing.

4. Electronic Control Technology

A centrifugal governor for engine speed control has been used for the previous GX series; however, the iGX engine uses an adaptive control electronic governor that has enabled robust governor characteristics relative to various dynamic characteristics.

Table 1 Engine specifications

Item	iGX440	GX390
Engine type	4-stroke, single-cylinder	4-stroke, single-cylinder
Displacement (cm ³)	438	389
Bore × Stroke (mm)	88.0 × 72.1	88.0 × 64.0
Compression ratio	8.1	8.0
Valve train	OHC 2-valve	OHV 2-valve
Valve inclination angle (deg)	22	0
Lubrication system	Splash	Splash
Ignition system	CDI	Transistorized magneto
Governor system	Electronic	Mechanical
Choke	Automatic/Manual	Manual
Fuel valve	Automatic/Manual	Manual
Starting system	Electric/Recoil	Electric/Recoil
Dimensions: L × W × H (mm)	407 × 505 × 454	380 × 450 × 443

In addition, the ability to change the target engine speed of this electronic governor based on work equipment requirements has enabled enhanced ease of use.

4.1. Enhancement of Ease of Use from Installation of Electronic Governor

Centrifugal governors have a mechanical characteristic of the engine speed being reduced relative to the target engine speed proportional to load increases. By employing an electronic governor, it is possible to achieve operation at a prescribed speed relative to the target engine speed, irrespective of an increase or reduction in load. Output characteristics of a centrifugal governor and of an electronic governor are shown in Fig. 3.

In addition, the ability to change the target engine speed of the electronic governor based on the requirements of work equipment has enabled the realization of various operating modes such as those shown in Fig. 4.

4.1.1. Auto throttle mode

Status confirmation of load on/off by the engine ECU based on the correlation of throttle opening and engine speed of this system

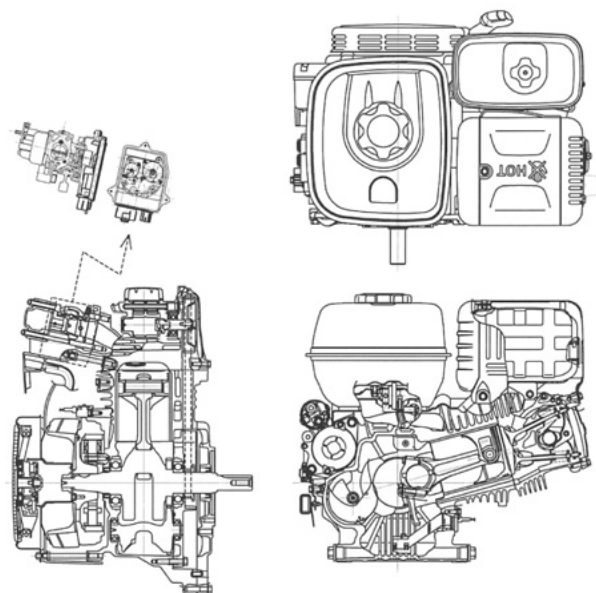


Fig. 2 Engine configuration

enables automatic throttle operation corresponding to the given load on working equipment. For example, when mounted on work equipment where the load is repeatedly turned on and off such as with welders and high pressure washers, by using auto throttle mode, automatic idling can be enabled when the load is turned off, without requiring the addition of a load sensor on the completed equipment.

4.1.2. Communication mode

If this engine is installed on work equipment that uses an electronic control system such as an ECU, it is possible to control engine speed using instructions from the work equipment ECU by making a mutual connection. In this case, as load information is not only received from the engine throttle opening, but also from the work equipment, highly precise load detection becomes feasible, which enables fine tuned engine speed control.

For example, for cases of completed equipment where power requirements for the working portion is provided by the engine and the self-propelled drive system is installed separately, the ECU of the work equipment can receive both load information concerning the working portion from the engine in addition to load information from the drive system, and control engine speed.

In addition, linking control of the working equipment drive section, such as the drive speed using this type of load information, enables construction of a system that provides ease of use for the whole working equipment corresponding to user requirements. The system may include a "working time management operation mode," a "fuel economy prioritizing mode," or an "operation mode prioritizing torque characteristics during transition."

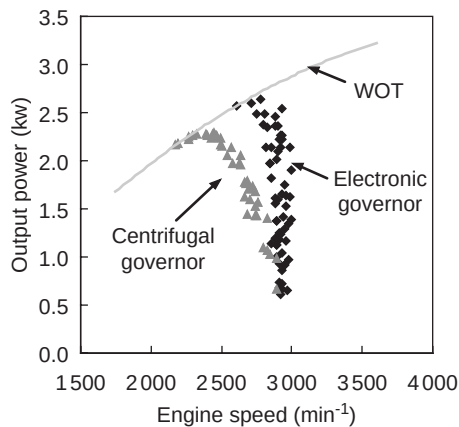


Fig. 3 Governor performance

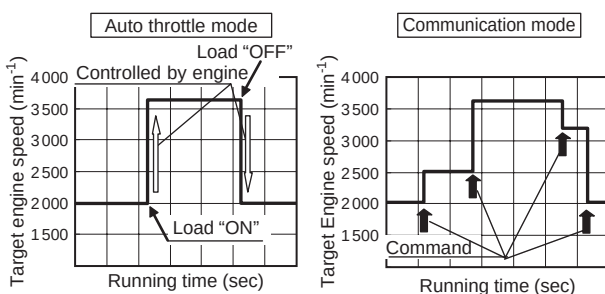


Fig. 4 Operation mode

4.2. Drive System for ECU without a Battery

Many types of work equipment equipped with general purpose engines do not have a battery and even if a battery is used, there are cases whereby the equipment is stored for long periods and the battery loses its charge. In order for the engine to start and for operation to be possible in these cases, a drive system where the ECU does not require a battery is employed.

To make the ECU work without requiring a battery, a power coil that supplies power to the ECU from the rotation of a flywheel with a multi-pole magnet has been established.

When the engine is started and engine speed exceeds 1 000 min⁻¹, power is supplied by the power coil to the ECU which controls the throttle so that the target engine speed is reached. In addition, when stopping, the engine switch is turned off and at the same time, the throttle valve is moved to a wide open position using the power derived until the engine rotation is stopped, preparing for the next time the engine is started. A drive system for an ECU without a battery is shown in Fig. 5.

4.3. Configuration of the ECU and Throttle Drive

As a general purpose engine, it is necessary to place the ECU and wire harness without increasing overall dimensions. Therefore, the throttle drive motor and gears were meshed together, in 3 layers forming a compact configuration and placed on top of the carburetor. In addition, of the elements built on the ECU circuit board, large elements such as capacitors were placed on one side, and the motor was placed in the space opened inside the motor case. This layout has enabled an overall height reduction of 16 mm compared to a box style ECU with uniform thickness. Also, the wire harness from the ECU mounted below the air cleaner to the control panel was placed in front of the fan cover, enabling a configuration where the communication connector discussed later can easily be connected. In addition, by using an airtight construction for the motor case, water resistance and dust resistance of the internal components such as the motor is ensured.

Figure 6 shows a sectional drawing of the ECU.

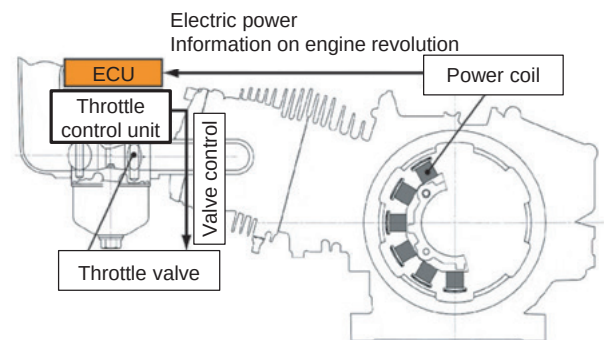


Fig. 5 Engine control system

4.4. ECU Communication System

Engine operation mode and engine speed settings based on the working equipment on which the engine is installed can be written into the ECU and engine operating conditions and operational history can be read from the ECU. Specifically, one configuration allows easy access to the communication connector by removing the electronics panel, and by linking with an exclusive communication unit, writing to and reading from the ECU are enabled. The wiring harness that connects the communication connector and the ECU is shown in Fig. 7.

Assembling a basic mode ECU on the assembly line and having mode parameters written to the ECU at the end of the assembly line eliminated the need for control derived from assembly of ECU.

In addition, when performing inspection of the completed equipment at the plant for shipment, inspection of the completed equipment in operation mode as previously established is enabled by automatic operation communicated from the inspection equipment. At the same time, historical control of operating conditions is conducted enabling enhanced quality control.

In the case of failure diagnosis, utilizing this control information enables prompter issue resolution.

In addition, when dealing with customers who request several types of ECU characteristics, the need to stock multiple engine types or exchange ECU's is eliminated by ability to rewrite ECU.

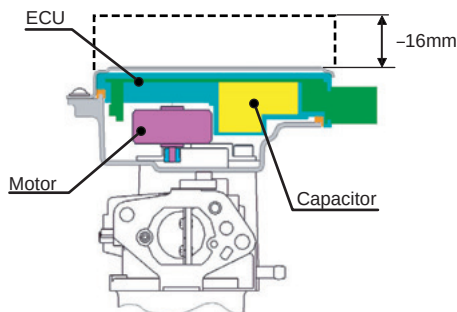


Fig. 6 Throttle motor and ECU

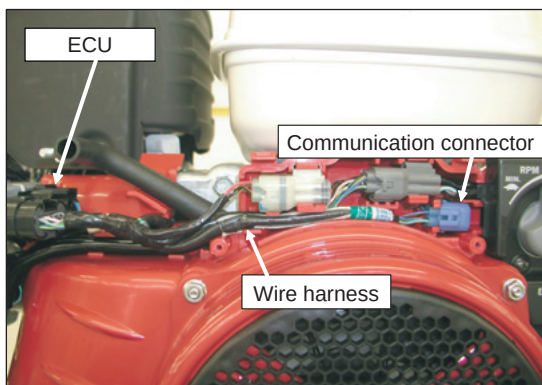


Fig. 7 ECU, wire harness and communication connector

5. Engine Output, Fuel Economy, and Emissions Enhancement Technology

5.1. Engine Output

Figure 8 shows the power output performance of the engine.

Figure 9 shows a comparison of intake valve diameters for this engine and for conventional engines. Based on the current model, by changing the intake valve diameter from 40 mm to 31 mm, the flow speed of the intake gas has been increased. At the same time, the amount of offset of spark plug placement with respect to the bore center was reduced to 9 mm, compared to 23 mm for the GX390, enabling a shortening of the flame propagation distance inside the combustion chamber. These modifications have enhanced knock avoidance performance.

Valve port shapes and valve timing were reviewed to prevent any reduction in fill efficiency caused by the smaller intake valve diameter. As the cross sectional shape of the intake port gets closer to a trapezoid, the cross section area is increased by 10% compared to a circular cross sectional surface. The valve timing overlap period of intake and exhaust valve lift has been shortened, compared to that of the GX390, and the amount of combustion products remaining in the cylinder after the exhaust stroke reduced.

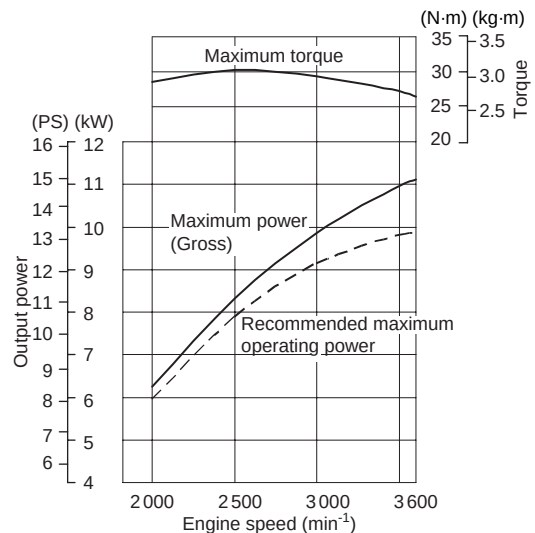


Fig. 8 Engine performance

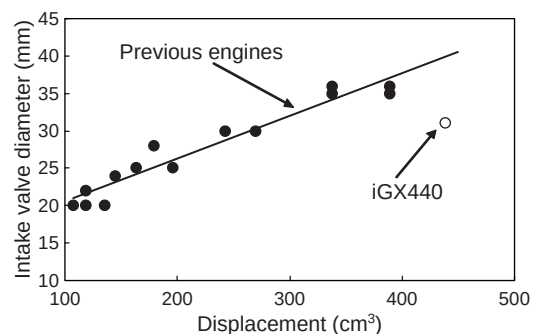


Fig. 9 iGX440 intake valve diameter

5.2. Fuel Economy Enhancement Technology

Figure 10 shows the level of fuel economy and exhaust gas emissions achieved by this engine. By employing the technology shown below, a 15% increase in fuel economy for EPA mode operation has been achieved, without increasing emissions which meet EPA Phase 2 exhaust requirements.

5.2.1 Shape of combustion chamber

The GX390 has a wedge type combustion chamber with a stroke bore ratio of 0.73. In contrast, the iGX440 is equipped with a compact combustion chamber of which its shape is closer to being spherical with stroke bore ratio of 0.82 and a valve angle of 22 degrees. Because of this, the combustion chamber surface/volume ratio (S/V ratio) was enhanced by 6%.

5.2.2. Offset cylinder and piston specifications

In order to reduce piston side pressure friction, an offset cylinder configuration was employed. As shown in Fig. 11, with respect to the crank shaft, the centerline of the cylinder is offset in the direction opposite the direction of piston thrust.

In conjunction with the offset cylinder configuration, piston side pressure on the thrust side is reduced; however, piston side pressure on the anti-thrust side is increased; therefore, while evaluating friction, piston noise and conditions of the piston skirt hitting the side, the amount of offset was set to 7 mm.

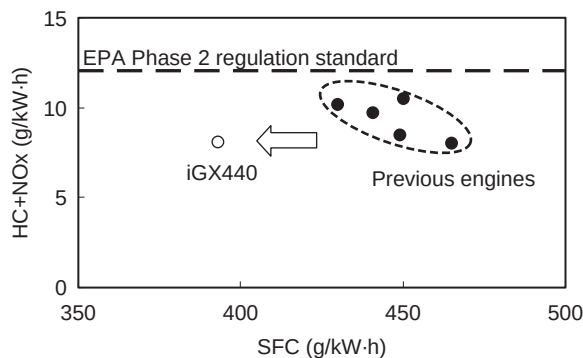


Fig. 10 Results for fuel economy and mass emissions in EPA Phase 2 emission mode

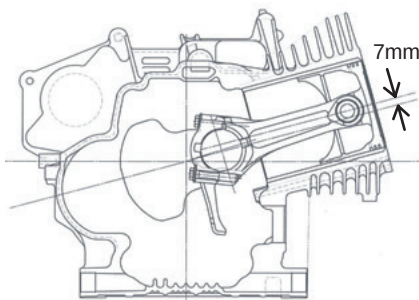


Fig. 11 Offset cylinder

In order to increase the following performance of piston rings with the cylinder, the ring width dimension was reduced and to further reduce friction, the tensile strength of the piston rings was reduced. Compared to the GX390, the top ring and second ring were changed from a width of 2 mm to 1.5 mm and the oil ring was changed from a width of 2.8 mm to 2.5 mm. The total tensile strength of the piston ring was reduced 45% compared to that of the GX390. To address the reduction in heat dissipation from piston rings to the cylinder associated with the piston rings being smaller, the dipper, which is integrated with the connecting rod and flips up oil to cool the piston, was enlarged and the amount of oil flipped onto the back side of the piston increased. With respect to the reduced tension strength of the piston rings, the temperature distribution around the perimeter of the cylinder was made more uniform and the amount of blow-by gas and oil consumption equivalent to that of the GX390 achieved.

5.2.3. Ignition timing control

Ignition timing for this engine is changed based on engine speed and throttle opening. Ignition timing is determined by the ECU using engine speed and throttle opening information, and ignition using CDI is performed.

Figure 12 shows the ignition timing map. These settings help avoid knock and reduce emissions at high loads, reduce fuel consumption at medium loads and reduce piston noise at low loads.

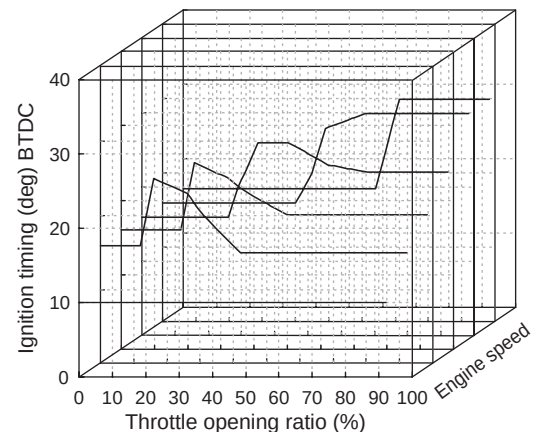


Fig. 12 Ignition timing map

6. Noise and Vibration Performance

6.1. Noise Reduction Technology

In order to maintain cooling performance, fan noise of this engine increased compared to that of the GX390; however, through efforts to reduce mechanical system noise, noise emitted from tank and exhaust noise, a noise level of 96 dB, which is lower than the target LwA value of 97 dB, was achieved. Figure 13 shows analysis results for noise contribution ratios of the iGX440 and GX390.

By using a bearing holder as shown in Fig. 14, the crank shaft receiver distance was reduced by 15 mm with respect to the GX390 and shaft diameter was increased for each part of the crank shaft. As a result, crank pin rigidity relative to in-cylinder combustion pressure was increased by 10%, with respect to the GX390, and crank system noise was reduced. Also, as discussed in section 5.2.2,

by reviewing the piston side pressure reduction effect of utilizing an offset cylinder and of the amount of piston pin offset as well as changing the ignition timing, piston slap noise has been reduced. In addition, the use of in-oil timing belt drive OHC construction has reduced cam gear noise. As a result, the noise energy value of the mechanical system was reduced by 47.5%.

With respect to exhaust noise, the muffler layout is shown in Fig. 15 and placement of a rib on the plating reduced noise emissions. The inside of the muffler is formed by 3 chambers and the employment of a diffuser pipe, from the 3rd chamber to the opening of the exhaust, increased sound transmission loss performance. In addition, a baffle plate was placed at the exhaust opening to reduce flow noise. As a result, the noise energy value of the exhaust system was reduced by 43.8%.

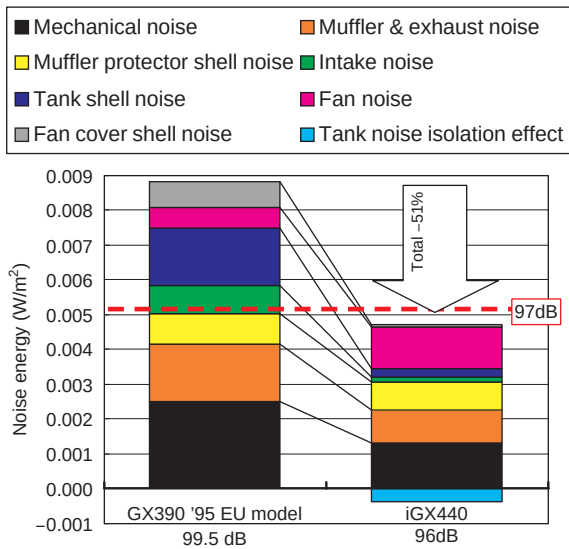


Fig. 13 Effective noise level

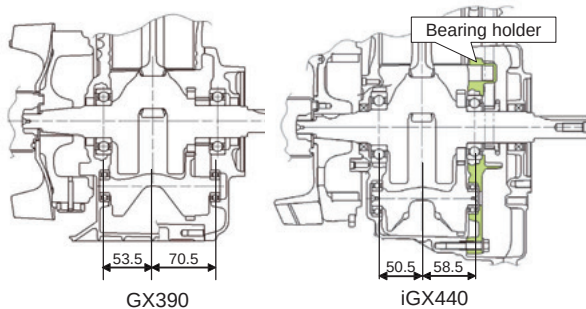


Fig. 14 Crankshaft and bearing layout

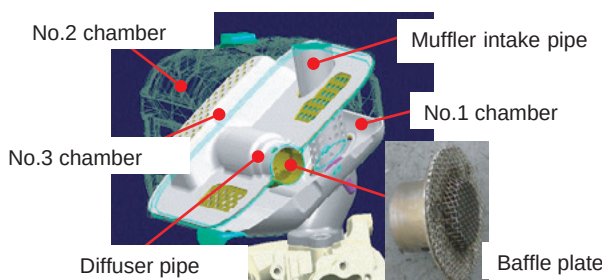


Fig. 15 Muffler structure

By using a rubber mount support construction for the fuel tank, solid borne sound from the engine is shielded resulting in a reduction of noise emissions, reducing the noise energy of the tank by 84.2%. And for cases where the tank is used, the construction exhibits a noise isolation effect for fan and mechanical noise and has enabled a reduction in the overall noise energy by 7%. Through these efforts, with respect to the GX390, overall engine noise energy was reduced by 51%.

6.2. Vibration Reduction Technology

Similar to the GX390, the iGX440 uses a single axis single order rotation balancer. The balance efficiency of the crankshaft counterweight and the rotation balancer was revised so that the 1st and 2nd order vibration of the mounting joint of the base of the engine are minimal. In addition, a nearly uniform distribution of the left to right ratio of the crankshaft counterweight suppressed the couple of force applied on the engine. As a result, as shown in Fig. 16, the vibration acceleration of the engine mount joint was reduced compared to that of the GX390. Figure 16 shows measurement results using rubber mounts for the engine with an engine speed of 3 600 min⁻¹ and at no load.

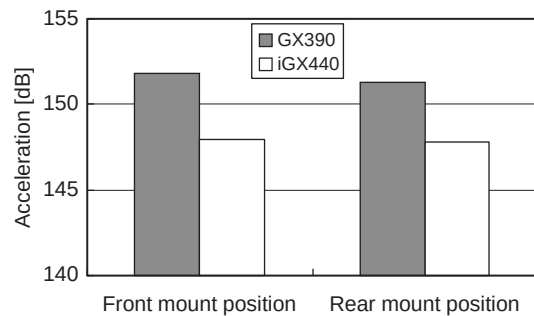


Fig. 16 Vibration performance

7. New Manufacturing Technology

7.1. Pre-Coated Steel Sheet Fuel Tank

With the goal of removing the coating process, pre-coated steel sheets were used for the fuel tank material.

Pre-coated steel sheet is used in general for residential electrical products. To use the material for the fuel tank, additional performance enhancements were required in terms of gasoline contaminants, the appearance after deep draw, the weldability, and rust that develops on the ends of the plate.

Therefore, joint development was performed with a steel plate manufacturer; for gasoline resistance, the hardness of the coating was adjusted to make it difficult for the pigment to permeate the coat layer; for the appearance after deep draw, an appropriate color tone was distributed in two layers of coating to prevent gloss from deteriorating. Also, verification was performed using a press simulation so that plate stretching would be held within 15%. A gloss meter was used to measure gloss at an incident angle of 60° and a gloss greater than 80 was obtained. Clinching was used in place of spot welding. Tank seaming was changed as shown in Fig. 17 and a construction where the end of the plate is not exposed is used to make rust less prevalent.

Figure 18 shows the external view of the fuel tank.

7.2. Cold Forged Camshaft

In order to simplify the manufacturing process using near net forging of the camshaft material, a cold forged camshaft was used.

The point that makes this camshaft feasible is that there is no space in the linkage between the intake and exhaust cam pieces. Therefore, it can be formed from round material and as shown in Fig. 19, separated by the parting line, the punch side produces the intake cam and the die side produces the exhaust cam. This makes it possible to make cam pieces with separate profiles on one object. As the cam profile shape is forged using a multistage parts former, the grinding process was eliminated.

7.3. Thermoplastic Resin Molded ECU

With the goal of enhancing manufacturability through a reduction of the manufacturing cycle time, and reduced size and weight, an ECU with a circuit board protected by a thermoplastic resin molding was used⁽²⁾.

A conventional method for protecting circuit boards includes the casting method of flowing a thermosetting resin into the case for the circuit board. In thermosetting resin casting, injecting resin and the hardening processes take a lot of time. Another characteristic of the casting method is that the depths of cases are made uniform so that they are deep enough for large components such as capacitors, causing a lot of space and materials to be wasted. By selecting a resin that can be molded at lower than normal molding resin temperature and pressure for thermoplastic resin molding, it is possible to perform molding without damaging the electronic circuit board and the following advantages have been obtained.

Forming the mold to the shape of the components enabled the height of the case to be reduced by 20% and weight by 50%, compared to the use of casting. In addition, compared to the 1 to 12 hours that are conventionally required depending on shape, resin hardening requires roughly 10 seconds, enabling efficient production. Figure 20 shows a comparison of the manufacturing processes, and Fig. 21 shows an external view of the ECU.

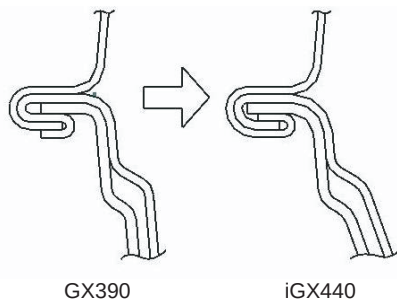


Fig. 17 Cross-section view of fuel tank



Fig. 18 View of fuel tank

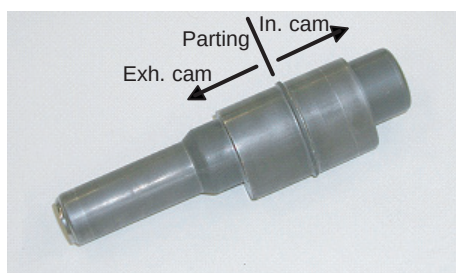


Fig. 19 View of camshaft

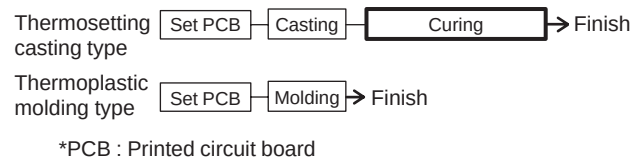


Fig. 20 Comparison of process between casting and molding



Fig. 21 View of ECU

8. Conclusion

A general purpose engine iGX440 was developed using electronic control technology, pursuing further functionality in terms of the ease of use, low fuel consumption, and low noise.

- (1) In order to secure stable rotation for any type of work equipment, an adaptive control type electronic governor was adopted. The operation mode was made changeable according to requirements of the working equipment, and a system that provides ease of use was created.
- (2) An ECU system that does not require a battery was employed.
- (3) The ECU and throttle drive parts were placed in a compact manner, enabling installation without increasing the overall dimensions compared to that of the conventional engine series.
- (4) By connecting an exclusive communication unit, a system where engine output characteristics, operating conditions and

other information can easily be written to and read from the ECU was achieved.

- (5) A 15% increase in fuel economy has been achieved for EPA operating mode without increasing emissions, meeting EPA phase 2 regulations.
- (6) A level of 96 db was achieved for base engine noise, making it possible to meet EU noise directive stage 2 standards. Also, by suppressing the couple of force created by the engine, vibration acceleration of engine mounting joints on the completed equipment has been reduced.
- (7) The following new manufacturing technologies have been implemented in mass production.
 - Pre-Coated steel sheet fuel tank
The coating process was eliminated.
 - Cold forged camshaft
Machining and grinding processes were eliminated.
 - Thermoplastic resin molded ECU
Compared to thermosetting resin casting, weight was reduced by 50% and the height of the case by 20%.
Manufacturing efficiency was increased by shortening the resin hardening process.

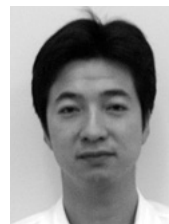
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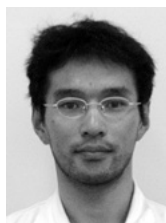
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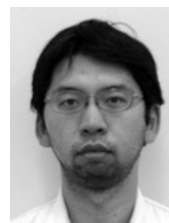
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