

Innovative Technologies for Compactification of Inverter Generator, “EU3000i Handi”

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ABSTRACT

In addition to their use as an emergency backup power source during power outages and as a power source for construction applications, portable engine generators are also used in leisure activities. In the latter category, their main application is a power source for the air conditioners used in camper vans and recreational vehicles, necessitating a quiet and highly portable 3 kVA-class generator. The EU3000i Handi was developed in response to this need.

The volume of the EU3000i Handi has been reduced by 36% and its weight by 42% from the professional-use EU3000is (3 kVA), realizing class-leading lightness and compactness.

The maximum speed of the engine used in the new generator has been increased and full transistor ignition timing control has been employed, helping to reduce engine displacement to 163 cm³ from the 196 cm³ engine used in the EU3000is. A plastic monocoque structure reinforced with magnesium alloy is used for the frame, further reducing overall weight in comparison with that of the steel frame. In addition, the use of a Hershel resonator has reduced air intake noise, and the modification of the housing configuration has increased the absorption and shielding of mechanical noise. This has resulted in the achievement of the noise level of L_{WA} 91 dB, when the unit is being operated at rated output, equivalent to that of the previous recreational use generator, the 2 kVA EU2000i.

1. Introduction

Portable generators are widely used to provide an emergency backup power source in case of power outages and natural disasters, or as a power source for electrical devices and tools on construction sites, and as an outdoor power source for leisure activities. The generators are also extensively used as a backup power source for work sites and in daily life in developing countries, where power outages frequently occur, as rapid economic development generates imbalances in power supply and demand. With increasing economic activity worldwide, the demand for power and the need for portable generators are increasing as well.

The production of light, compact, quiet, vibration-free, and fuel-efficient portable generators with good performance is necessary in order to respond to these various needs.

Inverter generators display better electrical performance⁽¹⁾ than that of conventional double-pole field rotary generator systems, and their ability to vary engine speed in response to generator output helps ensure lower

noise and vibration and higher fuel efficiency⁽²⁾.

Given these characteristics of inverter generators, in 1998 Honda met the market's needs by producing the first EU series of soundproof-type inverter generators, the 3 kVA EU3000is. Since then, generators with outputs ranging from 1 to 6.5 kVA have been included in the series, and have proven successful with Honda customers. The 1-3 kVA-class are mainly positioned for recreational use, providing power at camp sites and for camper vans and RVs, while the 3-6.5 kVA class are mainly used to provide emergency backup power in power outages during natural disasters and as power sources for electrical devices and tools on construction sites.

Figure 1 shows the relative weights and output levels of EU series generators, the EM3800SX, an open frame-type double-pole field rotary generator, and other soundproof-type inverter generators.

The weight of the EU3000is inverter generator was reduced from that of the EM3800SX open frame-type due, among other factors, to the use of a multi-pole outer rotor-type alternator⁽²⁾ that also functions as a flywheel. In addition, the mass per output of the EU3000is is higher

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than that of the EU1000i or the EU2000i, models mainly employed for recreational use.

The EU3000i is designed for professional use, for example on construction sites, and as an emergency backup power source for offices and other places of business, and is therefore provided with a high-capacity fuel tank and a starter motor and battery. In addition, because the use environment of the unit on construction sites is more severe than that of the EU2000i, the use of the latter's simple plastic monocoque frame would have been impractical from the perspectives of strength and stiffness, and a frame configuration using multiple steel plates was therefore employed for the EU3000i. This is a major factor in the difference in mass per output for the two units.

However, in many cases the output of the EU2000i is insufficient to enable the unit to act as a power source for RV air conditioners, their main use in the North American market. Because of this, despite the need for low weight, compactness, and portability, the professional-use EU3000i is being used to power RV air conditioners. The development of a lightweight, compact, and easily usable 3 kVA-class generator was also desirable from the perspective of providing a generator for recreational use as well as emergency domestic power supply.

The 3 kVA-class EU3000i Handi was developed in response to these needs. This paper will discuss the technologies employed in making the unit lightweight and compact.

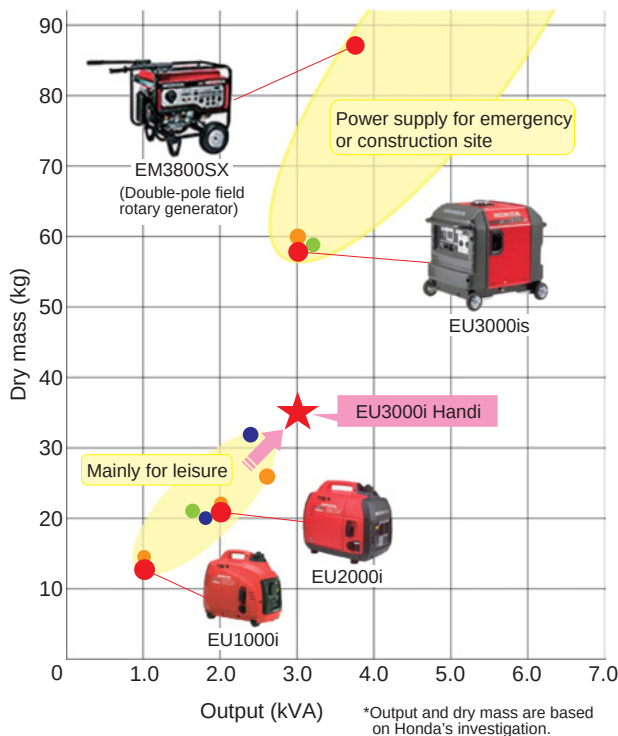


Fig. 1 Output and dry mass

2. Development Goals

The following goals were established for the development of the EU3000i Handi in order to respond to market needs for a lightweight and compact 3 kVA-class inverter generator.

(1) Easy portability and handling

In general, generators for recreational use are transported to a camping site in a camper van or truck, and then manually unloaded from the vehicle and moved to the location where they will be used. Focusing on the achievement of sufficient lightness to enable one person to manually unload the unit from a truck or camper van and then comfortably move it to the desired location, subjective tests were conducted on prototype models. Based on the results of these tests, target figures of a dry mass of 35 kg with gasoline and engine oil removed and a pulling load of 80 N with wheels and pulling handle attached were set for the unit.

Figure 2 shows the EU3000i used as a power source for a camper van.

Generators are often placed next to a camper van for them not to be stolen. To help ensure that the exhaust outlet of the generator does not face the body of the camper van, and also because the plug and the engine switch are located on the opposite side to the exhaust outlet, it is normal to position the units parallel to the camper van body, in order to make it easy to use the power cable and operate the engine switch. Given this, the space necessary for positioning the unit would be reduced in proportion to its total width, and a reduction of same by 20% from that of the EU3000i was established as a target.

(2) Power output for RV air conditioner

The target established for the unit here was, while maintaining a maximum output of 3 kVA, to be capable of instantaneous power output sufficient to start an RV air conditioner with a cooling performance of 4 kW.

(3) Achievement of quiet performance

The target established in this area was to achieve a sound power level, L_{WA} , of 91 dB when operated at rated output, equivalent to the level of the EU2000i when operated at its rated output of 1.6 kVA.



Fig. 2 Example of use as camper power source

3. Technologies for Reduction of Size and Weight

3.1. Use of Low-displacement Engine

The 163 cm³ GX160 engine, with a displacement 17% lower than that of the 196 cm³ GX200 engine used in the EU3000is, was employed in order to reduce the weight of the new generator. The use of this engine reduced the weight of the unit by approximately 500 g.

In order to help ensure the achievement of a maximum output of 3 kVA, equivalent to that of the EU3000is, despite the reduction of engine displacement, the four changes discussed below were made to the standard specifications of the GX160. As the result of these changes, the output of the engine at wide-open throttle was increased by 11% at the target speed for maximum output, 4000 min⁻¹.

(1) Increased engine speed at maximum output

Because the EU3000i Handi is an inverter generator, the frequency of the output voltage is not dependent on engine speed⁽¹⁾. Given this, the target engine speed at maximum generator output was increased to 4000 min⁻¹ from the figure of 3800 min⁻¹ for the EU3000is.

(2) Increase of valve operating angles

Because output at high engine speeds was prioritized, the valve timing was modified, with the valve-operating angle increased by 20° on the intake side and 10° on the exhaust side against the standard specifications of the GX160.

(3) Expansion of carburetor venturi diameter

From considerations of startability, idling stability, and ability to track loads, the charging efficiency of the engine at high speeds was increased by increasing the area ratio of the carburetor venturi diameter by 21% against the base GX160 specifications.

(4) Ignition timing control

Because the transistor-type magneto ignition used in the EU3000is applies constant ignition timing irrespective of engine speed or load, the ignition timing across the entire operating range is mainly determined by the knocking limit and the strength of components at the engine speed for peak torque. Full-transistor ignition was employed in the EU3000i Handi to enable control of ignition timing at each engine speed, helping to realize the optimum ignition timing for startability and maximum output at each engine speed.

Figure 3 shows the engine performance curve.

3.2. Engine Layout and Cooling System Configuration for Reduced Size

In order to reduce the space necessary for positioning the generator when used as a power source for a camper van, the reduction of the unit's total width was prioritized and attention was focused on the packaging.

Figure 4 compares the orientation of engine placement, total width, and the channels for the flow of

cooling air in the EU3000is and the EU3000i Handi.

In the EU3000is, the direction of the width of the generator unit is at a right angle to the direction of the crankshaft to help realize short, straight-line cooling channels, thereby reducing cooling air pressure loss in the housing. By contrast, in the EU3000i Handi, the direction of the crankshaft, in which the engine width is narrowest, is the direction of the width of the generator. This helped to achieve a total width of 379 mm for the generator body, a reduction of 21% from that of the EU3000is.

With the change in the positioning of the engine, cooling air no longer flowed in a straight line, and the high-density arrangement of parts reduced the amount of available space in the housing. In the initial specifications of the new generator, this increased cooling air pressure loss and impeded cooling air flow in comparison to the EU3000is. However, application of computational fluid

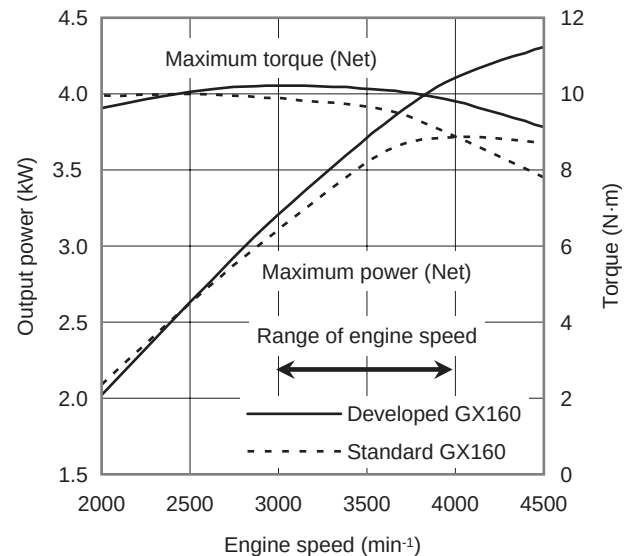


Fig. 3 Engine performance

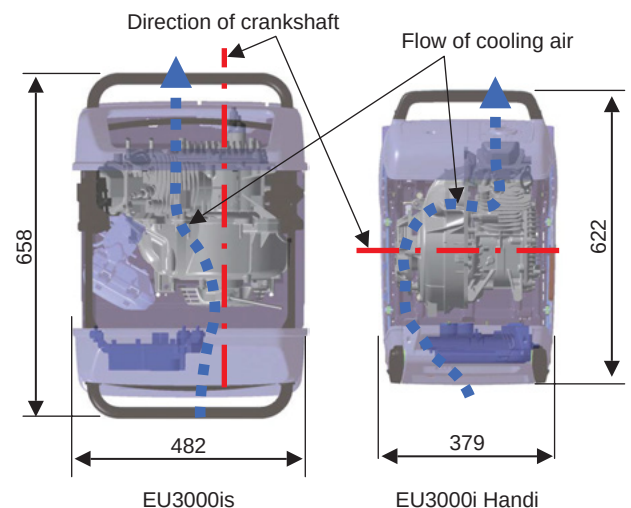


Fig. 4 Location of engine in relation to full width of generator

dynamics (CFD) analyses helped to realize good cooling performance through optimization of the form of the cooling channels.

Figure 5 shows an example of the optimization of the cooling air flow around the engine cylinder head using CFD.

As can be seen, the insufficient flow of cooling air around the underside of the cylinder head in the initial specifications has been corrected.

Figure 6 shows an image of the flow of cooling air around the interior of the body of the generator.

The center frame separates the parts that produce a low level of heat, such as the inverter unit, from those that produce a high level of heat, including the alternator, engine and muffler. Cooling air flows from the low-heat area to the high-heat area for efficient cooling.

3.3. Simple Frame Configuration

One method employed to reduce weight in relation to the frame structure was the use of multiple plastic sheets in place of the steel sheets used in the EU3000is.

Figure 7 shows the structure of the frame and cover of the EU3000is, while Figs. 8 and 9 respectively show

the structure of the frame and the cover of the EU3000i Handi.

Because the EU3000is is designed for professional use on building sites and similar situations, the frame and the covers, with the exception of the front and rear covers, are constructed of steel sheets to ensure durability.

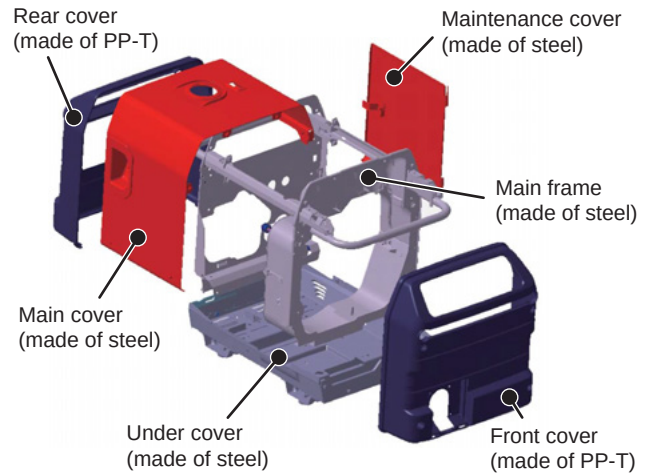


Fig. 7 Structure of frame and cover (EU3000is)

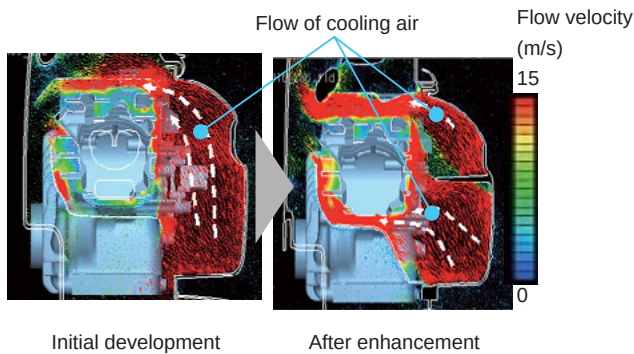


Fig. 5 Cooling air flow dynamics around cylinder head

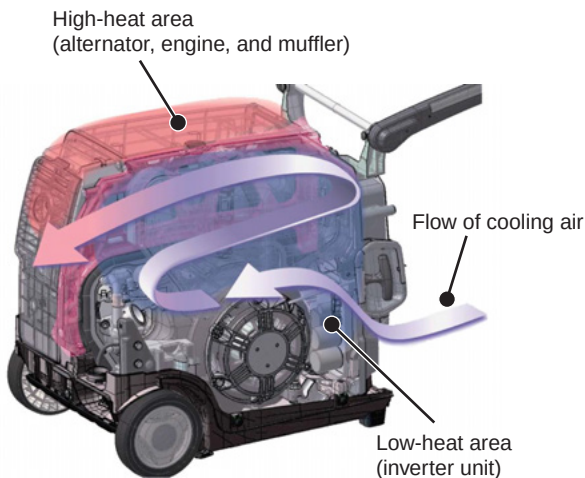


Fig. 6 Flow of cooling air

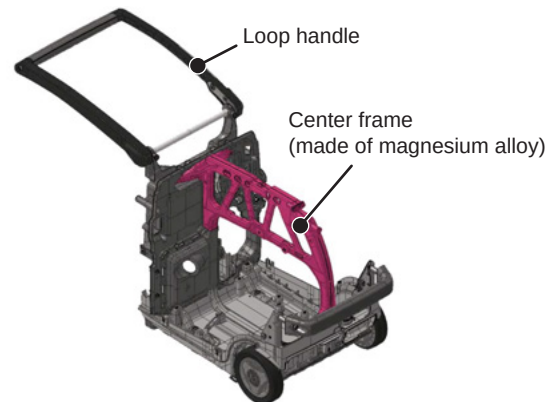


Fig. 8 Structure of frame (EU3000i Handi)

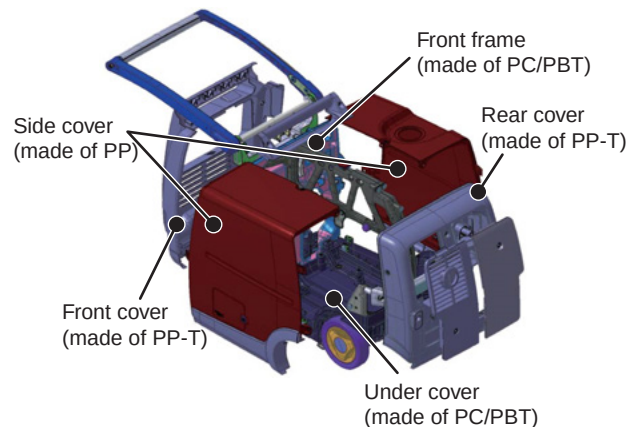


Fig. 9 Structure of cover (EU3000i Handi)

By contrast, since the EU3000i Handi was designed for recreational use, it was necessary to create a light unit. For this reason, a plastic monocoque structure reinforced by a center frame was selected for the new generator.

The center frame, which is the main frame that connects the pulling handle and the wheels, is positioned close to the muffler. Because of this, thermal radiation from the muffler immediately after operation of the unit stops and the cooling air ceases to flow would cause its temperature to increase. In order to maintain the stiffness of the frame when its temperature increased, it was necessary to employ a metal in which the modulus of elasticity had a low level of temperature dependence. A magnesium alloy was selected for the EU3000i Handi.

The use of a high-strength, high-stiffness center frame that was not significantly affected by heat made it possible to use a plastic monocoque structure fashioned exclusively from a general-purpose plastic for the other parts of the frame and the covers. This had the merit of not only realizing weight savings, but also of reducing costs.

As a result of these efforts to achieve weight savings, the total weight of the frame and the covers of the EU3000i Handi has been reduced to 6 kg, a reduction of approximately 60% from the 14 kg of the EU3000is.

3.4. Inverter Unit

Because the maximum speed of the engine used in the EU3000i Handi had been increased against that of the engine in the EU3000is, the voltage range of the alternator sub-winding had been increased, necessitating a power supply circuit configuration able to respond to a wide range of input voltages.

The use of a power supply circuit configuration identical to that employed in the EU3000is would result in increased power circuit loss in the high engine speed range, and would increase the size of the unit. A low-loss ringing choke converter system able to operate stably at a wide range of input voltages from low to high engine speeds was therefore employed in the EU3000i Handi.

The use of software to conduct waveform feedback control helped to enable the number of parts to be reduced, in turn reducing the printed circuit board area. Figure 10 shows the inverter units of the EU3000is and the EU3000i Handi. Despite the fact that the noise filter, which was a separate part in the EU3000is, has been built into the inverter unit, the external dimensions of the unit are identical to those of the EU3000is inverter unit, while its weight has been reduced by 13%, or 500g.

In addition, a simple hour meter function has been newly built-in to the inverter unit. In contrast to professional-use situations, generators for recreational use are often used intermittently, making it challenging for users to calculate hours of use and time oil changes and other maintenance procedures. To make users aware of recommended times for unit maintenance, the inverter unit of the EU3000i Handi records the operating time of the

generator, and, when specific cumulative operating times have been reached, indicates this fact to the user by flashing the output indicator light at engine start. The light will not flash before 100 hours has been reached. After 100 hours, the light flashes once and increases the number of flashing times by one for every 100 hours, until it flashing five times at 500 hours.

3.5. Alternator

Figure 11 shows the alternators used in the EU3000is and the EU3000i Handi.

In the EU3000i Handi, the use of a high-magnetic-force magnet and the realization of an increased permeance coefficient (determined by the form of the magnetic circuit and the magnet) in the magnetic circuit has helped to reduce the thickness of the magnet, increasing the winding space. In addition, the use of the magnetic flux density distribution simulation shown in Fig. 12 to analyze the magnetic flux flowing in the stator core during its design helped to reduce the thickness of the stator by 5 mm and its weight by 14% (-730 g) against the EU3000is while maintaining the same generating capacity.

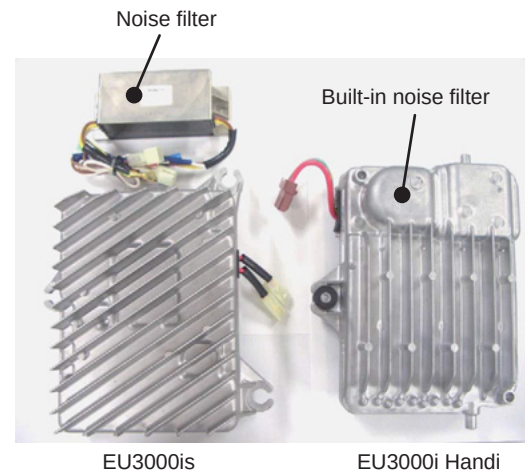


Fig. 10 Inverter unit

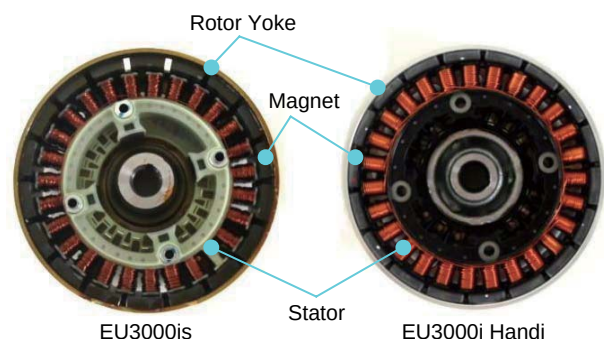


Fig. 11 Alternator

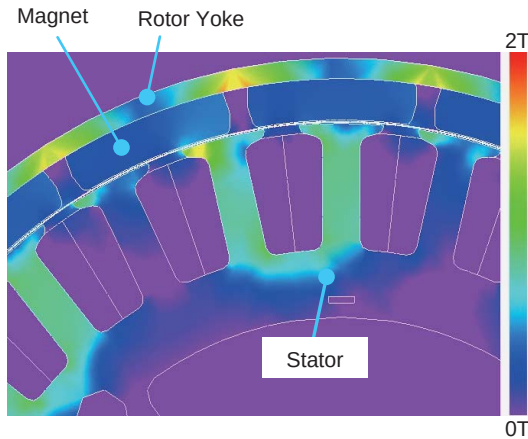


Fig. 12 Distribution of magnetic flux density of alternator

4. Power Generation Performance

Inverter generators are provided with an overload protective function that protects the loading devices and the generator itself when an overload or short-circuited output occurs. The over-current protective function counts the time for which the detected value of the output current exceeds the over-current threshold level, and shuts off power generation if the over-current continues for a predetermined period of time. In addition to this overload protective function, when short-circuited output occurs, an over-current limit circuit stops switching operations in the semiconductor power devices in order to control the peak current of the output short-circuit current and protect the generator. While this is happening, a microcomputer detects the over-current, and shuts off power generation after a predetermined period of time.

Air conditioners with a cooling performance of 4 kW are the most common type among RV air conditioners, and a generator with a 3 kVA output is generally sufficient to operate them. However, if switching occurs rapidly a number of times in an RV air conditioner, the air conditioner compressor locks and a lock current flows in the system, making an output of more than 3 kVA instantaneously necessary. Because the output current at this time exceeds the over-current threshold level, unless the compressor returns to normal operation within the predetermined period of time, the overload protective function will go into operation, and the generator will be unable to power the RV air conditioner. For this reason, despite the fact that at normal times a 3 kVA generator is sufficient to operate an RV air conditioner with a cooling performance of 4 kW, a generator with an output of 3.5 kVA or higher is actually necessary.

High-capacity semiconductor power devices able to resist lock current have been used in the EU3000i Handi, and the period for operation of the overload protective function has been extended to ten seconds from the conventional five seconds. These modifications have

helped to enable the 3 kVA unit to operate an RV air conditioner with a cooling performance of 4 kW until the compressor returns to normal operation.

However, if the same period for operation of the overload protective function was used in the case of short-circuited output, the period for which output short-circuit current flowed would double, and the semiconductor power devices would be destroyed by the current. A new function for the detection of short-circuited current has therefore been added. If short-circuited current is detected for five seconds, the generator output is shut off in order to protect the unit.

5. Noise Reduction Technologies

(1) Reduction of air intake noise

The EU3000i Handi is the first portable engine generator to feature an intake air resonator in order to reduce air intake noise. Figure 13 shows the intake port, the intake air resonator, and the carburetor.

The space under the carburetor has been used to fit a Hershel resonator⁽³⁾.

Figure 14 shows the noise characteristics around the air inlet with and without the resonator fitted.

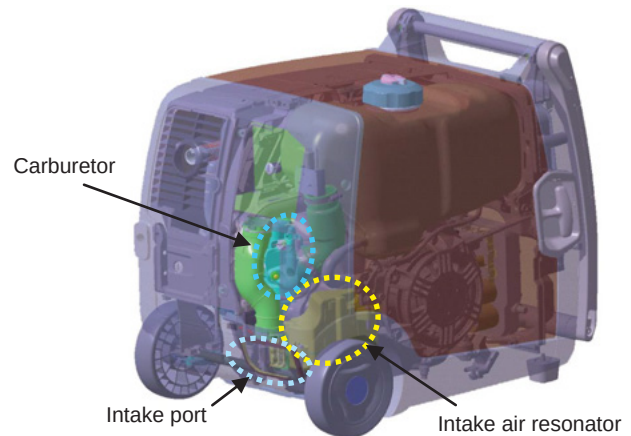


Fig. 13 Location of intake port, resonator and carburetor

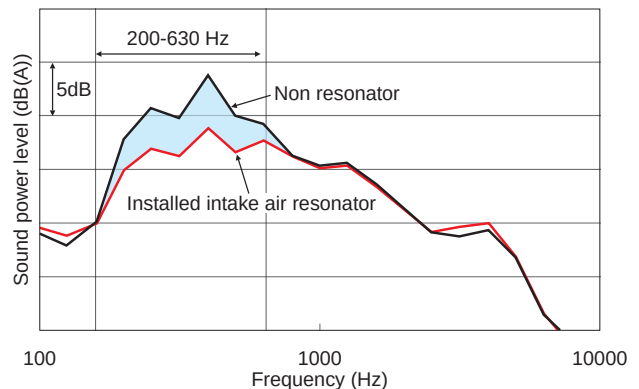


Fig. 14 Noise characteristics around inlet

The volume and shape of the resonator were designed using CAE in order to control noise in the 200-630 Hz intake noise band. As a result, a noise reduction of 5 dB(A) or more was achieved at positions 500 mm from the intake port at an angle of 45°.

(2) Reduction of radiated noise

Measures were also taken to reduce mechanical noise. A sound-absorbent material has been welded to the inside of the plastic covers to absorb noise, and large components (the inverter unit and muffler) have been positioned between the openings of the housing (the inlet and outlet for cooling air) and the engine, a source of mechanical noise, in order to increase the shielding effect. These measures have reduced the level of radiated noise to the exterior of the housing.

Urethane foam and felt were used as sound-absorbent materials in the EU3000i. The new generator, however, employs a polypropylene non-woven fabric⁽⁴⁾ that has proven to display a good acoustic absorption coefficient in the automotive field. The new material achieves an identical acoustic absorption coefficient at an approximately 40% reduced thickness, and has contributed to the reduction of the total width of the unit. The use of the new material has also reduced weight by approximately 200 g.

The use of these noise reduction technologies has helped to achieve the target noise level of L_{WA} 91 dB at the rated output of 2.6 kVA. The noise level is 3.5 dB lower at an output of 1.6 kVA, the rated output of the EU2000i. The EU3000i Handi has thus achieved a level of quiet operation one rank higher than that of the other unit.

Figure 15 shows the noise characteristics of the EU3000i Handi in the practical use range and the noise level of the EU2000i when operating at rated output.

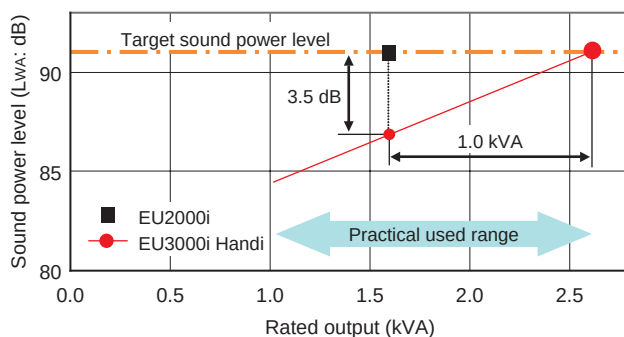


Fig. 15 Noise characteristics of EU3000i Handi

6. Conclusion

Each component used in the EU3000i Handi was reduced in size and weight, and a simple frame structure was employed. In addition, the specifications of the fittings and the range of continuous operation were

Table 1 EU3000i Handi specifications

		EU3000i Handi
Engine	Displacement (cm ³)	163
	Speed (min ⁻¹)	3000-4000
Generator	Max. AC output (kVA)	3.0
	Rated AC output (kVA)	2.6
Continuous operating hours (h)		3.5
Operating noise level (L_{WA} : dB)		91
Dimensions	L×W×H (mm)	622×379×489
	Dry mass (kg)	35.2
	Wet mass (kg)	40.1

modified to suit the unit to recreational use. The cell starter used in the professional EU3000i was removed, and the unit is operated using only the recoil starter. The fuel tank was reduced in size, while at the same time the 3.5 hrs of continuous operation at rated output necessary for recreational use was also realized. These measures have helped to enable the realization of a compact, lightweight, and easy-to-use 3 kVA-class generator.

Figure 16 shows an exterior view of the EU3000i Handi, and Fig. 17 shows the unit being moved using the pulling handle. Table 1 shows the specifications of the new generator.



Fig. 16 Appearance of EU3000i Handi



Fig. 17 EU3000i Handi with handle

The details of the technologies used to reduce the size and the weight of the EU3000i Handi can be summarized as follows:

- (1) The reduction of the size and weight of each component and the use of a plastic monocoque structure reinforced with a magnesium alloy center frame helped to achieve a dry mass of 35.2 kg, a comfortable weight for users. This represents a reduction of 42% in weight from that of the previous EU3000is, a generator with the same output. The unit is provided with two wheels and a handle that can be folded away. The generator is surprisingly portable, and with a pulling load of 80 N, can be comfortably moved by one person. The total width of the new generator is 103 mm lower than that of the EU3000is at 379 mm, and its volume has also been reduced by 36%.
- (2) The weight of the generator has been reduced through the use of an engine with a 17% lower displacement than the engine used in the EU3000is, while maintaining an output of 3 kVA and realizing the instantaneous output necessary for use with an RV air conditioner.
- (3) A noise level of L_{WA} 91 dB at rated output has been achieved, equivalent to that of the EU2000i, a generator with a rated output approximately 40% lower.

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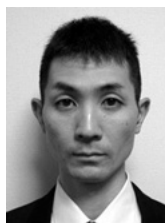
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