

Low Noise and Lightweight Technology of Inverter Generator EU6500is

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ABSTRACT

A lightweight, portable engine generator, EU6500is, which has a rated output of between 4.5 and 5.5 kVA and a world top-level quietness was developed.

The EU6500is, which is based on the existing EM6500is open frame type inverter generator, on which an air-cooled single cylinder engine is mounted, employs a muffler cooling system with an air guide for cooling the muffler and realizes low noise and reduced weight due to the use of a highly rigid monocoque frame, and the like. As a result, the noise value L_{WA} at the rated output of 5.5 kVA was 90 dB. This is at least as low as the EU series soundproof frame type inverter generator, which has an output of about half that of the EU6500is. Also, while the noise emitted from the new generator is at least as low as that of the EX5500 portable engine generator, on which a 2-cylinder water-cooled engine of comparable output is mounted, the weight has been successfully reduced by 35% and the volume by 33%.

As a result, the new generator can cope with a wide range of needs, such as an emergency backup power source or for leisure, as the top model in the EU series.

1. Background

Portable engine generators are being demanded at many sites as emergency backup power sources for use in natural disasters, which have been occurring with increasing frequency in recent years, as power sources for electrical appliances, tools, etc., at work sites, as outdoor power sources for leisure, and the like. Also, in developing countries where power outages frequently occur due to the imbalance between supply and demand of electric power as a result of rapid economic development, many portable engine generators are being used as emergency backup power sources for electrical and electronic appliances in business and at home. As living standards rise throughout the world, the demand for electric power increases, resulting in greater needs for portable power sources. In order to cope with these various needs, higher quality electrical performance, lower noise, greater compactness, and reduced fuel consumption (reduction of CO₂) are being demanded.

An inverter generator has high quality electrical

performance⁽¹⁾ and is also advantageous from the viewpoint of its performance, which is friendlier to the environment (low fuel consumption, low noise). By utilizing noise reduction technology in this inverter generator, a generator that meets these market needs as well can be produced.

Previously, a soundproof type generator with an inverter type generating system was mainly used for leisure activities, such as camping, so a generating system for the 3 kVA and lower class was developed. On the other hand, the market for emergency backup generators, for example, has also demanded higher output, at 5 kVA or more. Also, as a result of the widening applications of electronic appliances and the heightened interest in environmental conformity such as noise reduction, there are greater demands for higher quality electrical performance and lower noise. In order to meet these diverse needs, a system with the rated output of the generator set to 5.5 kVA was developed, focusing on noise reduction and weight reduction technology.

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2. Development Goal and Issues

Portable engine generators are divided into a simple, lightweight open frame type construction, and a soundproof frame type construction for reducing noise. Also, the generating systems consist of a 2-pole or 4-pole field rotating type cylinder alternator, which was the conventional system, and a combination of a multi-pole field rotary alternator and inverter unit, which has come into increasing use in recent years (Fig. 1).

In the development of the EU6500is, the noise target value was set to the same level as that of the existing EU series^{(1), (2)} generators (EU1000i, EU2000i, EU3000is). The existing EU series used a two-tiered noise dampening system, and a load-dependent speed control function that reduces the rotational speed of the engine during light load operation, thus reducing noise in the heavily used practical use load range (hereafter called the service load range, from no load to 1/2 load) (Fig. 2). As a result, the noise target value of the EU6500is is no higher than a sound power level of $L_{WA}80$ to 85 dB in the service load range, and is less than 90 dB at rated load. These target values are approximately 10 dB lower than those of the EM6500is open frame type inverter generator.

When the sound power level of $L_{WA}80$ to 85 dB in the service load range was compared with the sound pressure level in a living area L_{PA} (Table 1), at a distance of 7 m

		Generator type	
		Double-pole field rotary	Multi-pole field rotary & inverter unit
Frame type	Open frame type generator	EM6500 	EM6500is 
	Soundproof type generator	EX5500 	EU6500is 

Fig. 1 Type of generator

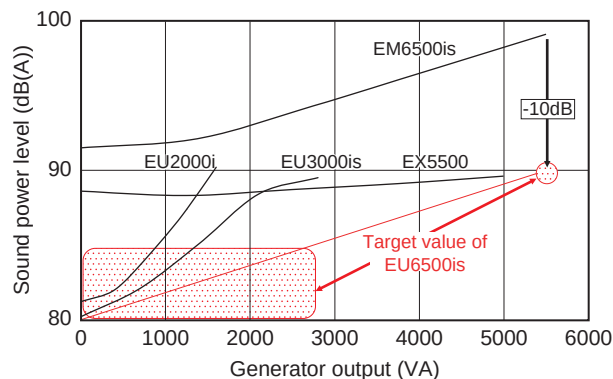


Fig. 2 EU series sound power level

Table 1 Sound pressure level in living area

Sound pressure level L_{PA} (dB)	Typical sound
100 – 110	Loud car horn
90 – 100	Noisy factory
80 – 90	Inside subway
70 – 80	Noisy office
60 – 70	Business office
50 – 60	Conversational speech
40 – 50	Living room
30 – 40	Library

from the generator, the noise level was roughly the same level as that of ordinary conversation (50 to 60 dB), which was recognized as an adequately low noise level, and so was set as a target.

Figure 3 shows the ranking in respect of weight and noise level of the open frame type generators and conventional model soundproof type generators, and the target value settings of the EU6500is. The EX5500 is a low noise generator, but it is heavy. Also, the EM6500is is light, but from a noise viewpoint, not as good as the EU series. Accordingly, it was decided to realize the abovementioned noise target in a generator of the same size and weight as those of the EM6500is.

The issues for achieving the above noise values and weight are shown below.

1. Simultaneous achievement of noise absorption and noise insulating performance, cooling performance, and compactness of the housing
2. Acquiring airtightness of the housing to keep noise leakage from happening
3. Development of low cost noise reduction technology

In order to address these issues, it was decided to develop a generator based on the lightweight and compact open frame type EM6500is inverter generator⁽³⁾, which can achieve enhanced fuel economy and reduced noise by reducing the rotational speed in the service load range, using the same generating section and basic structure as

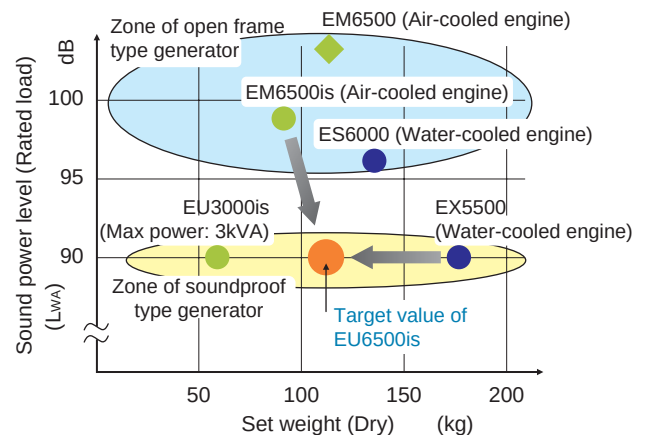


Fig. 3 Target positioning for sound power level and set weight

Table 2 Comparison of specification with EM6500is and EX5500

Engine	Displacement (cm ³)	EM6500is	EX5500
	Speed (rpm)	* 2400 - 3600 ☆ 3300 - 3600	3600
Operating noise level (L _{WA} ; dB)		98	90
Generator	Type	Multi-pole field rotary	Double-pole field rotary
	AC voltage (V)	120/240	120/240
	AC frequency (Hz)	60	60
	Max. AC output	6500	5500
	Rated AC output	5500	5000
Dimensions	L × W × H (mm)	810 × 672 × 692	942 × 580 × 650
	Dry weight (kg)	97	177

* : Eco SW ON
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Fig. 4 External view of EM6500is and EX5500

that of the EM6500is.

Figure 4 shows the exterior of the soundproof type EX5500, which uses the conventional cylindrical type alternator, and the EM6500is base inverter generator, and Table 2 shows a comparison of the main specifications.

3. Noise Reduction Technology

The noise emitted by the EM6500is base generator was analyzed using the noise masking method. Figure 5 shows the noise contributory ratio. In order to reduce the noise emitted from the EU6500is, it was decided to reduce the noise emitted by each of the following four paths, which constitute 97% of the cause of the generator noise.

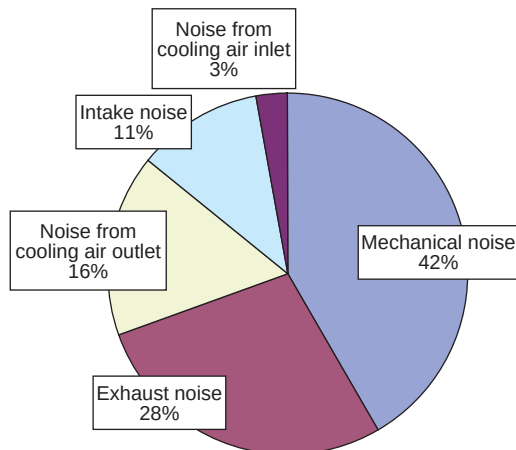


Fig. 5 Sound contribution ratio (EM6500is)

1. Path of engine radiation
2. Path of air intake system
3. Path of exhaust system
4. Path of cooling air outlet

The methods used to reduce noise in each path are shown below.

3.1. Reduction of noise from the path of engine radiation

In order to reduce radiation of mainly mechanical noise (radiation noise, due to additional vibration force of engine, valve system noise, piston noise, fan noise, and the like) emitted from the engine, it was decided to adopt a two-tiered noise dampening system consisting of a shroud and a housing outer panel covering the entire periphery of the engine. By making the space formed by the shroud and the housing outer panel a sealed space, the generator was provided with a soundproofing effect. Also, regarding the housing, leakage of noise was prevented by using a clearance seal.

As a result of the above configuration, engine radiation noise was reduced by 95%, in terms of energy level, compared to the open frame type EM6500is. Details of the lightweight and highly sealed housing structure are described in Section 4.

3.2. Reduction of Noise from the Air Intake System

Figure 6 shows the layout of the air intake system.

For this air intake system, the air intake system of the EM6500is was used, with an expansion room additionally installed mid-way between the narrow part, which is made of rubber, and the air intake path at the air intake port, in order to acquire a high transmission loss of noise so as to reduce the air intake noise, which was emitted from the EM6500is mainly between 200 and 500 Hz. The resulting change in transmission loss is shown in Fig. 7.

As a result of the change in the air intake system, the air intake noise was reduced by 70% of that of the EM6500is in terms of energy level.

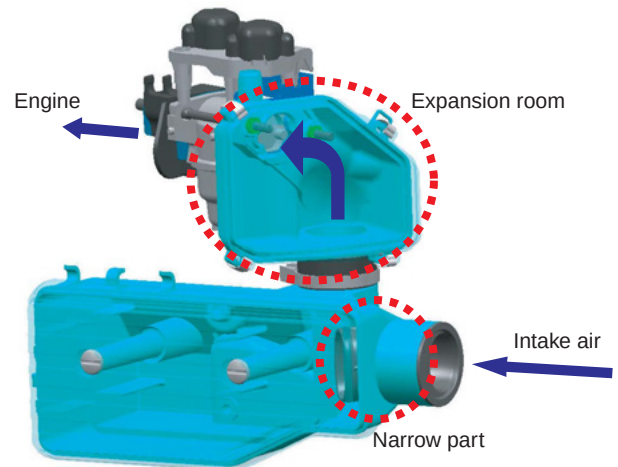


Fig. 6 Layout of intake system

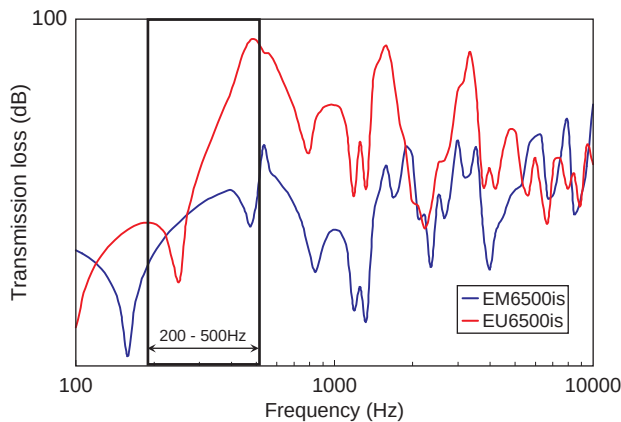


Fig. 7 Comparison of transmission loss (EU6500is, EM6500is)

3.3. Reduction of Exhaust Noise

In order to reduce the exhaust noise, a 6.4 liter big muffler structured with four chambers, with acoustic absorbent installed in part of the expansion room, was adopted. The end part of the entrance side of the internal chamber joint pipe was flared in order to reduce exhaust gas flow noise and back pressure.

As a result of the increased size of the muffler and change in the internal construction, noise from the exhaust outlet was reduced by 95% in terms of energy level.

3.4. Reduction of Cooling Air Outlet Noise

The main noise source in the cooling air outlet system is engine mechanical noise radiated from the exhaust air outlet. Although it was decided to reduce this engine mechanical noise, if an air-cooled engine is used as the motive power source there will be a risk of a change in the cooling air path, causing the cooling performance to fall. Consequently, with a focus on the cooling performance, and by changing the muffler room structure, the associated noise reduction was examined.

The development targets with respect to the EM6500is were the following three points.

- (1) A reduction of the noise energy emitted from the exhaust air outlet of at least 80%
- (2) A cooling performance at least as good as that of existing generators, both when the generator is running and after it has stopped
- (3) Lightweight and compact structure

Figure 8 shows the cooling structure of the EM6500is for reference.

The concept of cooling in the EM6500is, both when the generator is running and after it has stopped, is as follows.

Cooling when the generator is running: Cooling is performed by forced convection generated by a cooling fan that is directly connected to the engine, in sequence from low heat generation.

Cooling after the generator has stopped: An incline is formed on the internal structure of the housing, and heat is allowed to dissipate by free convection from the exhaust air outlet at the top end.

In the case of a conventional portable engine generator, compactness is demanded, so as shown in Fig. 8 the exhaust air outlet and engine are brought close to each other, and as a result there is a tendency for the engine mechanical noise from the exhaust air outlet to increase.

Methods of reducing this mechanical noise include a method in which noise insulating material or acoustic absorbent is installed near the exhaust air outlet, and a method in which the area of the exhaust air outlet is reduced, with a silencing chamber added after the exhaust air outlet⁽⁴⁾. However, these methods generate issues such as exacerbating cooling performance and increased size. For this reason, all of the targets using conventional methods were not easily achieved.

In this development work, the above issues, which were in a tradeoff relationship, were addressed by installing the air guide shown in Fig. 9 between the engine and the muffler.

3.4.1. Noise reduction

The installation location of the air guide was determined so as to partition the muffler and engine for the following three reasons.

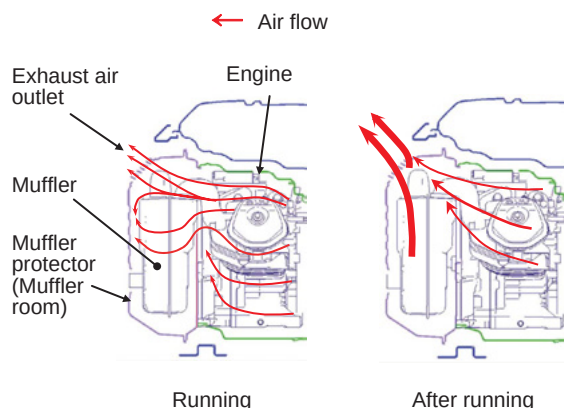


Fig. 8 Conventional cooling system (EM6500is)

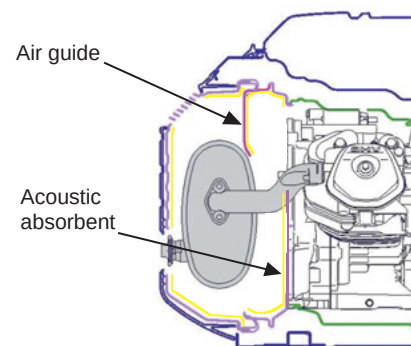


Fig. 9 Air guide

- (1) The engine mechanical noise that is discharged directly from the exhaust air outlet is able to be reduced.
- (2) Because the cooling air path is able to be lengthened from the engine to the exhaust air outlet without increasing the overall length, noise is able to be attenuated using a compact structure.
- (3) Maintaining the cooling performance (Described in 3.4.3.)

Here, in order to increase the effect of (1), the air guide was made into a shape such that the engine could not be seen directly from the exhaust air outlet. Also, to increase the effect of (2), acoustic absorbent was installed inside the cooling air path.

As a result of measurement, it was found that by using the air guide, the noise energy reduction in the exhaust air outlet was 90%, which exceeds the target value. Also, the feeling of noise was lessened due to a reduction of unsteady noise in the high frequency range resulting from the use of acoustic absorbent.

3.4.2. Cooling performance during operation

There was apprehension that the installation of the air guide might have decreased performance of the engine and the muffler during operation as a result of reduction of the cooling air flow due to pressure loss, however the engine oil temperature and the temperature of the electrical parts during operation was of the same level as that of existing models.

Regarding the cooling performance of the muffler, the temperature of the exhaust gas inside the muffler was measured. As a result of temperature measurement, it was found that the exhaust gas temperature fell by approximately 30°C. This indicates that the air guide causes the cooling air to be rectified, enabling the surface of the muffler to be efficiently cooled. The enhanced cooling of the muffler reduces the risk of after-burn after the engine has stopped. Figure 10 shows a pattern diagram of the flow of cooling air around the muffler and the ambient cooling air flow during operation rendered visible using the tuft method.

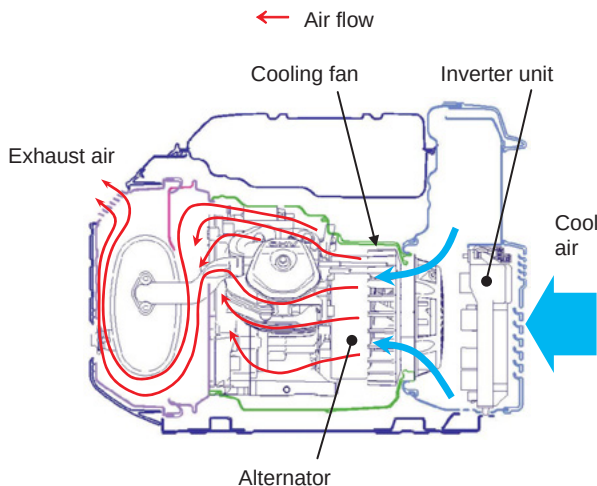


Fig. 10 Ambient airflow of muffler (Running)

3.4.3. Countermeasures for heat after the engine-stop

An important point in cooling an air-cooled soundproof type generator is the adoption of countermeasures for heat after the engine has stopped. In the case of a generator that uses an air-cooled engine, because the cooling fan is directly connected to the engine, the supply of cooling air stops as soon as the engine stops. As a result, the atmospheric temperature in the vicinity of the muffler, which is the hottest part inside the housing, rises abruptly as soon as the engine stops. If this high temperature air flows in reverse to the engine chamber or electrical chamber, the functions of the electrical and plastic parts may fall, and the restarting performance may fall due to the increase in temperature of the gasoline inside the carburetor float chamber.

In the case of the EU6500is, conventional heat dissipation due to free convection was developed in order to address the heat issue after the engine stops.

The installation location of the air guide was set at a partitioning position between the muffler and the engine. This was done so as to utilize the free convection (updraft) generated by the heat of the muffler after the engine stops, in order to actively exhaust the heat inside the housing. Figure 11 shows the flow of heat after the engine stops.

When the engine stops, the muffler atmospheric temperature (T_m) abruptly rises. As a result of this temperature rise, the gas in the vicinity of the muffler becomes an updraft, and is exhausted from the exhaust air outlet to the outside of the housing.

Also, the air guide causes the partitioned engine atmospheric temperature (T_e) to rise as well. However, as a result of the updraft in the vicinity of the muffler, the air in the engine atmosphere is drawn to the bottom of the muffler chamber. Next, it is heated by the muffler to become an updraft and is exhausted to the outside of the housing.

Because the entire engine is covered by the shroud, the cooling air path from the cooling air inlet to the exhaust air outlet has been made a closed path, hence this heat

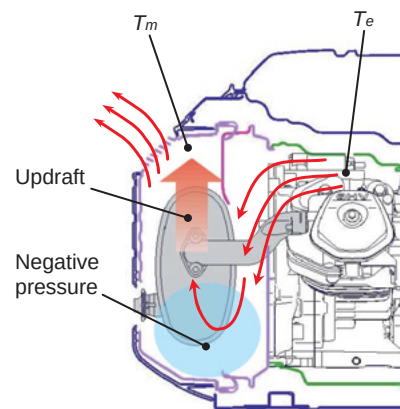


Fig. 11 Waste heat flow (After running)

flow is generated continuously immediately after the engine stops.

Figure 12 shows the relationship between the muffler atmospheric temperature (T_m) and engine atmospheric temperature (T_e) after the engine stops.

Immediately after the engine stops, the muffler atmospheric temperature rises to a maximum of 200°C,

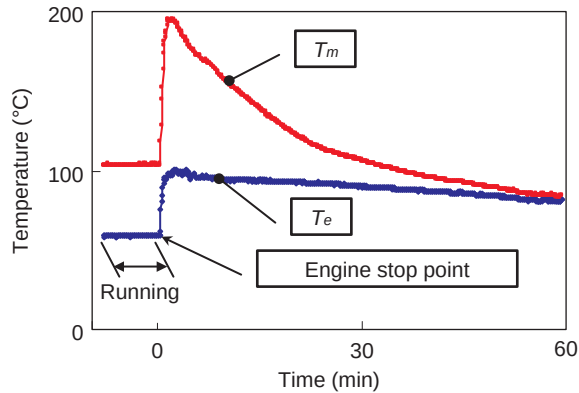


Fig. 12 Temperature of T_m , T_e

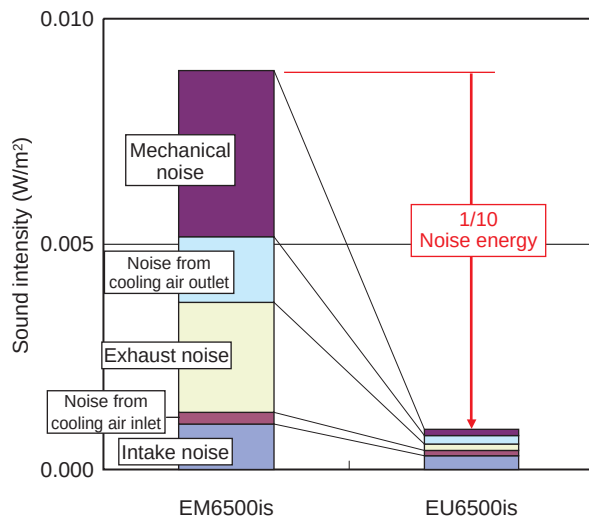


Fig. 13 Effective noise level

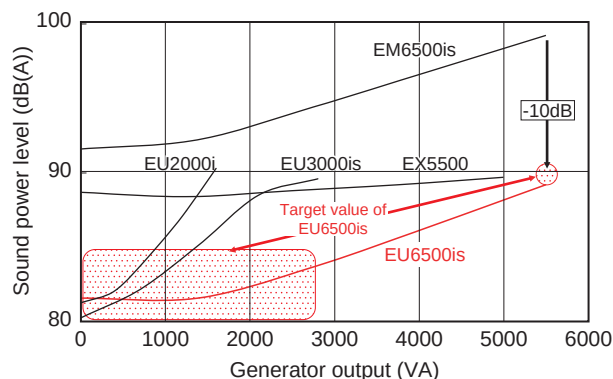


Fig. 14 Sound power level

but the engine atmospheric temperature does not rise past 100°C. This indicates that the hot air near the muffler is being discharged to the outside of the housing, without flowing in the reverse direction. Also, because the heat is dissipated continuously, the temperature inside the housing falls along with the passage of time, and the result obtained was of the same level as that of existing soundproof type generators.

Figure 13 shows the noise contributory ratio of each noise transmission path concerning both EU6500is, for which countermeasures have been taken in respect of the above four paths, and EM6500is, and Fig. 14 shows a noise comparison between the target value and the values for other models.

Compared to the EM6500is, the noise level in terms of noise energy has been reduced to 1/10, and a level of L_{WA} 90 dB was attained at the rated load. Also, the noise performance was at least as good as that of the existing EU series (rated output 2.8 kVA or below).

4. Lightweight Frame Technology

The EU6500is realizes a weight and volume reduction compared to the EX5500 soundproof type generator, which produces the same order of output, due to the abovementioned noise reducing technology, cooling structure, and monocoque frame structure. Details are described in this section.

Reduction of weight and cost of the frame structure of a soundproof type generator is an issue. The issues concerning a soundproof, lightweight frame are as follows.

1. In order to increase the soundproof performance, a highly sealed structure is necessary.
2. Rigidity using the outer panel alone should be able to be secured, without increasing the weight, even when a maintenance door is provided.
3. Easy assembly, without increasing the number of parts, should be able to be secured.

Figure 15 shows the basic frame structure of the conventional EX5500 and the EU6500is.

Conventional large soundproof type generators, including the EX5500, mainly use a frame structure consisting of a highly rigid ladder frame with stiffeners installed in the perpendicular direction to fix the outer panel. In this case, it is easy to replace the panel, but on the other hand, there is a tendency for the number of parts to increase, which is disadvantageous from the viewpoints of lightness and cost. Also, airtightness is not able to be easily secured by increasing the area of the mating faces of the outer panel.

Accordingly, it was decided to make the EU6500is of a simple construction in which the under-frame supporting the heavy sprung weight, such as the engine and alternator, consists of a combination of pipes and channels. The stiffeners in the perpendicular direction were integrated with the outer panels on the left and right

sides, and were then welded to the under-frame to form a monocoque frame. As a result, strength that permitted the generator to be hoisted without any need for special stiffeners in the vertical direction was obtained. The under-cover can be set so that its only function is to reduce noise, and weight reduction and low cost can be realized by using plated steel sheet.

The maintenance cover was formed simultaneously when the side panels were being pressed, and the frame was designed in such a way that there was no waste material, thus reducing the cost considerably. Also, to facilitate engine mounting, the front was opened wide, and the engine was connected to the front frames.

The monocoque frame structure provided adequate rigidity, so a structure in which the front and rear were covered by a plastic cover having a high degree of freedom was used, realizing greater weight reduction and higher sealing performance. Also, the fuel tank was made to function as an upper cover, thus contributing to additional weight reduction.

As a result, the number of main frame components was reduced from 19, as used by the conventional EX5500 model, to 8, and the weight was reduced from 81 to 27.5 kg, and in addition, the soundproofing effect was successfully increased.

The results are shown in Table 3.

Table 3 Number of frame components and weight reduction effect

Item \ Type	EX5500	EU6500is	Reduction ratio
Number of principal constitute parts for frame	19	8	-58%
Weight of principal constitute parts for frame	81.0 kg	27.5 kg	-66%

Table 4 Specification of EU6500is

		EU6500is
Engine	Displacement (cm ³)	389
	Speed (rpm)	* 2400 - 3600 ☆ 3300 - 3600
Operating noise level (L _{WA} ; dB)		90
Generator	Type	Multi-pole field rotary
	AC voltage (V)	120/240
	AC frequency (Hz)	60
	Max. AC output	6500
	Rated AC output	5500
Dimensions	L × W × H (mm)	850 × 672 × 699
	Dry weight (kg)	115

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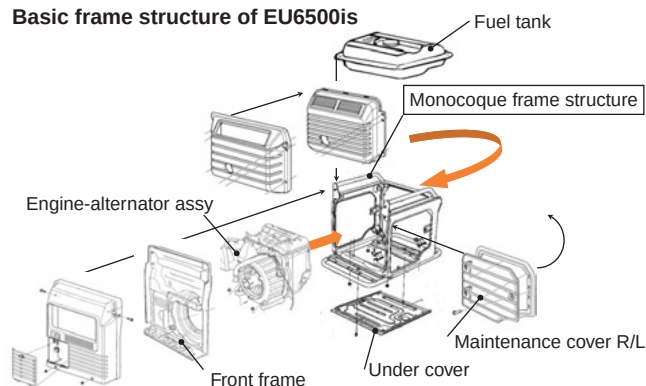
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5. Conclusion

The newly developed EU6500is has a noise level of approximately 10 dB less than that of the EM6500is. It achieved a value of L_{WA} 90 dB, which is the same as that of the existing EU series (EU1000i, EU2000i, EU3000is). Also, the noise level is approximately 5 dB lower than that of the EX5500 soundproof type generator in the service load range, which produces the same order of output (Fig. 14), and the weight has been reduced by 35%, as well as the volume by 33%.

The points that were enhanced in this development are as follows.

Basic frame structure of EU6500is



Basic frame structure of EX5500

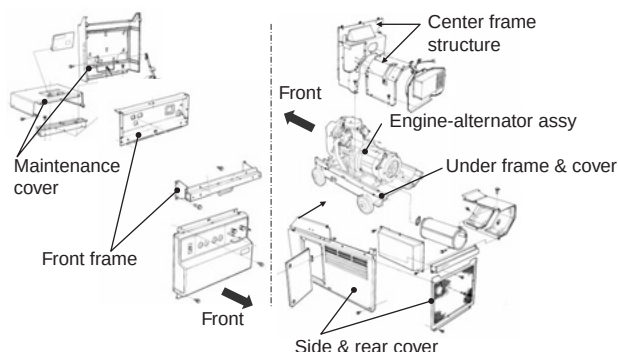


Fig. 15 Frame structure of EU6500is and EX5500



Fig. 16 External view of EU6500is

1. The noise generation and transmission paths are divided into four (engine radiation system, air intake system, exhaust system, and cooling air outlet). Countermeasures were adopted for each path, resulting in a noise reduction of approximately 10 dB, compared to the EM6500is.
2. An air guide was installed in the cooling air path, enabling noise from the cooling air outlet to be reduced and cooling performance to be maintained, without increasing the capacity of the muffler room.
3. A lightweight and compact soundproof type frame was made by using a lightweight, highly airtight, and highly rigid monocoque frame structure.

By employing these noise reduction and weight reduction technologies in the EM6500is, results could be obtained that conformed to the target, and a generator that has higher product strength has been developed.

Table 4 and Fig. 16 show the specifications and exterior of the generator.

References

- (1) Kouchi, T., Ito, K., Nakamura, M.: Development of a Lightweight and Compact 1 kVA-class Potable Generator, SAE Paper, 1999-01-3304 (1999)
- (2) Kouchi, T., Shimizu, M., Hirose, T., Sugimoto, Y.: Development of Lightweight, Compact Sine Wave Inverter-Equipped EU16i Generator, Honda R&D Technical Review, Vol. 13, No. 2, p. 35-42
- (3) Nakamura, M., Kasagi, S., Hirose, T., Shinkawa, Y., Asai, K., Kamimura, K.: Development of EM7000is Dual-voltage Inverter Generator, Honda R&D Technical Review, Vol. 16, No. 2, p. 55-64
- (4) Fukuda, T., Maruyama, K., Takemura, K., Suzuki, S.: Study of Sound Isolation Structure for Engine Generators, SAE Paper, 2005-32-0070 (2005)

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