

Study of Sound Isolation Structure for Engine Generators

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ABSTRACT

In the development of sound isolation type generators, a three-division case structure divided into two cool zones and one hot zone was studied. This study was aimed at achieving compatibility between sound isolation and cooling capabilities that are in a trade-off relationship. Sound isolation of 12.1 dB(A) was achieved by this structure, while obtaining equivalent cooling capabilities to that of open frame type generators. As a result of adopting this new generator structure for India domestic consumption, the Indian noise regulation phase II was achieved for the first time by a mass produced generator.

1. Introduction

As generators are used at any time of the day or night — in the fields of leisure and construction, for business use in worksites, etc., or for emergency backup power — there has long been a strong demand for sound isolation. In recent years there has been an increasing demand for inverter generators that control engine speed according to electrical load, and for sound isolation type generators with an engine and alternator covered by a case. Moreover, reflecting the market demand for sound isolation, many countries and regions have enacted strict sound isolation regulations regarding generators. For instance, the EU has issued 2002/2006 regulations, and India has issued 2002/2003 regulations.

Generally, the following two types of sound isolation methods are employed with generators.

- 1) Methods to reduce the noise created by the source — engine, alternator, air cleaner, and muffler.
 - 2) Methods to reduce the noise emitted from the source — engine, alternator, air cleaner, and muffler — by covering them with a case.
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Of these two, the sound isolation type generator (2) shows a tradeoff relationship between sound isolation and cooling capability. For instance, if there are openings in a casing to introduce cooling air, the area of the openings must be as large as possible to improve cooling capability, but at the same time noise can be emitted through those openings.

Therefore, a case structure for the sound isolation type generator was adopted that achieves both an advanced sound isolation effect and sufficient cooling capability. This paper gives an overview of a case structure and examines its sound isolation effect and cooling capability by using the example of an open frame cylindrical alternator generator's sound isolation.

2. Development Goals

Representative generators are shown in Fig. 1.

- 1) Open Frame Type (Pipe Frame Structure)
The engine and a cylindrical or integrated winding alternator are mounted to a pipe frame.
- 2) Inverter and Sound Isolation Type

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The engine and multi-polar alternator are placed inside a case⁽¹⁾.

3) Sound Isolation Type

The engine and a cylindrical or integrated winding alternator are placed inside a case.



Fig. 1 Typical structure of engine generators

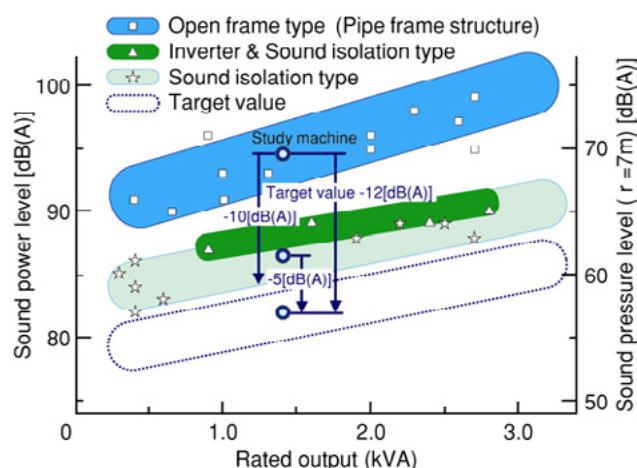


Fig. 2 Noise value according to type

The noise values at a rated power of 3 kVA or less (when rated power is 3/4) are shown in Fig. 2 according to type. The left vertical axis is the sound power level (L_w), which expresses the sound output from the generator (source of noise). The right vertical axis is the sound pressure level (L_p) at a point 7 m from the generator. The relationship between L_w and L_p is shown in Equation 1, with the generator placed on the ground in an ideal half-free sound field, therefore, $L_p = L_w - 25$ [dB(A)].

$$L_p = L_w - 20 \log_{10} r - 8 \quad (1)$$

For reference, sound pressure levels⁽²⁾ in ordinary living environments are shown in Table 1.

Table 1 Sound pressure level in a living environment

80 dB(A)	Subway in the car
70 dB(A)	Bell of a telephone, Loud street
60 dB(A)	Quiet passenger car, Ordinary conversation
50 dB(A)	Quiet office

The target when applying sound insulation to the open frame type has been set as -12 dB(A)⁽³⁾ based on the following points.

- 1) In comparison with the open frame type, there must be a reduction of -10 dB(A) or more, at which level, the average human being feels the noise reduced by 1/2.
- 2) In comparison with conventional sound isolation types, there must be a reduction of -5 dB(A) or more, at which the average human being clearly recognizes sound isolation.

The target value positioning is shown in Fig. 2, in the same manner.

Figures 3, 4, and 5 show the flow of cooling air and engine exhaust for each representative type generator. The cooling capability is evaluated according to temperatures of various parts of the generator including: oil temperature, spark plug seat temperature, and fuel temperature inside the carburetor. The target temperature for each part was set at the level of the existing generator.

The issues of sound isolation and cooling capability with the existing sound isolation type generator arise from the fact that the structure is essentially an open frame type (Fig. 3) enclosed in a case. As for noise, the major source of noise is the direct exhaust of the engine's combustion gases, which is also true of the inverter and sound insulation type shown in Fig. 4. As for cooling capability, there is a rise in temperature inside the case due to the retention of cooling air duct surface heat and air leaking from gaps in the duct joints. At the same time, heat is recirculated to cooling air inlets, resulting in a drop in cooling efficiency. Furthermore, after operation has stopped, because the height difference between the cooling air outlet and inlet is relatively small, cooling through natural convection inside the cooling air ducts does not occur, and the temperature inside the case rises due to residual heat.

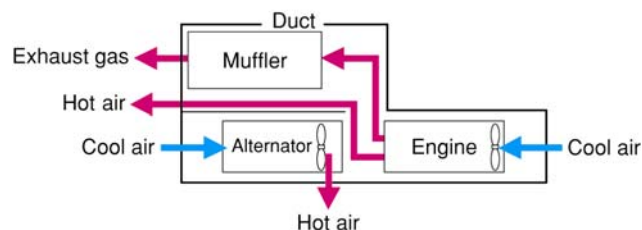


Fig. 3 Open frame type (Pipe frame structure)

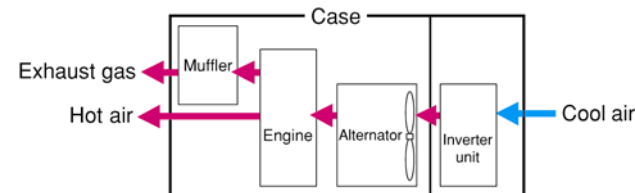


Fig. 4 Inverter & Sound isolation type

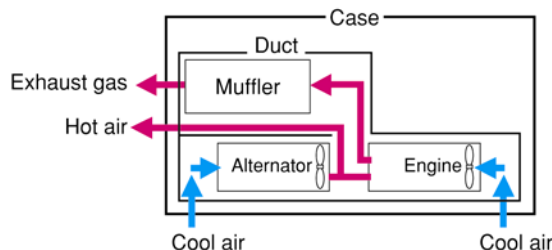


Fig. 5 Sound isolation type

In order to resolve these issues with the conventional sound isolation type, a new structure was studied, considering the following points in terms of sound isolation and cooling capability.

The main sound isolation points were as follows.

- 1) Engine exhaust gases are emitted through indirect exhaust, reducing exhaust noise.
- 2) Cooling air ducts are made long, and noise absorption material is placed inside the ducts, to attenuate noise.
- 3) The opening area of the cooling air inlet is made as small as possible to minimize noise leakage.

The main cooling capability points were as follows.

- 1) A simple divided structure with a seal effect was used to completely separate cool zones and hot zones inside the case. This prevents retention and recirculation of heat due to thermal transmission.
- 2) The height difference of cooling air outlets and inlets is maximized, creating sufficient cooling through natural convection, thereby minimizing a temperature rise when stopped.
- 3) Cooling air flow path obstructions are reduced, maintaining sufficient cooling air volumes.

3. Sound Isolation Technologies

3. 1.Case Structure

A new case structure was proposed based on the main points in sound isolation and cooling capability noted above. Figure 6 shows the flow of cooling air and engine exhaust inside the case. An overview is given below.

- 1) The case is divided into 3 sections internally by vertical dividers. The dividers completely separate the central hot zone from the cool zones on either side. The hot zone contains the engine, alternator, and muffler, while the cool zones contain the air cleaner, carburetor, fuel tank, battery, and electrical parts.
- 2) On top of the central hot zone is a silencing chamber, and the muffler's exhaust gas is exhausted indirectly through this.
- 3) The cooling air inlets are in the bottom plate, and the exhaust outlet is on the top of the case.

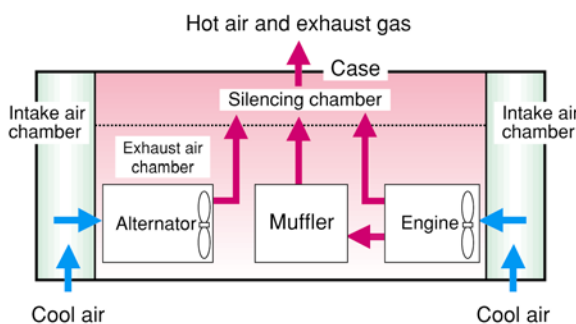


Fig. 6 New sound isolation type

3.2. Confirmation of Sound Isolation Effect

The sound isolation effect was confirmed using a prototype with a 3-section case structure.

Figure 7 shows the level of sound isolation effect in each chamber, using the 3-section structure. In total, the sound reduction effect was 12.1 dB(A).

The spec is explained from the left (the numerical values are the sound power level).

- 1) Engine and alternator only (same level as the open frame type). [94.1 dB(A)]
This shows the state before being enclosed by the case.
- 2) Addition of hot zone exhaust chamber. [-5.6 dB(A)]
This shows the noise source sound insulation effect.
- 3) Addition of a separated silencer chamber above the exhaust chamber. [-0.9 dB(A)]
This shows the further sound absorbing effect of the indirect exhaust and the longer exhaust path.
- 4) Addition of an intake air chamber on the engine side. [-4.8 dB(A)]
This shows the effect of isolation from the air intake noise of the air cleaner and recoil starter, and from noise in the hot zone leaked from the divider walls.
- 5) Addition of an intake air chamber on the alternator side. [-0.6 dB(A)]
This shows the effect of isolation from the alternator air intake noise, and from noise in the hot zone leaked from the divider walls.

Moreover, a sound absorbing and heat insulating material is attached to the hot zone within the case, and sound-absorbing material is also placed in the cool zones. In order to determine the contribution rate of a case without the heat-insulating and sound-absorbing material for sound isolation, noise measurements were taken both with and without the heat-insulating, noise-absorbing material. As shown in Fig. 8, the results show a reduction of 6.3 dB (A) with the case structure, which is equivalent to 52% of the total sound isolation effect of 12.1dB (A). This shows that even without the heat-insulating noise-absorbing material, it is possible to achieve a noise level that is on a par with the conventional sound isolation type.

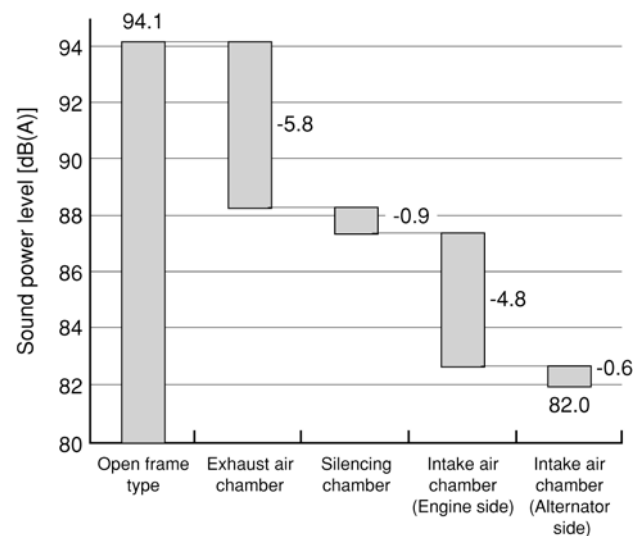


Fig. 7 Effect according chamber

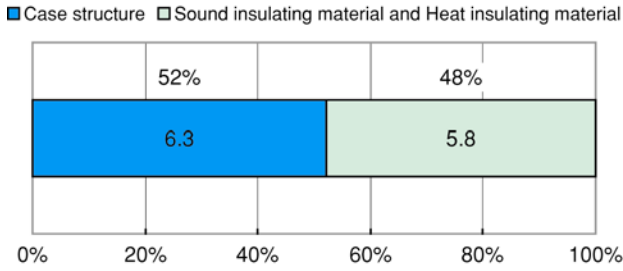


Fig. 8 Effect according chamber

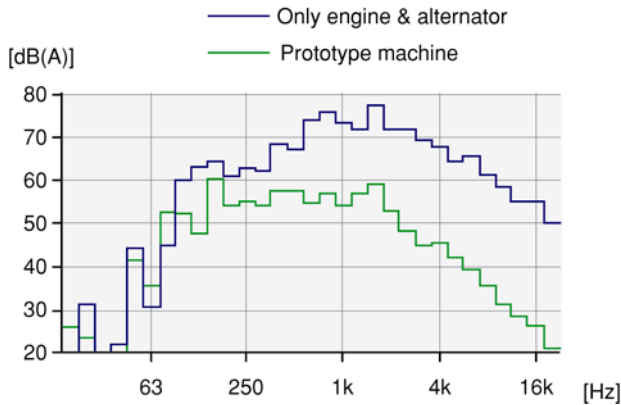


Fig. 9 Frequency analysis result

In addition, Fig. 9 shows the results of frequency analysis during rated load operation. (The location of the measurement microphone is 2 m from the generator.) In comparison with the engine and alternator only, the prototype unit demonstrates a sound isolation of 250 Hz or more at all frequencies.

3.3. Cooling Air Volume

3.3.1. Estimating the required cooling air volume

In order to make cooling capability feasible, the cooling fan air volume required for the 3-section structure to maintain output equivalent to the open frame type was estimated.

Taking the amount of heat of the fuel as Q_k ,

$$Q_k = Q_p + Q_g + Q_c + Q_w^{(4)} \quad (2)$$

Q_p : Generator power

Q_g : Amount of exhaust gas heat

Q_w : Amount of heat by which the cooling air is warmed

Q_c : Heat generated from the hot zone

Here,

$$Q_k = H \times F_c \quad (3)$$

$$Q_g = \Delta T_g \times \rho(T) \times C(T) \times V \times N \times \eta_v \quad (4)$$

$$Q_w = W \times \rho(T) \times C(T) \times \Delta T_1 \quad (5)$$

H : Fuel lower calorific value

F_c : Prototype engine's fuel consumption rate

ΔT_g : Exhaust temperature rise from the temperature of the prototype muffler's cool zone

ρ : Air density

C : Specific heat of air

V : Prototype engine's displacement

N : Engine speed

W : Cooling fan air volume

ΔT_1 : Temperature rise from the temperature of the cooling air's cool zone

η_v : Charging efficiency

The temperature of the cooling air discharged from the engine must be 80 °C or less, as determined by the heat resistance temperature of the wire harness in the hot zone, and the outside temperature is assumed to be 40 °C.

Q_c consists of the amount of heat exhausted to the outside of the engine immediately from the hot zone, and of heat exhausted into the cool zone through the barrier wall.

$$Q_c = Q_1 + Q_2 \quad (6)$$

Q_1 : Amount of heat exhausted outside immediately from the hot zone

Q_2 : Amount of heat exhausted into the cool zone through the separator

In order to prevent a rise in temperature of the case surface and thermal transmission to the cool zone, heat-insulating material is applied to each of the hot zone surfaces, as noted in Table 2.

Table 2 Heat insulating material

Front / Top / Rear face	With heat insulating material
Bottom surface	With no heat insulating material
Separator	With heat insulating material to one half

Here, with a steel plate thermal conductivity of 80 (W/mK) and an insulation material thermal conductivity of 0.04 (W/mK), and considering the insulation material's area ratio, it can be assumed that almost all the heat transmitted from the hot zone to the cool zone is transferred to the cooling air. Therefore,

$$Q_2 = \rho(T) \times C(T) \times W \times \Delta T_2 \cong 0.50 \times Q_c \quad (7)$$

ΔT_2 : Temperature rise in inlet cooling air

Figure 10 shows the relationship between cooling air volume and ΔT_2 . According to the open frame type data, when the target is $\Delta T_2 = 5$ °C, air volume W is approximately 5.5 (m³/min).

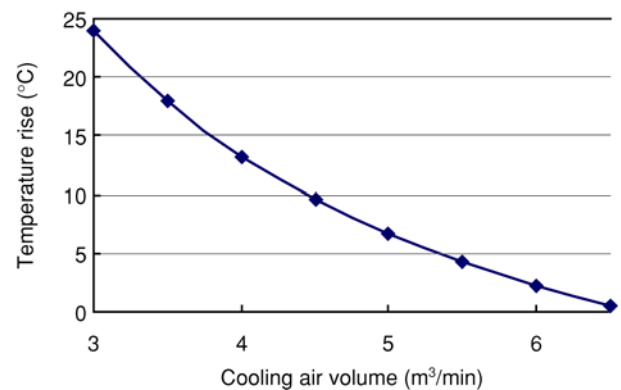


Fig. 10 Relation between temperature rises and cooling air volume

3.3.2. Confirmation of cooling air volume

Table 3 shows the results of the intake air temperature measured by the prototype unit at an air volume of 5.5 (m³/min). The alternator intake air temperature near the muffler was high, but other values were close to those of the open frame type. In addition, in order to evaluate the cooling capability, the results of the temperature measurements for the main parts must be considered. Table 4 identifies the results. Although slightly higher than with an open frame type, all are within the requirement limits.

Table 3 Intake air temperature

Intake air temperature	Open frame type (°C)	Prototype machine (°C)
Air cleaner	43	43
Recoil	43	46
Alternator	42	49

<ambient temperature : 40°C>

Table 4 Main parts temperature

Main parts temperature	Open frame type (°C)	Prototype machine (°C)
Oil	112	115
Plug seat	222	235
Carburetor gas	52	45
Main winding	90	100

<ambient temperature : 40°C>

4. Application on Generators for the Domestic Market in India

4.1. Background to Indian Noise Regulations

Most of the generator use in India is for emergency use during frequent power outages. The electrical power supply in India has not kept pace with economic growth. Per capita capacity of electrical generation facilities in India is 1/20th that of Japan, and comparing cities, Delhi has a capacity of approximately 1/40th that of Tokyo. In addition, due to poor transmission power networks and facilities, there is a transmission loss of approximately 45%. Therefore, power outages are chronic throughout the country. Generators used by individuals, shops, and small-scale offices, which account for 80% of generator users, begin operating simultaneously when power outages occur, so particularly in cities, generator noise and exhaust are large social concerns.

Therefore, the India government has enacted laws restricting the noise and exhaust gas emission from gasoline and kerosene powered generators.

Table 5 gives the specifics of timing and noise levels in the noise regulations.

Table 5 Noise limit for generator

	Phase I	Phase II
Application date	September, 2002	September, 2003
Sound power level (L _{WA})	90 dB(A)	86 dB(A)

4.2. Application to the EXK2000 (new sound isolation type generator)

The EXK2000 was developed, adopting the new 3-section structure. In addition to maintaining a cooling capability on a par with the open frame type, the new structure gives a noise value of 82.5 dB(A), which is an 11.6 dB(A) noise reduction in comparison with the open frame type EBK2000's 94.1 dB(A). The structure of the EXK2000 is given in Fig. 11, the external appearance is shown in Fig. 12, and the major specifications are given in Table 6.

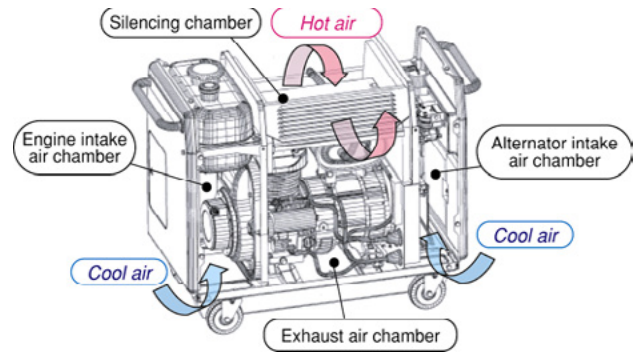


Fig. 11 Configuration of EXK2000



Fig. 12 EXK2000

Table 6 Major specifications

Model		EXK2000
Engine	Type	4-stroke SV
	Displacement (cm ³)	197
	Speed (rpm)	3000
Alternator	Type	Cylindrical type
	AC frequency (Hz)	50
	Max AC output (VA)	1600
	Rated AC output (VA)	1400
	DC output	12V-8.3A
Dimensions	Dimensions L × W × H(mm)	890 × 430 × 685
	Dry weight (kg)	76
	Sound power level [dB (A)]	82.5

5. Conclusion

The following results were achieved through research into sound isolation technologies for engine generators.

- 1) It was verified that by adopting a new 3-section structure for a sound isolation type generator, cooling capability equal to that of the open frame type is maintained while achieving sound isolation that is equal to or better than that of the conventional sound isolation type generator.
- 2) Applied to the EXK2000, it was possible to obtain approval for Phase II of India's noise restrictions, considered the world's strictest. This was the first generator in the world to meet India's Phase II requirements.
In addition, by adopting the 3-section structure to models with different output, both EXK1200 and EXK2800 were also able to obtain approval for Phase II of the noise restrictions.
- 3) By adopting the same structure, output equivalent to the open frame type generator can be maintained, and it is possible to change to the sound isolating spec.

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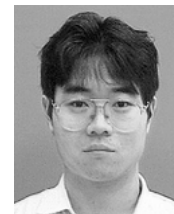
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