

An integrated experimental and computational approach to material selection for sound proof thermally insulated enclosure of a power generation system

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Abstract. Sound proof canopies for diesel power generators are fabricated with a layer of sound absorbing material applied to all the inner walls. The physical properties of the majority of commercially available sound proofing materials reveal that a material with high sound absorption coefficient has very low thermal conductivity. Consequently a good sound absorbing material is also a good heat insulator. In this research it has been found through various experiments that ordinary sound proofing materials tend to rise the inside temperature of sound proof enclosure in certain turbo engines by capturing the heat produced by engine and not allowing it to be transferred to atmosphere. The same phenomenon is studied by creating a finite element model of the sound proof enclosure and performing a steady state and transient thermal analysis. The prospects of using aluminium foam as sound proofing material has been studied and it is found that inside temperature of sound proof enclosure can be cut down to safe working temperature of power generator engine without compromise on sound proofing.

1. Introduction

Power generation systems are widely used in industry, defence and domestic applications. A power generation system consists of an engine of required power, power transmission system in the form of a gear box or pulley drives and a generator for producing output power. An enormous amount of heat and sound are generated during power generation process and need to be controlled. This paper presents a solution to engine overheating problem inside a sound proof enclosure through an integrated experimental and computation approach. Thermal insulation of the cabin is also required in order to prevent the heat from entering into a crew compartment. The thermal insulation further complicates the problem as the enclosure temperature continues to rise during the process making the ambient air available to the engine radiator hotter with the time. The sound proofing requirement limits the required air intake for the radiator resulting in engine overheating problem during the continuous operation. An optimum solution is developed providing sound suppression to required levels and ensuring smooth operation of engine without overheating. Various materials including PU, Aluminum foam and Glass wool are evaluated for cumulative required performance for thermal as well as sound proofing problem. Analytical methods, transient thermal analysis and experiments are used for obtaining the final solution and validation. A complete procedure is proposed for obtaining solution



for this problem of multi physics nature. After detailed analysis and comparison aluminium foam is suggested as preminent material for such type of application.

2. Literature review

Sound proofing of diesel generators has been a topic of interest for researchers in the past. Pish et al [1] developed a sound proof enclosure for a 0.3KW military purpose small engine. There are many engineering applications in which both sound proofing and thermal insulation needs to be treated simultaneously one such application is the automotive exhaust system. The exhaust pipe of automotive exhaust system passes through intricate spaces beneath the chassis. Berbner et al [2] developed a sound proof thermal shield to protect heat and sound from entering the automotive inner environment. Previously the sound thermal shield of exhaust system was made from two aluminum foil layers with a rock wool or glass wool layer sandwiched in between. Berbner et al used a special knit aluminum wire pressed in two layers of perforated aluminum foil. The added advantage of their design was that it can be reinstalled multiple times during repair works. A similar attempt has been made by Muller et al [3]. They use a perforated aluminum support layer that is placed such that it does not come in contact with the automotive body thus preventing the heat from exhaust system to be transferred to automotive main frame. Use of aluminum foam as sound proofing material in automobile has also been studied. Ilgaz Akseli [4] in his research work has used aluminum foam under the front hood of different automobiles and analyzed its effectiveness in terms of thermal conductivity and sound absorption coefficient against other commercially available sound proofing materials. Jorge P. Arenas and Malcom J. Crocker [5] have discussed in detail the latest trends in use of porous sound absorption material. They concluded that with the use of piezoelectric actuators a hybrid smart foam can be produced which utilizes both active and passive noise control techniques and covers a broad spectrum of sound waves. Jorge et al also concluded that new sound proofing materials are lighter, safer, environment friendly and can be recycled. Francois Xavier et al [6] in their research have developed a composite porous sound absorbing material by filling the perforations of a sound absorbing material with another porous material. One of the major disadvantages of fibrous sound proofing materials developed in early 1960 was their handling. These fibrous materials cause severe irritation when touched by a person also their fibers pollute the air in form of fine particles during installation. The environmental effect of various sound absorbing materials has been discussed by Francesco et al [7]. Another disadvantage of using fibrous material is the resistance to flow of air especially when the sound proofing material is applied to an area where air flow rate is of prime importance. Massimo et al [8] developed an empirical relation for the friction on polyester fiber materials. In this research work a comparison has been made between glass wool and aluminum foam as sound absorption material.

3. Problem statement

In this research work a diesel generator with specifications given in Table 1 have been selected.

Table 1. Diesel Generator general specifications

Generator Data	
Engine rated power at 2800 rpm	42 KW
Engine rated power at 2500 rpm	37 KW
Electrical power produced by Generator	16 KW
Oil cooler temperature	<75°C
Engine exhaust temperature	<160°C
Required Cfm	4200 l/m

The above generator is installed in a sound proofed cabin. The construction of cabin is such that the cabin frame structure is made up of steel box sections. The outer layer is of GI sheet 22 gauge (0.8mm thick). The inner lining is made up of glass wool bats packed in perforated steel sheet. The pockets

between main frame pipe sections are filled up with polyurethane foam. A schematic view of the sound proof cabin is shown in Figure 1.

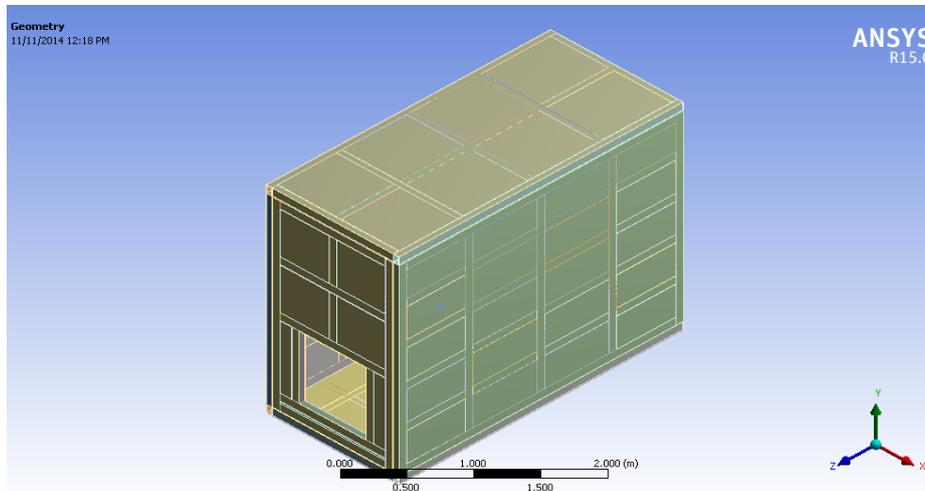


Figure 1. Sound proof cabin

The physical properties of different materials used in this research are given in Table 2.

Table 2. Physical Properties of Materials

Material	Density (Kg/m³)	Specific heat (J/Kg.K)	Thermal Conductivity (W/m.°K)
Steel	7850	434	60.5
PU	30	1500	0.03
Glass Wool	40	1400	0.02
Al Foam	700	890	30.0
Air	1.16	1007	0.026

To collect acoustic data, sound producing equipment needs to be tested in a perfect sound proof environment preferably anechoic chamber, since the sound produced by generator has a substantial difference with the ambient noise level of an open environment (≈ 60 db) away from traffic and machine/equipment noise therefore the first test of generator is performed in open space. The sound pressure level (SPL) produced by the generator was 105 db. The second test was performed by placing the generator inside the sound proof cabin. It was observed that majority of sound is coming from the engine radiator side. The reason behind is that the air flows along the length of engine as it is sucked up by radiator fan and blown out of radiator. The sound proof hood installed in front of the radiator attenuates this sound and bring it down to 80 db. It was also observed that engine gets over heated after an operation of 2 hours. After various experiments and analysis of data the root cause of engine heat up issue was found out to be reduced air at inlet and out let of sound proof cabin. This observation was inferred by measuring cfm of air at inlet and exhaust side of cabin. After removing the sound proof hood at exhaust side the engine heat up problem can be resolved but it takes up the sound pressure level to alarming limits of 95db

The main objectives of this research work was to operate the engine at its intended time stretch of 8hrs under allowable temperature limits and maintaining the sound pressure level < 80 db. To resolve this multi constrained problem the strategy adopted has been explained in next section.

4. Methodology

First of all data has been gathered through a series of experiments to identify all problems. It has been found through the experiments that there are five main contributors to the sound attenuation of generator set.

- I. Sound proof material applied to the inner walls of cabin (absorbs engine sound as it strikes the walls and restrict it to be transferred outside)
- II. Exhaust system of engine (takes heat and exhaust gases out of the cabin along with engine noise).
- III. Rubber mounts to install engine on the floor of cabin (controls engine rattling and vibrations transferred to the floor of cabin)
- IV. Strainers at inlet of cabin (to reduce the noise of air flowing in)
- V. Sound proof hood at cabin outlet (the hood is designed such that all the air going out of the cabin must strike some sound absorbing material on the way thus attenuating sound).

The contribution of above five aspects in attenuating generator sound level has been calculated by applying them in isolation with the others e.g. to calculate the effectiveness of sound proof hood, the hood is removed and engine is operated with air flowing free out of the cabin. The amount of contribution is shown in Table 3 in terms of sound pressure level.

Table 3. Parameters contributing to sound attenuation

Modifications in Generator and Cabin	Difference in Attenuation of Sound Pressure Level (db)	Percentage of contribution
Sound proof material at inner walls of cabin	4 db	16 %
Modification in Engine Exhaust System	2 db	8 %
Modified Rubber mounts	3 db	12 %
Strainers at cabin inlet	4 db	16 %
Sound proof hood at cabin outlet	12 db	48 %

As mentioned earlier the engine heat up problem is due to the insufficient amount of air entering and leaving the cabin. The air flow level can be maintained by removing the sound proof hood. From Table 3 it can be seen that by removing the sound proof hood required sound attenuation level cannot be achieved as it is contributing to 48% of the average noise control. To further strengthen this argument a steady state and transient thermal analysis of generator cabin has been performed. These analyses revealed that the glass wool material present on the inner walls of cabin is the cause of heat accumulation inside the cabin. When the hot air coming out of engine radiator is restricted it transfers heat to air surrounding generator through conduction and convection. This heat starts to accumulate inside the cabin as inner walls have a layer of glass wool which is thermal insulator. A steady state and transient thermal analyses are further performed by removing the inner glass wool layer. The results were better than the previous. In this case sound attenuation is further compromised by 12%. As case study aluminium foam is selected for sound proofing of inner walls of cabin. The thermal conductivity of aluminium foam is very high compared to glass wool (can be seen from Table 2). Aluminium foam can transfer heat quickly in addition to restricting the sound waves from crossing the cabin boundaries. The results with aluminium foam as sound proof material were even better.

A further investigation has been made by performing all the above analysis in two sets of ambient air condition. One is at ambient temperature of 30°C while the other is at ambient temperature of 50°C keeping in view the local extreme weather conditions. The reason behind these analyses was to check the heat transferring rate of aluminium foam in hot weather conditions. The steady state and transient thermal analysis performed in this research are further elaborated in the preceding section.

- A. Steady state and transient thermal analysis with insulation
- B. Steady state and transient thermal analysis without insulation
- C. Steady state and transient thermal analysis with Aluminium foam as sound proof material

5. Steady state and transient thermal analysis

To check the behaviour of sound proof cabin under various heat loads and thermal insulation both steady state and transient thermal analysis were performed. For transient analysis a time period of two hours was selected to check the operation of generator set in sound proof cabin with convective boundary conditions. The external heat load which is the ambient temperature was taken as 30°C and 50°C. The heat produced by the engine during operation was recorded through temperature sensors. The engine is modelled in the analysis as heat producing body. Engine is cooled continuously by air flowing on its surface by forced convection. The convection is taken as 5 W/m².°C. In heat producing bodies there is always a heat sink designed to allow a passage for heat flow. The thermal insulation on walls of the cabin was a hindrance in the path of heat flow as can be seen in the results given in Table 4 below.

Table 4. Steady state and transient thermal analysis

Analysis	Ambient Temperature 30°C		Ambient Temperature 50°C	
	With insulation	Without Insulation	With insulation	Without Insulation
Steady state	82.31°C	47.69 °C	85.265 °C	63.43 °C
Transient	79.87 °C	47.646 °C	83.621 °C	62.46 °C

The temperature is taken on all the walls roof and floor. In Table 4 the temperature of front wall near to the engine radiator is given. Maximum temperature is observed in this area.

There is a slight difference between values of temperature in steady state and transient analysis however the difference in temperature is large when analysis is done without insulation. At 30°C the difference in temperature is 32°C considering transient analysis. At 50°C the temperature difference is reduced to 21°C. The temperature values without insulation were a clear indication that temperature inside sound proof cabin can be further reduced by introducing a material that should act as a heat sink. For this purpose aluminium foam was selected, which can act both as sound absorber and heat sink. Another analysis was run with layer of aluminium foam on the walls and roof of sound proof cabin in placement of glass wool.

6. Comparison of results

The results of aluminium foam are compared with cabin walls with glass wool as sound proof material at 50°C ambient temperature.

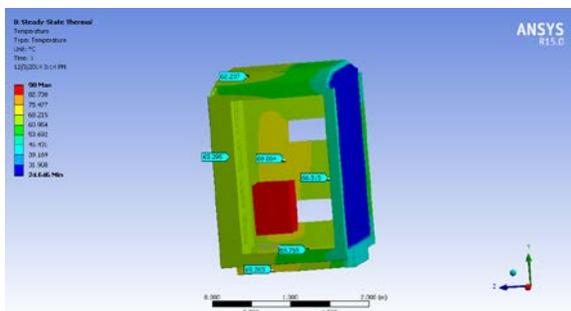


Figure 2. a) Temperature inside cabin with aluminium foam

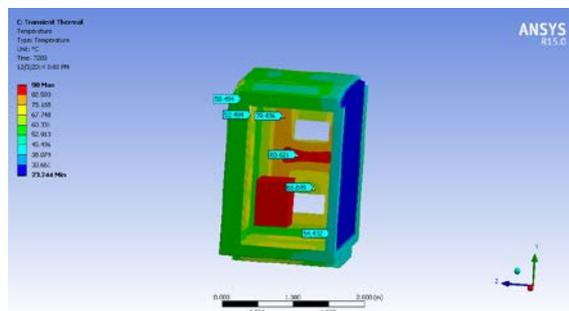


Figure 2. b) Temperature inside cabin with glass wool

It can be seen from Figure 2a and Figure 2b that temperature inside sound proof cabin has been reduced by the use of aluminium foam. As the properties of aluminium foam are slightly different from pure aluminium therefore the advantage of high thermal conductivity of pure aluminium cannot be gained however temperature difference of 21°C is still good enough to prove aluminium foam as suitable material for sound proof cabins of diesel generators.

7. Conclusion

A steady state and transient thermal analysis of sound proof cabin for diesel generator set has been performed with thermal insulator sound proof material, without sound proof material and with aluminium foam as sound proof material. It is concluded that glass wool has raised the cabin temperature beyond maximum allowable limits for safe working of diesel generator. By using aluminium foam the cabin temperature has been reduced substantially. A total removal of sound absorbing material is helpful in reducing temperature but sound absorption is compromised. It can be further concluded from this research that temperature effects inside a sound proof cabin are more profound at low ambient temperature than at higher temperature.

8. Future work

Air entering and leaving a sound proof cabin is major source of noise. As the air coming out of cabin is the only sound carrier, sound reduction can be achieved by designing sound proof hood at cabin exhaust point in front of the engine radiator. Care must be taken in designing of the sound proof hood as the reduction in volume of air leaving the cabin can elevate inside temperature of cabin. Aluminium foam can also be used in sound proof hoods as it does not deteriorate easily and has very low surface friction

9. References

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