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THERMAL MANAGEMENT INSIDE ACOUSTIC ENCLOSURE IN MOBILE POWER GENERATION SYSTEM (MPGS) FOR MILITARY ENGINEERING APPLICATIONS

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Abstract: In light of the rapid development in the field of advanced technologies, it is very much possible to develop advanced & compact mobile power generation systems, to synchronize with the real-time mission critical system. But in spite of this advancement, Systems designers and systems integrators are faced with the challenge of heat management because of size, weight, and power constraints specifically in defense sector. Power and thermal management considerations move to the forefront in the design, development, system engineering and integration of aerospace and defense systems. In mobile power generation system lot of mechanical, electrical & electronics subsystems are present. Heat generated by these subsystems are required to be handled very carefully in order to improve efficiency &reliability to prevent premature failure. This Paper discusses about design criteria & optimization for thermal management in acoustic container.

Keyword: Lube oil Pressure, Lube oil temp kilo watt, Kilo volt Amp, winding, temp, volumetric flow, Air velocity, Dry Correction Factor ,ambient Engine Room Temperature, Heat Radiated by the Generator (kW),Ventilating Air (m^3/min), Power supply system(PSS) etc.

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INTRODUCTION

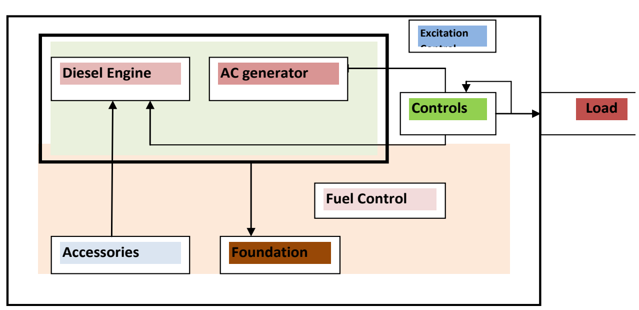
Reliable and efficient systems are indispensable for successful battle field operations. There is an ever increasing demand for specialized electrical systems for defense applications. Mobile or transportable type captive power generation systems are used as the main or standby power supply in the units of defense forces at forward areas. A great variety of vehicle or trailer mounted sets are available with defense forces, ranging in power output from 1 kW to about 125 kW. The majority employs medium speed diesel engines running at 1500 rpm of both the air-cooled and the water-cooled type. In the absence of utility power supply in remote areas, army units at field are wholly dependent on captive gensets. Today's military applications are more demanding than ever, with requirements to push the limits of bandwidth and performance while enduring intense environmental conditions. Survivability is critical, as sophisticated features are only as good as their ability to operate without fail. The rigors of battle in remote locations continue to present an evolving range of unique challenges to military system designers. Everything from severe temperatures, shock and vibration, to explosive decompression, immersion and exposure to sand and dust are variables that must be considered when building rugged, high performance systems for the armed forces. Innovative thermal management techniques have become essential to meeting these requirements for fault-free performance, and military designers are now making it a priority to solve cooling challenges early in the design phase. Thermal options will vary accordingly depending on application, expertise, cost and development time. As a result, it is necessary to have a thorough understanding of how designs generate heat and how design choices reliably dissipate that heat.In light of the rapid development in the field of advanced technologies such as latest engine technology, much faster solid-state power electronics devices, synchronous AC machines with higher power densities & their drives ,intelligent control systems, signal processors and the state-of-the-art energy storage technologies, it is very much possible to develop advanced mobile power generation systems , Electrical Drives & actuators to synchronize with the real-time mission critical system. But in spite of these advancement, Systems designers and systems integrators are faced with the challenge of heat management because of size, weight, and power constraints. Power and thermal management considerations move to the forefront in the design, development, system engineering and integration of aerospace and defense systems.

One of the most important considerations in the design and selection of a power supply is its thermal management because ; Heat-dissipation efficiency has a direct impact on the performance of a power supply system.. For the same lot of conventional as well as advanced technologies are available. Heat dissipation can include exhaust fans, ducts, blowers, louvers heat sinks for electronics and air intake cooling fans for air cooling, and other forms of computer cooling such as liquid cooling, heat pipes electronic cooling etc. In cases of extreme low environmental temperatures, it may actually be necessary to heat the electronic components to achieve satisfactory operation.

Considering the essentiality &potential applications for present and future, this work was carried out.In this paper, overview of PSS & subsystems is explained. Design methodologies arealso discussed. Thermal calculations are carried out using standard design equations. Some experimental results are also discussed.

II. DESCRIPTION OF POWER GENERATION SYSTEM

The mobile power Generation system shall consists of alternator which can be Radial or axial based PM machines A Turbo charged diesel engine shall be used as a prime mover to drive the above alternator. Also, a fuel tank with adequate capacity to enable continuous genset operation for up to ten hours along with engine starting batteries has been provided. The power output of genset shall be may routed through a Power Conditioning Unit to regulate and supply the required voltage & current to various users if required . There will be electronic control panel which will have display & protection units to display all electrical parameters. The Power to the load shall be routed through a Power distribution board (PDB) which shall be supported with a Transient Voltage Suppressor (TVS) and a grounding system. All the required accessories and tools shall be provided along with the power supply system. The DG sets and PCU shall be housed in a acoustically treated container .Acoustic treatment shall be provided for DG set compartment to arrest the noise level up to 75 dBA at one meter distance from the surface of container. The provision of grounding system shall be electrically connected to the ground, in order to supply ground to all electrical systems.



Block dia: Subsystems of PSS acoustic container

III. Aspects of System Design in An Acoustic Container for Efficient Heat & Power management

A diesel generator is the combination of a diesel engine with an electrical generator (often called an alternator) to generate electrical energy. Diesel generating sets are used in places without connection to the power grid, as emergency power-supply if the grid fails, as well as for more complex applications such as peak-lopping, Grid Support and export to the power grid. Sizing of diesel generators is critical to avoid low-load or a shortage of power and is complicated by modern electronics, specifically non-linear loads. The packaged combination of a diesel engine, a generator and various ancillary devices (such as base, canopy, sound attenuation, control systems, circuit breakers, jacket water heaters and starting system) is referred to as a "generating set" or a "genset" for short.

Generating sets are selected based on the Electrical load they are intended to supply, the

electricalloads total characteristics (kWe, kVA,var's and Harmonic Content including starting currents (normally from motors) and non-linear loads. The expected duty, for example, emergency, prime or continuous power as well as environmental conditions such as altitude, temperature and emissions regulations must be taken into account as well.Generating set requires adequate quantities of air inside the enclosure for combustion of engine, cooling of engine & alternator and ventilation system. There should be minimum nos. of cutouts in the enclosure for adequate cool air intake and hot air outlet; otherwise objective of noise reduction will be defeated. If the distance between the engine - alternator and enclosure wall is very small (i.e. a compact genset) then a systematic design approach has to be taken for suitable layout of all sub-assemblies of the generating set including proper cooling scheme in the enclosure.Air intake system should be designed to supply clean air to the engine & alternator at, or as near, site ambient temperature as is possible and with the minimum restriction. Both engine and alternator carcasses radiate heat. Approximately 8 % of the generator rating (in KW) is dissipated in such heat. It is therefore necessary to make provision for constantly renewing the air supply to the genset compartment in order to prevent undue temp. rise within it. Consideration should also be given to the need to remove the heat rejected by un insulated exhaust pipes and silencer (if it is inside the genset compartment) and by any other heat-producing auxiliary equipments in the machinery space. A temp. differential (between outlet and inlet air to the genset room) shall be maintained at between 15 to 20 deg C is usually satisfactory. All engines are fitted with crankcase breathers which prevent the build-up of pressure within the crankcase caused by blow-by from the pistons. The resulting fumes contain contaminants from the combustion process and minute globules of lubricating oil and will pollute the engine room if they are not directed to atmosphere.

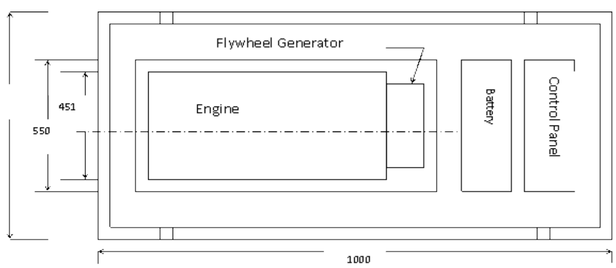
For water cooled engine, cooling radiator mounted on genset's base plate shall be positioned in the wall of the enclosure directly in line with the air flow through the radiator. There are two choices on air flow direction. The radiator's cooling fan may either be of the suction ('puller') type or of the pressure ('pusher') type. Pusher fans are usually capable of providing sufficient air flow to remove all heat rejected by the engine & alternator. Re-circulation of hot air must be avoided and it is preferable to use a flanged duct between the radiator and the wall opening. The length of the duct should be kept to a practical minimum. A short section of treated canvas or rubberized canvas should be included in the duct run to cater for expansion and to give flexibility where genset is fitted with anti vibration mountings. Re-circulation of hot air is also possible if air discharge and air inlet apertures are too close together.

Ductsshould be designed to minimize restriction of air flow. They should have sufficient cross-sectional area to ensure that back- pressure does not occur. If a long run of duct is unavoidable the cross-sectional area will need to be increased, as also willthe free area of the louvered aperture in the external wall. The total effective area of all inlet apertures to generator room should be at least 50 % more than that of the outlet vents. Where aspiration air is ducted to an engine's inlet manifold (or turbo charger) from an externally mounted air cleaner, care should be taken to ensure that the total restriction at the engine's intake point does not exceed the values permitted by the engine maker.

Special care has to be taken in the design of container housing air cooled engines. Cooling air is drawn into an engine- driven impeller and discharged through shrouding to the finned external surfaces of cylinders and cylinder heads. It is important that the hot air is expelled from the machinery space through a insulated duct to the atmosphere and is not re-circulated within it as this will cause both engine and alternator to overheat. All wall apertures should be protected with louvers against the ingress of rainwater and snow etc. Suitable shields/ filters should be provided for protection of the cooling air intake against dust and fine particles of sand in desert locations. Since noise created by gensets is a significant problem, silencing of generating set is an essential tactical requirement of arm forces. Moreover, reduction of noise level is now mandatory as Central Pollution Control Board, Govt. of India imposes a regulation on noise level limit for diesel generating set vide notification G.S.R. 371(E),dated 17 May 2002. Acceptable limit is up to 75 dB(A) at 1 meter. Hence, while doing the heat management it is very essential that the noise level shall be maintained at 75 dBA @ 1 mtrs distance, Reduction of noise pollution in DGSET is possible by controlling noise leakage from genset by designing of soundproof acoustic enclosure. The total spectrum emitted by a system using a diesel power generation system for mobile and stationary application will consists of engine related noise (exhaust, air intake cooling fan, radiation of combustion and mechanical noise) and alternator cooling fan noise. To control the sound and vibration, it depends upon a passive structure or device covering a relatively large fraction of an acoustic wavelength. The major drawback of this technique is that acoustic material has to be applied too close to the fans or duct elbows, thus restricting airflow and causing additional pressure drops and heat generation.

IV Design Methodology

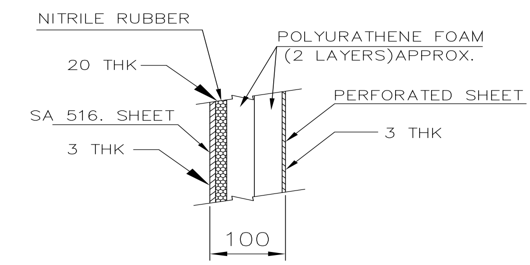
Design calculations are carried out for specific rating which is generally used for weapon system applications and some assumptions are also considered As this system is designed for defense system worst environmental conditions like high temp + 550 C and low temp with an altitude of 3000 meters has been considered. For the same deration factors were considered for selection of all subsystems like Engine, Alternator, Batteries, cables etc. The most important aspect is dimensions which is considered for this application is very compact.



The maximum site rating of a generator is obtained from the below relation.

Site KVA = (Nominal KVA) x (Derating factor)

Considering the worst derating factor as per BS 4999 standard for the environmental conditions as stated above, rating of the alternator is finalized. The axial flux alternator (Flywheel Alternator is used for this application.40kVA Flywheel Generator is a disc alternator which uses Axial Field Permanent Magnet (AFPM) technology wherein, the direction of the magnetic flux is along the shaft and that of the current is radial to the shaft. The system shall include a stator, a rotor. It shall use high energy permanent magnets such as Samarium cobalt, Neodymium Iron Boron (NdFeB) etc leading to an increase in the overall efficiency of the system as the ohmic losses in the field winding are no more present. Thisaxial flux alternator gives rated power (40kVA) at extreme environmental conditions. As this alternator takes input power from a diesel engine running at 2800rpm, the number of poles required for generating 400Hz power supply are calculated using formula [4] P= 120f/NS. The power output of the alternator at each frequency is given by S = 1.11 Kw 2 .B.ac. D2.L.ns x 10 -3 kVA.To drive the above selected alternator, turbo charged diesel engine is used as a prime mover considering de-ration factor. because size of the engine is smaller as compared to Naturally Aspirated (NA) engine. The current required to crank a diesel engine is a function of the Displacement of the engine either (in cubic inches or cubic centimeters), System voltage, Viscosity of engine oil, Temperature of engine oil, Lowest temperature of the battery, Efficiency of the starting motor. Considering all this factors engine starting battery is selected. Alternator and prime mover is l be mounted on a sturdy skid made of formed channel of MS sheet. Facility is also provided on the skid for lifting purpose. Reputed make anti-vibration mounts with Neoprene rubber or rubber suitable for extreme temperatures is provided between the flooring and the skid of the generating set to reduce the vibration and shock to the minimum while the set is in operation / transportation.



CROSS SECTION (X–X) OF ACOUSTIC ENCLOSURE

The fuel tank capacity for 10 hrs continues is calculated using equation. Fuel required for 1hrs. Run on full load =(Power output kW x SFC gm/kW-h/ (0.827 x 1000) Liters. After that, heat related calculations are carried out. Heat rejected inside the genset room/container is calculated using equation;

Qtot = 0.607 mj/hr/kW.(Ref. diesel generator handbook by LLJ Mahon p-468. Air flow required for ventilation (cooling combustion air) is given by Vtot=Vroom+ comb

Where, Vroom = air flow for cooling the generator room/container & Vcomb = air required for combustion of fuel in engine. Air flow for cooling the generator room/container is calculated using equation

Vroom = Qtot./(Cp x ΔT x d)

Where; Qtot. = Heat rejected inside the container,

Cp = specific heat of air in mj/kg/0c,

ΔT = generation room temperature rise in 0c and

d=density of air in kg/m^3

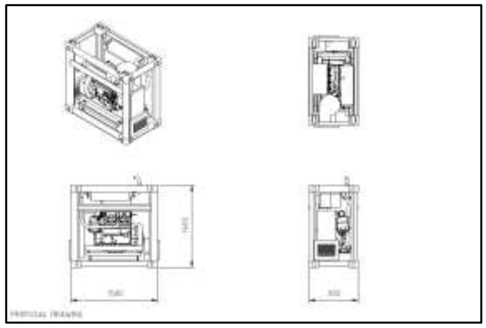
Air required for combustion of fuel in engine i.e. Vcomb is calculated using - cubic capacity of engine x no. of power strokes/min and combining both values gives you the term Air flow required for ventilation. The air flow required for ventilation is provided by the louver of suitable capacity which is calculated as using generic term i.e. The open area of the louver = air required for ventilation in cfm ÷ free area velocity in fpm. Heat radiated by other auxiliary system is also considered which 0.1percent of Vcomb is. Considering all these aspects exhaust & fresh air intake fans has been selected. As this is mobile system it should design to cater vibrations caused by the mechanical equipment. For the same Ant vibration mounts (AVM).By considering the percentage isolation, distribution and natural frequency, static & dynamic deflections and load per mount AVMs are selected using equation;

$$Isolation = \left[\frac{1}{\text{mod} of 1 - \left({fd}/{fn} \right)^2} \right]$$

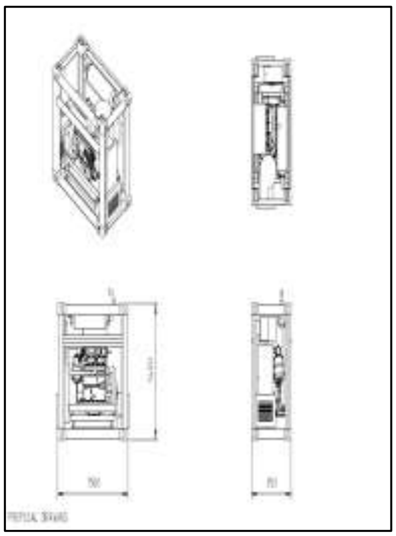
Acoustic container shall be designed for reducing the noise level of DG set to less than 75 dBA at a distance of one meter from the surface of the container. The cross section is as given below;

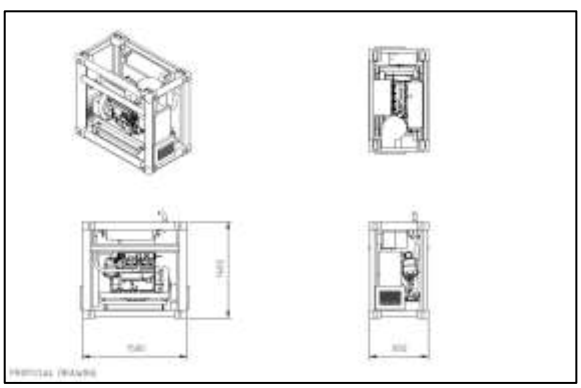
Cross Section of Acoustic Container

50/100 mm thick Melamine or Polyurethane of acoustic quality shall be used as sandwichmaterial between outside and inside claddings mentioned above Fig shows the various exploded views of generating set mounted in acoustic container where in all the subsystems are mounted in a confined space 1500x 1400x 850 (LXHXW)mm .



View of DG set layout in Acoustic container



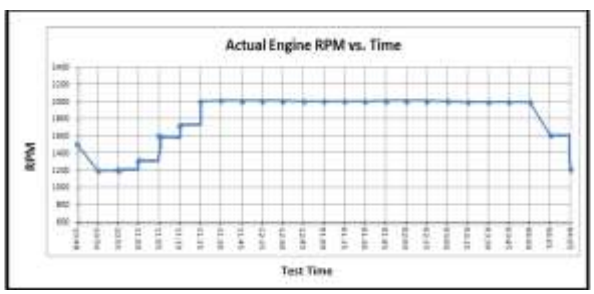


Front View of DG set layout in container

V. Experimental Results

Using above given design criteria, power generation system has been designed and developed for total 40-kVA power output The system has been tested under simulated conditions to study the characteristic and behavior in terms of all electrical Performance, Temp rise etc. The power generation system was under test for around 5 hrs and load was simulated as per the profile given. The voltage & frequency regulation, temp rise at various locations (at engine , alternator and PCS) where recorded which was within range irrespective of the load and Diesel Engine Speed. The noise level was measured at full load condition and the data found was satisfactory. The overall performance of the PSS was quite satisfactory during testing mins heat management thermal management inside the acoustic container &engineering inside the container is optimal.

Load in kW VS time graph



Actual Engine RPM VS time graph

View of DG set t in Acoustic container

VI. Conclusion:

Increasingly complex military systems are driving increased challenges in integrating effective thermal management methodologies. Designers are learning that making early choices about power dissipations, design layouts, paths for air flow and overall thermal performance has become essential to developing rugged systems suitable for mission-critical military environments. From the above work it can be concluded the system efficiency & reliability fully depends on heat management, proper system engineering & its implementation. As these systems are mission critical system shall be properly designed and tested to use it in the worst environmental conditions. Various advanced heat management techniques like electronic cooling, liquid and spray cooling etc. are can be utilized in power generation systems for weapon system applications.

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