Application Guidance Notes: Technical Information from Cummins Generator Technologies

AGN 088 – Air Flow and Cooling

COOLING AIR FOR AN ALTERNATOR

Both open air ventilated alternators and enclosed alternators with cooling sub-systems, must have a cooling system that operates at a certain temperature and volume of air through the alternator, to cool the components to a satisfactory temperature so that alternator does not overheat. The temperature that must be maintained is influenced by the air surrounding the alternator. This is commonly referred to as ambient temperature.

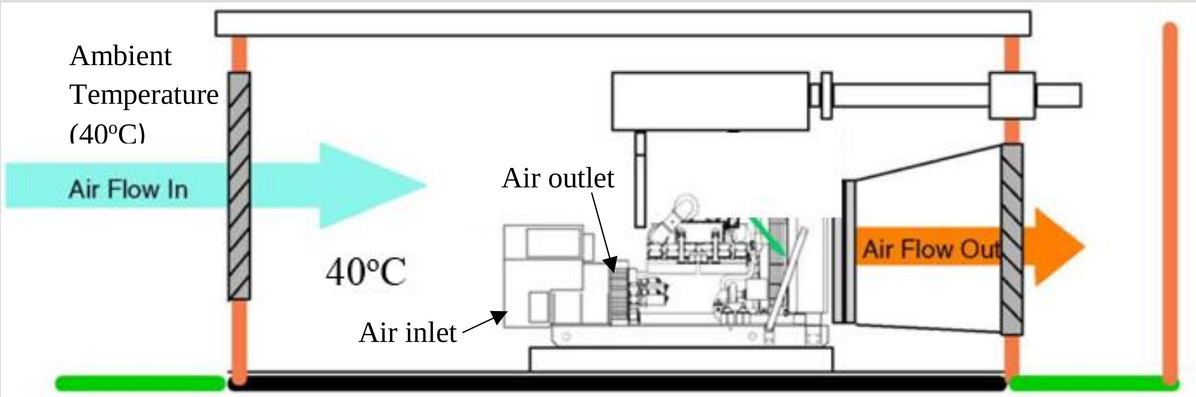

Figure 1: An example of a Generating Set cooling system design.

Ambient Temperature

Ambient temperature can be defined as the temperature of the surrounding air at a particular location. The internationally accepted standard value for industrial use alternators is 40°C.

Marine Societies set the ambient temperature for alternators installed in a vessel at either 45°C or 50°C. Alternators are designed and manufactured to operate in these ambient conditions at the base continuous ratings.

The ambient temperature measured should be that of the cooling medium. In the case of an air cooled machine such as an AvK or STAMFORD alternator, this would be the air inlet air temperature. This may be higher than the surrounding air ambient temperature, due to the heat generated by the prime mover within the confined space of an engine house.

It is essential that the total actual temperature does not exceed the limits set by the Class of insulation used. In some cases, especially marine machines, ambient temperatures higher than 40°C, are encountered.

It follows then, that an industrial alternator operating in an ambient temperature greater than 40°C, must be de-rated to ensure that total actual temperature does not exceed the specified maximum. The converse of this is also true; that by reducing temperature a greater output can be obtained from an alternator for the same actual temperature. This is permitted in most standards down to an ambient of 30°C.

The adjustments required to base continuous ratings for operating in various ambient temperatures is detailed in AGN012 – Environmental Rating Factors.

Airflow Through the Alternator

As a standard, industrial alternators are designed for use in a maximum ambient temperature of 40°C, and altitude no higher than 1000 meters above sea level. Ambient temperatures in excess of 40°C and altitudes above 1000 meters can be tolerated with reduced ratings. The internal air flow is moved by a fan fixed on the machine shaft which is designed to create a pressure drop which in turn cools the alternator rotor and stator windings. The air inlet is located at the non-drive-end of the alternator while the air outlet is located at the drive-end of the alternator as show in Figure 2. Cooling air flows into the alternator through the air inlet at 40ºC, cools the windings as it passes through the air gap (air path) and exit through the air outlet at about 70ºC.

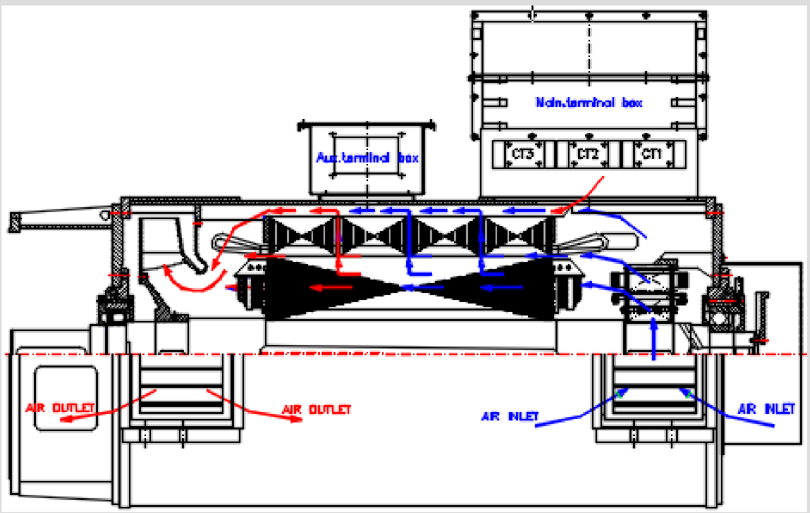

Figure 2: Example of the air cooled alternator.

Airflow requirements

If the Generating Set is installed in a building or enclosure, efficient cooling will depend on maintaining the condition of the cooling fan and air filters. There shall be no recirculating air in the Generating Set room to maintain the ambient temperature entering the room. If the operating environment differs from the values shown on the alternator nameplate, the rated output must be adjusted. The adjustments required are detailed in AGN012 – Environmental Rating Factors.

Determining airflow volume

The airflow volume required is set at the design stage of an alternator and is quantified through testing. The alternator cooling airflow information is published on the Technical Data Sheet and in the Owner's Manual. For a complete Generating Set, the ventilation system should sufficiently move air to control temperature in all areas of the engine room. Airflow testing using **BS-848** standard is recommended to measure total air flowing through an alternator.

The airflow volume of all the AvK and STAMFORD alternators is listed on the alternator's Technical Data Sheet, shown for the specific AvK alternator design or, for STAMFORD alternators, at both 50Hz and 60Hz running speeds.

STAMFORD

S4L1D-C41 Wdg.311

Electrical Data								
Insulation System	Class H							
Stator Winding	Double Layer Lap							
Winding Pitch	Two Thirds							
Winding Leads	12							
Winding Number	311							
Number of Poles	4							
IP Rating	IP23							
RFI Suppression	BS EN 61000-6-2 & BS EN 61000-6-4,VDE 0875G, VDE 0875N. Refer to factory for others							
Waveform Distortion	NO LOAD < 1.5% NON-DISTORTING BALANCED LINEAR LOAD < 5.0%							
Short Circuit Ratio	1/Xd							
Steady State X/R Ratio	11.86							
	50 Hz				60 Hz			
Telephone Interference	THF<2%				TIF<50			
Cooling Air	0.85 m³/sec				1.02 m³/sec			
Voltage Star	380	400	415	440	416	440	460	480
kVA Base Rating (Class H) for Reactance Values	250	260	260	250	288	310	315	325
Saturated Values in Per Unit at Base Ratings and Voltages								
Xd Dir. Axis Synchronous	3.14	2.95	2.74	2.34	3.77	3.63	3.38	3.20
X'd Dir. Axis Transient	0.20	0.19	0.17	0.15	0.24	0.23	0.22	0.21
X''d Dir. Axis Subtransient	0.14	0.14	0.13	0.11	0.16	0.15	0.14	0.13
Xq Quad. Axis Reactance	2.70	2.53	2.35	2.01	3.25	3.13	2.91	2.75
X''q Quad. Axis Subtransient	0.39	0.37	0.34	0.29	0.44	0.42	0.39	0.37
XL Stator Leakage Reactance	0.10	0.09	0.09	0.07	0.10	0.09	0.09	0.08
X2 Negative Sequence Reactance	0.28	0.26	0.24	0.21	0.30	0.29	0.27	0.26
X0 Zero Sequence Reactance	0.10	0.09	0.09	0.07	0.10	0.09	0.09	0.08

Figure 3: Cooling air volume – STAMFORD Technical Data Sheet.

AvK	Technical Data Sheet for AvK-Alternators	FM 7.3-5	
Date:	04/03/14	Customer:	Bitte Interessent eingeben!
Project No.:		AvK Reference:	1-608-0000058-1

Object data:			
Site:		Prime Mover:	
Application:	Stationary Power Plant	Manufacturer:	

Generator data:					
Generator:	DIG 130 g/4	Poles:	4	Standards: IEC 60034	
Rated power:	1250 kVA	1000 kWe	1055 kWm		
Power factor:	0.80				
Power at pf 1,0	1006 kVA	1006 kWe	1055 kWm		
Rated voltage:	13.8 kV				
Speed:	1800 1/min				
Frequency:	60 Hz		Voltage range / frequency range:		
Rated current:	52.3 A		Zone A according IEC 60034-1 (dU = +/-5%, df = +/-2%)		
Winding pitch:	ca. 5/6				
Insulation class:	Stator: Class F	Rotor: Class F		Temperature rise:	F
Ambient temperature:	50 ° C		Environment:	Standard environment	
Site altitude:	1000 m				
Enclosure:	IP23		Filter:		
Cooling:	IC 01 - Open-circuit ventilation				
Coolant:	Ambient Air	Temperature Coolant:	50 ° C	Temperature Air inlet generator:	50 ° C
		Cooling air vol.:	3.6 m³/s	Cooling water quantity:	n/a
Moment of inertia (I):	77 kgm²	Weight:	5900 Kg	Losses (environment):	55 KW
				Losses (cooling):	n/a

Wires:	4 terminals, starpoint connected in terminal box
Operation mode:	Single mode
Regulators:	
Voltage regulator:	DECS 100

Electrical data:	(acc. IEC)				
Efficiencies:	110%	100%	75%	50%	25%
Power factor 0.8	94,49	94,75	93,85	91,75	87,92
Power factor 0.9	94,82	95,07	94,08	91,98	88,28
Power factor 1.0	95,15	95,38	94,31	92,2	88,63

Reactances and time constants

	unsaturated	saturated			unsaturated	saturated							
x_d	1.34	1.21	p.u.	x_q	0.67	0.66	p.u.	$T_{d0'}$	2.7	s	$T_{d0''}$	0.02588	s
$x_{d'}$	0.207	0.207	p.u.	$x_{q'}$	0.67	0.66	p.u.	$T_{d'}$	0.42	s	$T_{q0'}$	0.3	s
$x_{d''}$	0.132	0.120	p.u.	$x_{q''}$	0.131	0.131	p.u.	$T_{d''}$	0.015	s	$T_{q0''}$	0.15344	s
x_2	0.138	0.125	p.u.	x_0	0.040	0.036	p.u.	T_a	0.07	s	$T_{q'}$	0.3	s
x_{1s}	n.a.	0.072	p.u.								$T_{q''}$	0.03	s

Short circuit ratio saturated: 0.83 Z_n 152.352 Ohm

Figure 4: Cooling air volume - AvK Technical Data Sheet.

Fan Laws.

Fan Laws, also known as Affinity Laws, govern the performance of geometrically similar Centrifugal fans. The 'Fan Laws' take known data for a fan and determine the performance of the same fan or another fan under different conditions; as a result the Laws are basically a ratio of known data to the data at another condition.

According to the fan law for volume flow, the airflow from a fan varies directly with the speed, e.g. double the speed and you get twice the air. It also varies with the cube of the diameter, e.g. double the diameter and you get 2 x 2 x 2 = 8 times the amount of air.

I.e. Volume flow;

$$q \propto n * d^3$$

Therefore, below fan law is used to calculate the new airflow q_{v2} based on a known airflow q_{v1} (as measured by **BS-848** standard) when changing rotational speed and/or fan diameter;

$$q_{v2} = q_{v1} \text{ x } (\frac{n_2}{n_1}) \text{ x } (\frac{d_2}{d_1})^3 \qquad \text{Equation 1}$$

Where

- q_v is the volume flow of air (m^3/sec).
- n is the rotational speed of fan (rpm).
- d is the diameter of fan (mm).

For example, if a fan speed is increased by 10% and the diameter of the fan is doubled. The new volume flow of air is calculated by;

10% increase in fan speed:

$$\text{Volume flow, } q_{v2} = q_{v1} \text{ x } (\frac{n_2}{n_1}) \text{ x } (\frac{d_2}{d_1})^3 \qquad \text{Equation 2}$$

In the example, only the fan speed has changed. The diameter component of the formula has been removed, as it has no impact on the outcome.

Therefore,

$$q_{v2} = q_{v1} \text{ x } (\frac{n_2}{n_1}) = q_{v1} \left(\frac{1.1}{1.0}\right) = 1.1q_{v1} \qquad \text{Equation 3}$$

Double the fan diameter:

In this example, the fan speed components can be ignored as only the diameter has changed.

Therefore,

$$q_{v2} = q_{v1} \text{ x } (\frac{d_2}{d_1})^3 = q_{v1} \left(\frac{2}{1}\right) = 8q_{v1} \qquad \text{Equation 4}$$

NB: The fan law can only be applied to fans, which are geometrically similar if there is a change in the diameter. It doesn't matter what units are used as long as the units for speed, diameter etc. are the same.

Alternator considerations for cooling ductwork

In applications where the Generating Set is installed in a small room or enclosure, the installation engineer should consider fitting cooling air ductwork to the alternator to ensure effective ambient temperature air flow into the alternators as shown in

Figure 3 on the next page.

Alternator air-inlet (Ducting)

Any ductwork that is to be used to supply cooling air to inlet for the alternator must be designed such that it allows this quantity of air to flow with a maximum pressure drop across the Air-in ductwork [with alternator running] of 12.7mm WG. The ductwork must be made with no 90^o [right angle] sharp bends and it must be of a large enough internal cross sectional area, chosen in conjunction with the overall length of the ductwork, to offer an absolute minimal pressure drop, therefore resistance to air flow, with better that 12.7mm WG being most desirable. A minimum distance of 600mm from the alternator air inlet and outlet openings to the Generating Set's walls is recommended.

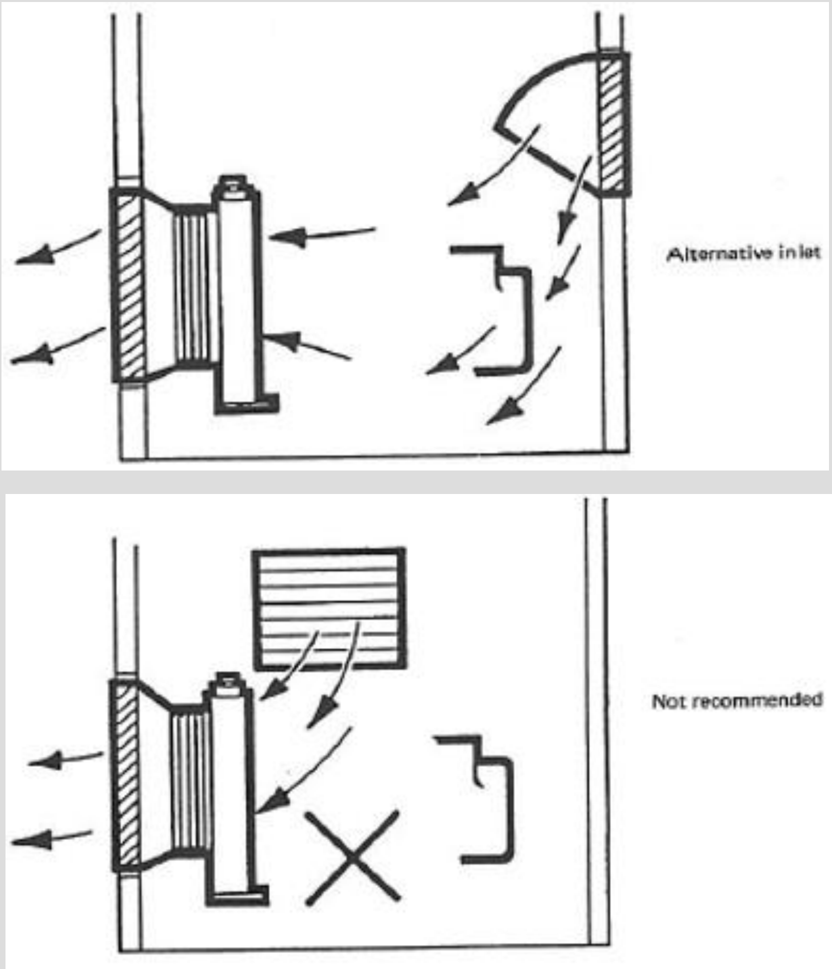

Figure 3: Examples of a flexible duct installation on a Generating Set. Ensure that air flows into the alternator and is not bypassed.

Alternator air-outlet (Ducting)

The air outlet ductwork must again be designed to incorporate no 90^o sharp bends, and be of a cross sectional area designed in conjunction with the ductwork overall length, such that the pressure drop across the ductwork with the alternator running is no more than 8mm WG.

The above values of 12.7mm WG on inlet, plus 8mm WG on the outlet, will reduce the overall volume of cooling air flowing through the alternator and so will cause the alternator to operate at slightly higher component temperatures. To compensate for this, the alternator should be de-rated by 5%. The total effective area of all inlet apertures to the plant rooms should be at least 50% more than that of the outlet vents.

It must be remembered that the alternator cooling airstream only takes away some 80% of the total alternator losses. The alternator's frame radiates the other 20% of the total heat losses. So, it is expected by the alternator manufacturer, that there will be an available supply of air at ambient air temperatures flowing along the sides of the alternator - in the same way that the engine manufacturer expects cool air to flow along the sides of his engine. Quite often this ambient airflow along the sides of alternator [and engine] is promoted by the fan that blows air through the engine radiator.

If it is proposed to have no circulating air around the outside of the frame of the alternator, then the de-rate factor must be some 25%.

There are no drawings of approved ductwork for AvK and STAMFORD alternators, because each installation of a Generating Set is different; therefore, requiring totally different ductwork shapes, cross sectional areas, overall lengths and designs for adapting/fixing the ductwork to alternator, whilst still allowing good access to the Generating Set for maintenance.

As a starting point, if the ductwork at both inlet and outlet is only some 1.5m long [at each end], then the cross sectional area of the inside of the ductwork should be twice the area that is designed at the alternator's Air-in and Air-out openings.

To assist with airflow and pressure drop reductions, the protective grilles at these openings can be removed, but the ductwork must be built with protective Grilles to stop objects being pulled into the alternator with the air flow.

Alternator considerations for cooling air slots

In some STAMFORD alternator frames, including the P7 and the new S Range products incorporating the CoreCooling™ technology, there are enhancements to the thermal management of the airflow.

The slots in the P7 frame are present as part of the overall cooling circuit of the P7 and are required in order to achieve the required cooling air flowing through the alternator to satisfy the published ratings of the P7 range. These slots are blanked off when air filters are fitted or when the IP44 package is fitted. Appropriate de-rates must then be applied.

- For fitting air inlet filters, a 5% de-rate to the published ratings is required.
- For the IP44 package, a 10% de-rate on the published ratings is required.

The CoreCooling™ technology designed in to the new STAMFORD S Range alternators is a key enabler to improve power density and deliver industry leading reliability to our customers. Design changes include:

- The introduction of axial and radial vents in the core pack.
- The redesign of the Drive End (DE) bracket.

Measurement types

If needed the installation engineer can install a thermometer or a multi-function thermal anemometers to measure air velocity, differential pressure, temperature, and humidity. The multifunction thermo-anemometers can calculate air flow, wet bulb, dew point, and turbulence. A water gauge should be fitted to measure pressure drop through the filter. Alternator manufacturers install resistance temperature detectors in the stator windings and bearings to monitor the operating temperature.

Air filters

Air filters as shown in
Figure 4 trap airborne particulates above 5 microns. The filters must be cleaned or replaced regularly as per service intervals, depending on site conditions. Dirty air filters, will cause the alternator to overheat, leading to premature failure of the insulation. Alternators with factory-fitted filters are rated to account for the reduced flow rate of cooling air. If filters are retrofitted, the alternator rating must be reduced by 5%.

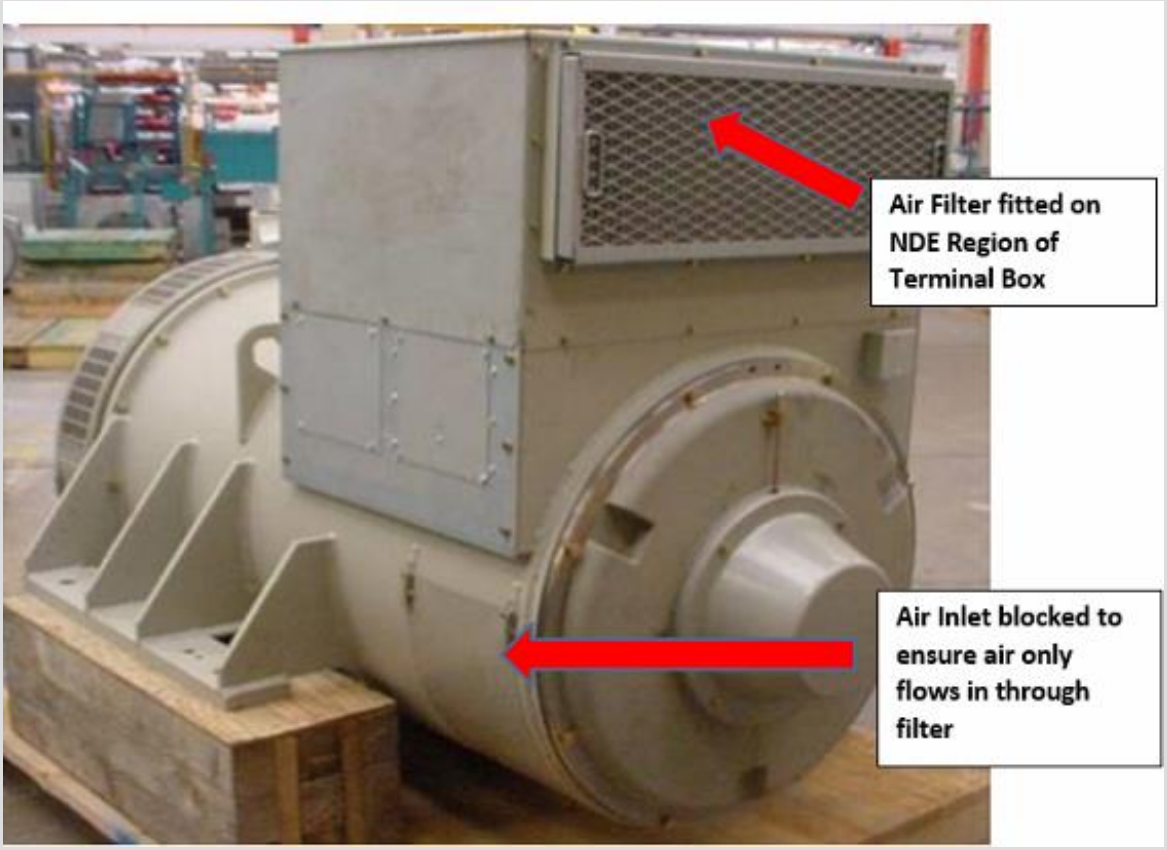

Figure 4: Example of an air filter installation on a CGT alternator.