Application & Installation Guide

Starting and Charging Systems

LEBW4980-12

Contents

1 Foreword

This section of the Application and Installation Guide generally describes Starting Systems for Cat® engines listed on the cover of this section. Additional engine systems, components and dynamics are addressed in other sections of this Application and Installation Guide.

Engine-specific information and data is available from a variety of sources. Refer to the Introduction section of this guide for additional references.

Systems and components described in this guide may not be available or applicable for every engine.

● Standard ○ Optional - Not Available	3126B	C7	C-9	C9	C-10 / C-12	C11 / C13	C-15 / C-16	C15 / C18	3412E	C27 / C32	3500	C175	3600	G3300 / G3400	G3500	G3600
Starters																
Electric Starter	○	○	○	○	○	○	○	○	○	○	●	●	-	●	●	-
Pneumatic Starter	○	○	○	○	-	-	○	○	○	○	●	●	●	●	●	●
Pneumatic Starter with Prelubrication	-	-	-	-	-	-	-	-	-	-	○	○	●	-	○	●
Hydraulic Starter	-	-	-	-	-	-	-	-	-	-	○	-	-	-	-	-
Starting Aids																
Jacket Water Heaters	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Battery Heaters	-	-	-	-	-	-	-	-	-	-	○	-	-	○	○	-
Ether Injection	○	○	○	○	○	○	○	○	○	○	○	○	○	-	-	-
Manifold Heaters	●	●	●	●	-	-	-	-	-	-	-	-	-	-	-	-

An engine starting system must be able to crank the engine at sufficient speed for fuel combustion to begin normal firing of the cylinders and keep the engine running. Startability of an engine is affected by factors such as ambient temperature, engine jacket water temperature, and lubricating oil viscosity. In addition, parasitic loads, usually associated with the driven equipment, can greatly influence the startability.

The diesel engine relies on heat of compression to ignite fuel. When the engine is cold, longer cranking periods or higher cranking speeds are necessary to develop adequate ignition temperatures. The drag due to the cold lube oil imposes a great load on the cranking motor. Oil type and temperature drastically alter viscosity; for instance, S AE 30 oil approaches the consistency of grease below 0°C (32°F).

Gas engines are spark ignited but are also affected by the drag due to cold lube oil. Fuel composition varies widely from site to site. Fuels with low energy content will lengthen the cranking time as these fuels burn slower and cylinder firing during start-up is more erratic than when using natural gas.

There are three types of starting systems normally used for Cat engines. They differ in the method of storing and recharging the energy required for restarting the engine.

Electric Starting Systems: Electrical systems use chemical energy stored in batteries. The batteries are automatically recharged by an engine-driven alternator or by an external source.

Pneumatic Starting Systems: Pneumatic starting systems use energy of compressed gas stored in pressure tanks. The tanks are automatically recharged by an electric motor or engine-driven-gas compressor.

Hydraulic Starting Systems: Hydraulic systems use hydraulic oil stored in steel pressure vessels under high pressure. The vessels are automatically recharged by a small engine driven hydraulic pump with an integral pressure relief valve.

Which One to Choose: The technology of all three of these systems is well developed. Any of the systems are easily controlled and can be configured to operate either manually or automatically.

2 Batteries

Batteries must store and discharge sufficient power to crank the engine long enough and fast enough to start the engine. Starting battery sizing guidelines are given in Section 4.3.

Ambient temperatures drastically affect battery performance and charging efficiencies. Maintain 21°C (70°F) temperature to assure rated output. Battery temperature should not exceed 52°C (125°F). The use of battery heaters is recommended when operating in cold climates. The heaters should be set to maintain battery temperature in the range of 21 to 32°C (70 to 90°F) for maximum effectiveness. The significance of colder battery temperatures is described in Section 2.2.

All battery connections must be kept tight and coated with grease or other terminal protectant to prevent corrosion.

2.1 Accessible Batteries

Accessible batteries are batteries where the caps can be removed to allow access to check the electrolyte levels and to top off the electrolyte (use de-ionized or de-mineralized water only) within the cells of the battery.

It is recommended to use accessible type batteries in all Genset applications. Genset applications commonly use a constant charge such as a float charge during operation and the use of this type of constant charge shortens the life of the battery (if the battery is not maintained properly). The use of accessible type batteries allows for proper maintenance (electrolyte level check) and service to the batteries, maximizing the life of the batteries.

If an accessible design is not available, a non-accessible design can be used but must be replaced after 3 years of service. For warmer geographical regions, replace the non-accessible battery within 2 ½ years.

The table below lists the recommended accessible batteries along with their non-accessible counterpart.

Group Size	Accessible	Non-Accessible
8D	101-4000	153-5720
4D	9X-9730	153-5710
4D	9X-9720	153-5700
31	155-2422 115-2421	9X-3404

2.2 Maintaining Accessible Batteries

Accessible batteries require periodic checks for proper electrolyte level. The electrolyte level should be covering the plates/grids (½ inch (13mm)) within the battery to maximize full charge transfer. If the liquid level is below the plates/grids, add **only** de-ionized water or mineral free water; never add battery acid to top off the volume, as the addition of extra acid will destroy the grids.

It is recommended to check the electrolyte level in the accessible batteries every 1000 hours. In warmer climates, check more frequently, such as every 500 hours to make sure the electrolyte level is ½ inch (13mm) above the top of the separators.

Battery Performance - Specific Gravity vs. Voltage			
Specific Gravity	**% Charge**	**Voltage per Cell**	**Freezes °F (°C)**
1.260	100%	2.10	–70 (–94)
1.230	75%	2.07	–39 (–56)
1.200	50%	2.04	–16 (–27)
1.170	25%	2.01	– 2 (–19)
1.110	Discharged	1.95	+17 (–8)

Temperature vs. Output	
°F (°C)	**% 80°F Ampere Hours Output Rating**
80 (27)	100%
32 (0)	65%
0 (-18)	40%

2.3 Battery Location and Hydrogen Venting

Battery compartments should be configured to allow easy visual inspection for terminal corrosion and damage.

Install batteries in well-ventilated compartments only. Batteries emit hydrogen gas during the recharging cycle. Hydrogen gas is highly explosive and very dangerous, even in small concentrations.

Hydrogen gas is lighter than air and rises harmlessly into the atmosphere unless trapped by a barrier, such as a ceiling, or within the battery compartment. Devices which can discharge electrical sparks or cause open flames must not be used where hydrogen gas is likely to collect or in the path of escaping hydrogen gas.

2.4 Battery Disconnect Switches (Battery Isolating Devices)

Solid-state electrical devices can be damaged by the use of battery disconnect switches. These switches often interrupt load bearing circuits and at the instant of a circuit disconnect, transient currents and voltages can cause failure in any component whose transistors are not specifically protected. ***Note:*** *Only use battery disconnect switches that do not cause voltage transients (spikes).*

Transient suppressers are to be used where applicable. Suppressers absorb current surges to prevent exposing these surges to sensitive electronic systems.

2.5 Battery Chargers

Various battery chargers are available to replenish a battery's charge. Trickle chargers are designed for continuous service on unloaded batteries and automatically step down to milliampere current when the batteries are fully charged. ***Note:*** *Overcharging shortens battery life. Excessive water losses may indicate overcharging. Conventional lead-acid batteries require less than 59.2 mL (2 oz) of make-up water during each 30 hours of operation.*

Float-equalize chargers are more expensive than trickle chargers and are used in applications demanding maximum battery life. These chargers include line and load regulation, and current limiting devices that permit continuous loads at rated output.

Chargers must be capable of limiting peak currents during cranking cycles or have a relay to disconnect during cranking cycles. Where engine-driven alternators and battery chargers are both used, the disconnect relay is usually controlled to disconnect the battery charger during engine cranking and running.

Engine-driven generators or alternators can be used but have the disadvantage of charging batteries only while the engine runs. Where generator sets are subject to long idle periods or many short stop-start cycles, insufficient battery capacity could threaten dependability.

Table: Optimum charging volts for 12-volt battery vs. temperature for lead acid batteries, ***utilizing a charger.*** *Use Caterpillar Data Sheet, PEHJ-0073 to identify chemical construction of Cat batteries to determine recommended charging voltages in the table.*

	Optimum Charging Volts for 12-volt Lead Acid Battery									
Temp °F (°C)	**MF CA/CA**		**SB**		**Low SB Hybrid**		**AGM**		**GEL**	
	Min Volts	Max Volts	Min Volts	Max Volts	Min Volts	Max Volts	Min Volts	Max Volts	Min Volts	Max Volts
176 (80)	12.90	14.70	12.60	13.20	12.60	13.80	12.90	13.50	12.80	12.90
140 (60)	12.94	14.74	12.64	13.24	12.64	13.84	12.90	13.54	12.80	12.94
104 (40)	13.32	15.12	13.02	13.62	13.02	14.22	13.02	13.92	13.02	13.32
68 (20)	13.80	15.60	13.50	14.10	13.50	14.70	13.50	14.40	13.50	13.80
32 (0)	14.46	16.26	14.16	14.76	14.16	15.36	14.16	15.06	14.16	14.46
-22 (-30)	15.90	17.70	15.60	16.20	15.60	16.80	15.60	16.50	15.60	15.90

3 Alternators

The following guidelines are for mounting and wiring of belt-driven charging alternators that come with Cat engines. Recommendations are given to help the user achieve satisfactory life and function of the product. Applications with non-typical requirements may have special considerations beyond the scope of this document.

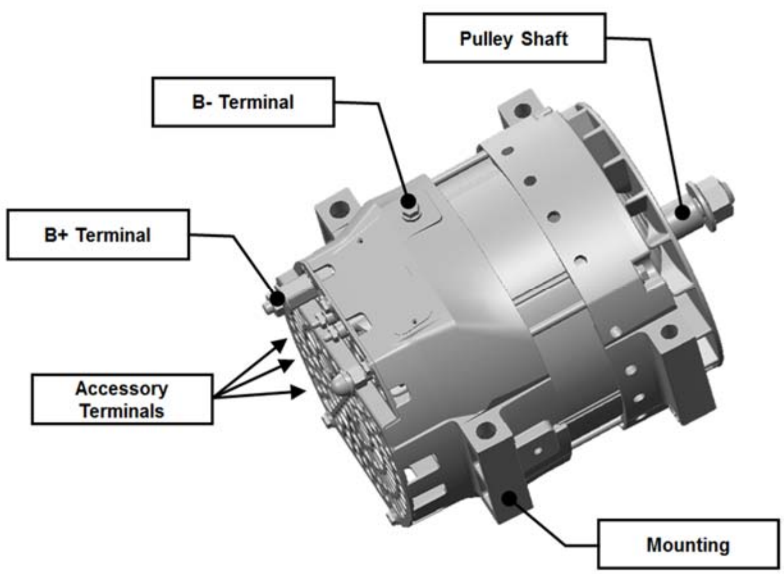
3.1 Battery Compatibility

Most Cat alternators have voltage regulation for use with flooded lead acid batteries. Some alternators have a user selectable switch that changes charging profile between lead acid, AGM, and deep cycle batteries.

Incorrect pairing of alternator and battery may cause over charging of the battery, shortened battery life, and increased risk of harm from thermal runaway depending on battery type.

3.2 Customer Touch Points

Customer touch points consist of mounting points to engine, pulley and belt installation, and electrical connections. No other hardware should be modified or removed from the alternator.



3.3 Mounting

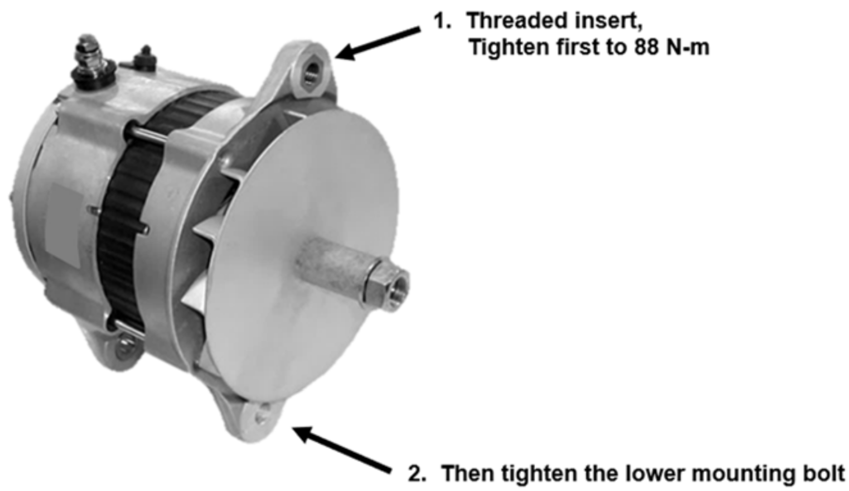
3.3.1 Pad Mount

The pad mount alternator has different size mounting holes front and rear. The front mount has a tighter fit to the mounting bolts to precisely align the alternator with the belt drive. The rear mount has larger holes with a looser fit to accommodate tolerance of hole position on the engine bracket. A hardened washer should be used with each bolt to avoid galling of alternator aluminum housing.

3.3.2 Hinge Mount

The alternator front mounting pivot stay is precisely located to align the alternator pulley to the belt drive. A thru-bolt is placed through the front and rear pivot stays, and the rear pivot stay is equipped with a floating bushing that takes the clamping force of the thru-bolt. The bushing should not be pulled flush against the alternator housing or else the housing may break from the stress applied by the thru-bolt. There should be no clearance between the bracket and alternator pivot stays after hardware is tightened.

Some types of alternator have a treaded insert in the top mounting ear for which a special assembly procedure and tightening torque must be used.



3.4 Pulley Shaft

3.4.1 Direction of Rotation

Most alternators are designed to rotate clock-wise, as viewed from the pulley end of alternator. The alternator will still function if rotated backwards but the performance of the cooling fan will be diminished, and the alternator may over heat.

3.4.2 Pulley Dimensions

The pulley should be able to slide on to the alternator shaft by hand, without forcing, and rest against the alternator fan or hub. The alternator part drawing shows critical dimensions of pulley to achieve compatibility.

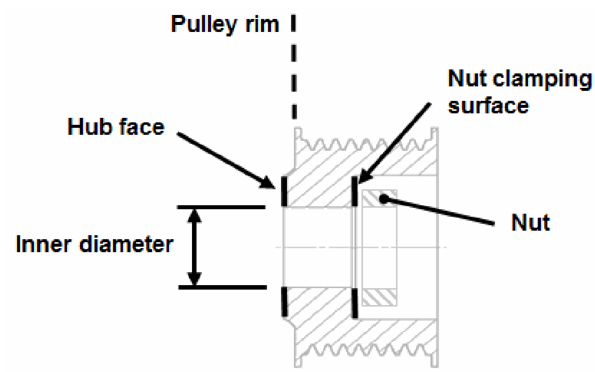
3.4.3 Shaft Key

If the alternator is equipped with a shaft key, then the pulley must have a complimentary keyway to keep the pulley from slipping on the shaft. Most alternators do not have a shaft key because the clamping force of the pulley nut is sufficient to keep the pulley from slipping. But high output alternators with large inertia are likely to have a shaft key.

3.4.4 Pulley Nut Torque Procedure

The alternator is provided with a pulley nut. A tool must be inserted in the end of the alternator shaft to back-hold the shaft while tightening the pulley nut. Different styles of tools are used depending on the type of alternator. See Section 3.8 for tightening torques and type of hold-back tool. Do not use the engine belt to hold the alternator while tightening the nut because belt stretch will prevent the nut from reaching proper tightening torque.

No paint is allowed on the inner diameter of the pulley, hub face that contacts alternator, or the surface under the nut. Paint will compress after tightening and may cause the nut to loosen.



3.4.5 Operating Speed

The alternator continuous speed rating should not be exceeded during normal engine operation, and the intermittent speed rating should never be exceeded. See Section 3.8 for maximum speed ratings.

Alternator pulley drive ratio should be chosen so that the alternator delivers adequate charging performance at lowest engine speed, without over speeding the alternator at highest engine speed. Alternator output typically peaks by 7,000 rpm so operating above that speed only wears the alternator more quickly with little benefit otherwise.

3.4.6 Belt Tension

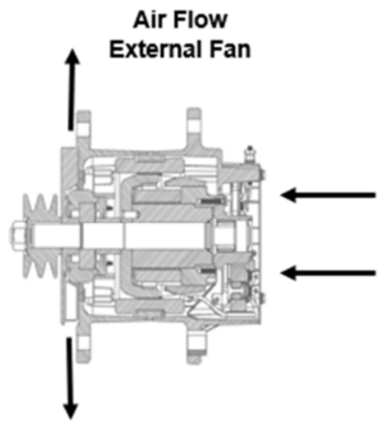
An auto tensioner is preferred since the tensioner sets correct belt tension and will automatically adjust as the belt stretches.

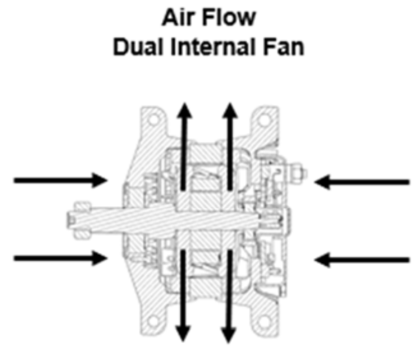
When manually setting belt tension, the tension should conform to specifications found on Caterpillar drawing number 7N-9693. Kent Moore or other manufactures offer tools to measure the belt tension.

A belt will ride high on the pulley grooves when first installed and the belt tension will relax immediately when the engine runs due to the belt seating deeper in the grooves. It is recommended to run the engine at least 5 minutes before setting final belt tension when using a manual belt tensioner.

3.4.7 Hand Guards

Any hand guards should not restrict air flow through the alternator.





3.5 Wiring of Alternator B+ and B-

3.5.1 Ground Path

Most alternators are fitted with a B- terminal and it is expected that the terminal be used and connected to a primary ground node of the machine system. The alternator can be tied to the starter B- post if the starter is connected to a primary ground node. An example of primary ground is machine chassis or other members connected directly to the battery B- cable. Engine and other members bolted to the frame are secondary ground and should not be part of the alternator grounding circuit.

Insulated ground alternators must have a B- cable or the alternator will not function. Case grounded alternators have parallel ground path by physical contact with the engine, but a solid and reliable ground path should be made at the B- terminal. A robust ground provides the most consistent regulation of system voltage throughout the life of the product.

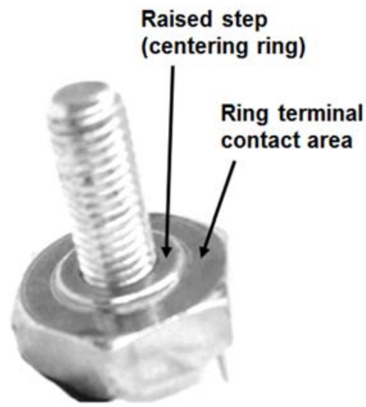
3.5.2 Cable Size

Alternator cable must be rated for continuous use at the maximum output of the alternator. Voltage drop in the entire charging circuit, from B+ to B-, should not exceed 0.5 V for 12V systems, and 1.0 V for 24V systems. Exceeding recommended voltage drop can result in undercharging of the battery.

The ground conductor should be of equal cross-sectional area as the alternator B+ cable and connected to a primary ground for the machine.

3.5.3 Terminal Step Nut

Some types of alternator have a step nut that accepts a ring terminal larger than the post size. In this design there is a raised step at the base of the stud that aligns the ring terminal. The ring terminal thickness must be greater than the height of the step so that the terminal can be firmly clamped in place by the terminal nut. See Section 3.8 for list of ring terminal sizes.



3.5.4 Terminal Stack

It is recommended that all alternators have only one cable connection regardless of terminal design. A step nut can accommodate only one ring terminal.

3.5.5 Terminal Strain Relief

Cable routing and clipping points should be prepared in a way that does not impart a physical load on the alternator terminals. The cable must be supported at a location on the engine within 12 inches (300 mm) of the terminal that moves in sync with the alternator. Flexible ground straps do not require special strain relief.

Overstress of the B+ terminal can cause the insulator to break with risk of battery short to ground. Close attention should be given to terminal stack, strain relief, and torque procedures.

3.5.6 Fastener Torque

All electrical terminals have special torque specifications because of the soft materials used in the terminal stud. A ‘customer nut’ is provided to tighten against the cable terminals. An inner jam nut secures the terminal to the alternator and must not be disturbed. See Section 3.8 for terminal torque specifications.

3.5.7 Circuit Protection

Alternator output varies with speed and temperature and can exceed the advertised rating shown on the part label. It is recommended that circuit protection is sized 15% above the alternator current rating to avoid nuisance faults. Circuit protection should be placed close to the battery, not the alternator, to protect cables in event of a battery short to ground.

Care should be taken to place circuit protection in a suitable location where ambient temperature does not cause too much current de-rate, or else the user may experience nuisance circuit protection trips.

3.5.8 Dual Alternators

Not all types of alternator may be used in multiple, parallel configuration within the same electrical system. Contact a Cat dealer for assistance if using dual alternators.

3.5.9 Battery Isolators

A battery isolator may cause voltage drop in the charging circuit resulting in undercharged battery. A 'Sense' terminal may be used to compensate for voltage losses in the charging circuit. See Section 3.6.4, *Sense Terminal (S, BS)*.

3.5.10 Battery-less Operation

Applications without a battery in the charging circuit must use an alternator compatible with battery-less charging. Only certain types of alternators can accommodate this type of function and voltage peak will increase with battery-less operation. Contact a Cat dealer for assistance to select correct alternator.

3.6 Accessory Terminals

A variety of accessory terminals may be available with an alternator. The following is a high-level description of the function and use of accessory terminals.

3.6.1 Lamp Terminal (L, D+)

Lamp terminal is used to drive a warning light. The terminal is a sink to ground when the alternator is not charging, or at system voltage when alternator is charging. Maximum allowable current must not be exceeded, or alternator will be damaged. See Section 3.8 for maximum current ratings.

Although the lamp terminal can be used as a low current power source, this kind of practice is discouraged due to risk of damage to alternator. It is recommended to use a protected circuit from elsewhere on the machine system.

3.6.2 Ignition Terminal (I, IG)

Ignition terminal is used to turn on the alternator. In some cases, the terminal can also drive a warning light. Use of the terminal is required with external-excite alternators, and optional with internal-excite alternators as a backup method to turn on alternator or to lower the turn on speed.

The terminal is connected to a switched power source, such as key switch, that is active when engine is running. Maximum allowable current must not be exceeded, or alternator will be damaged. Applying voltage to the terminal for long period of time while alternator is not in use can damage the alternator. See Section 3.8 for maximum current ratings.

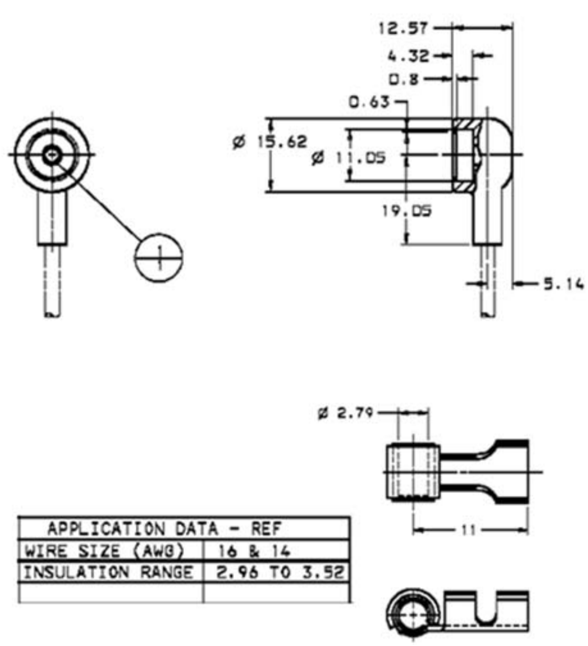
Although the ignition terminal can be used as a low current power source, this kind of practice is discouraged. It is recommended to use a protected circuit from elsewhere on the machine system.

3.6.3 Phase Terminal (R, P, W)

Phase terminal is used to drive an external device, such as hour meter or tachometer. The output is an AC square wave with a frequency proportional to alternator speed. Relationship between frequency and speed is shown in Section 3.8. Current limit must not be exceeded, or alternator will be damaged. This terminal should not be used for voltage diagnostics.

Alternators with the pin style R-terminal use a connector of the type shown in the drawing for Cat part number 9X-4997.

Caterpillar part number 9X-4997



3.6.4 Sense Terminal (S, BS)

Sense terminal can be used to regulate system voltage based on a voltage reference point external to the alternator. This can be useful with battery isolation or to compensate for large voltage drop in long runs of cable. Voltage measured by the Sense terminal will become the reference voltage for the alternator voltage regulator. Most alternator types will revert to internal voltage sensing when the Sense terminal is not used, or the circuit becomes disconnected.

3.7 Environment

3.7.1 Hazardous Operating Environment

Conventional starters and alternators may not be suitable in hazardous operating environments. Contact a Cat dealer for assistance if the application has such kind of requirements.

3.7.2 Paint

Alternator should not be painted and never exposed to chemicals used in the paint process to de-grease and etch metal. Doing so can remove protective coatings from internal components of the alternator.

3.7.3 Debris Screens and Ducting

A debris screen or ducted cover may need to be placed over the air inlet of the alternator when operating in environments with severe dust, organic chaff, wood chips, trash, or other types of airborne debris.

Debris screens are effective with particles that are too large to pass through the screen mesh. Some types of debris might cling to the screen and need to be brushed away periodically, even as frequently as daily.

Ducted covers are used with a hose that pulls air from a clean are source. Ducted covers are recommended for waste landfill applications or environments with airborne contamination that is highly corrosive. A debris screen should not be used in waste landfill since objects such as plastic bags can completely obstruct air flow to alternator.

Media type air filters are not recommended due to risk of restricting air flow to the alternator when the media becomes dirty. If a media filter is used, then very strict maintenance schedules should be followed.

See Section 3.8 for part numbers by group name

Alternator Model		Guard Type	Part No.
Group F, G	Hinge mount	Screen	183-7640
		Ducted	224-9665
	Pad Mount	Screen	
		Ducted	
Group I	all mounts	Screen	Front: 362-1181
			Rear: 362-1182
Group J	Hinge mount	Screen	239-7854
		Duct	239-7853
	Pad mount	Screen	248-4188
		Duct	248-4189
Group K	Hinge mount	Screen	292-4906
		Duct	292-4905
	Pad mount	Screen	293-0303
		Duct	293-0300

3.7.4 Ambient Air Temperature

The alternator cooling air supply should not exceed the maximum ambient temperature rating of the alternator. The alternator also should be protected from high temperature radiant heat sources.

3.7.5 Engine Fluid Spills

Service locations for engine or machine oil, fuel, coolant, and other fluids should not cause fluids to spill onto the alternator. Fluids spilled during service procedures may deteriorate seals and other non-metallic sub-components.

3.7.6 Cleaning of Alternator

Alternators should be cleaned by brushing or with compressed air. If water is used to clean the alternator, then the engine should be operated after cleaning to dry out the alternator. If the alternator is not dried, then it is possible for corrosion to seize the rotor to the stator.

3.8 Tables of Alternator Technical Data

Table 3.8-1, Alternator Mounting and Pulley Tightening

			Pulley Installation	
	Continuous Speed Rating	**Hinge mount threaded insert**	**Hold Back Tool**	**Tightening Torque**
Group A	15,000 rpm	no insert	Torx 50	95 ± 15 Nm
Group B	10,000 rpm	88 ± 7 Nm	Hex 5/16 inch	102 ± 7 Nm
Group C, D	10,000 rpm	88 ± 7 Nm	Hex 5/16 inch	102 ± 7 Nm
Group E	10,000 rpm	88 ± 7 Nm	Hex 5/16 inch	102 ± 7 Nm
Group F, G	10,000 rpm	88 ± 7 Nm	Hex 5/16 inch	102 ± 7 Nm
Group H	8,000 rpm	pad mount only	Hex 5/16 inch	102 ± 7 Nm
Group I	10,000 rpm	88 ± 7 Nm	10 mm triple square	100 ± 5 Nm
Group J, K	10,000 rpm	88 ± 13.5 Nm	Hex 8 mm	127 ± 10 Nm
Group L	8,000 rpm	no insert	Hex 8 mm	102 ± 7 Nm
Group M, N	8,000 rpm	pad mount only	Hex 8 mm	135 ± 5 Nm

Table 3.8-2, Alternator Electrical Terminal Specifications and Tightening Torques

	Alternator Electrical Application Data					
Group A	**Terminal Name**	**B+**	**B-**	**P, R, W**	**D+, L**	
	Ring Terminal Size	M8	M6	M5	M5	
	Tightening Torque	9 - 14 Nm	5 - 7 Nm	3 - 5 Nm	3 - 5 Nm	
	Maximum Allowable Current			4 Amp	1 Amp	
	R Terminal Calculation			rpm = (Hz) * (10)		
Group B	**Terminal Name**	**B+**	**B-**	**R**		
	Ring Terminal Size	7/16 inch	#10	push pin		
	Tightening Torque [N-m]	6.2 - 7.9 Nm	5.7 - 6.8 Nm			
	Maximum Allowable Current			4 Amp		
	R Terminal Calculation			rpm = (Hz) * (8.57)		
Group C	**Terminal Name**	**B+**	**B-**	**R**	**I**	
	Ring Terminal Size	7/16 inch	1/4 inch	push pin	#10	
	Tightening Torque [N-m]	9 - 13.5 Nm	5.7 - 6.8 Nm		1.7 - 2.8 Nm	
	Maximum Allowable Current			4 Amp	1 Amp	
	R Terminal Calculation			rpm = (Hz) * (10)		
Group D	**Terminal Name**	**B+**	**B-**	**R**	**I**	
	Ring Terminal Size	7/16 inch	1/4 inch	push pin	#10	
	Tightening Torque [N-m]	6.2 - 7.9 Nm	5.7 - 6.8 Nm		1.7 - 2.8 Nm	
	Maximum Allowable Current			4 Amp	1 Amp	
	R Terminal Calculation			rpm = (Hz) * (10)		
Group E	**Terminal Name**	**B+**	**B-**	**R**		
	Ring Terminal Size	7/16 inch	1/4 inch	push pin		
	Tightening Torque [N-m]	12.4 - 14.7 Nm	5.7 - 6.8 Nm			
	Maximum Allowable Current			4 Amp		
	R Terminal Calculation			rpm = (Hz) * (7.5)		
Group F	**Terminal Name**	**B+**	**B-**	**R**	**I**	
	Ring Terminal Size	7/16 inch	1/4 inch	push pin	#10	
	Tightening Torque [N-m]	6.2 - 7.9 Nm	5.6 - 6.8 Nm		1.7 - 2.8 Nm	
	Maximum Allowable Current			4 Amp	1 Amp	
	R Terminal Calculation			rpm = (Hz) * (7.5)		
Group G	**Terminal Name**	**B+**	**B-**	**R**	**I**	**S**
	Ring Terminal Size	7/16 inch	1/4 inch	push pin	#10	#10
	Tightening Torque [N-m]	6.2 - 7.9 Nm	5.6 - 7.9 Nm		1.7 - 2.8 Nm	1.7 - 2.8 Nm
	Maximum Allowable Current			4 Amp	1 Amp	
	R Terminal Calculation			rpm = (Hz) * (7.5)		

Group H	**Terminal Name**	**B+**	**B-**	**R**	**I**	**S**
	Ring Terminal Size	7/16 inch	1/4 inch	push pin	#10	#10
	Tightening Torque [N-m]	9 - 13.5 Nm	5.7 - 6.8 Nm		1.7 - 2.8 Nm	1.7 - 2.8 Nm
	Maximum Allowable Current			4 Amp	1 Amp	
	R Terminal Calculation			rpm = (Hz) * (10)		
Group I	**Terminal Name**	**B+**	**B-**	**R**	**I, D+**	**S**
	Ring Terminal Size	M8	M6	M5	M5	M5
	Tightening Torque [N-m]	12 - 18 Nm	5 - 7 Nm	3 - 5 Nm	3 - 5 Nm	3 - 5 Nm
	Maximum Allowable Current			2 Amp	500 Ω resistor	
	R Terminal Calculation			rpm = (Hz) * (10)		
Group J, K	**Terminal Name**	**B+**	**B-**	**R**		
	Ring Terminal Size	7/16 inch	1/4 inch	push pin		
	Tightening Torque [N-m]	15.8 - 20.6 Nm	3.4 - 5.4 Nm			
	Maximum Allowable Current			0.5 Amp		
	R Terminal Calculation			RPM = (Hz) * 7.5		
Group L	**Terminal Name**	**B+**	**B-**	**R**	**L, D+**	
	Ring Terminal Size	5/16 inch	1/4 inch	push pin	#10	
	Tightening Torque [N-m]	11.3 - 12.4 Nm	7.9 - 9.0 Nm		25 - 30 in-lb	
	Maximum Allowable Current			1 Amp	300 mA	
	R Terminal Calculation			RPM = (Hz) * 7.5		
Group M	**Terminal Name**	**B+**	**B-**	**P**		
	Ring Terminal Size	M10	M8	push pin		
	Tightening Torque [N-m]	15 ± 1 Nm	10.8 ± 1 Nm			
	Maximum Allowable Current			2 Amp		
	R Terminal Calculation			RPM = (Hz) * 10		
Group N	**Terminal Name**	**B+**	**B-**	**P**		
	Ring Terminal Size	M10	M10	push pin		
	Tightening Torque [N-m]	15 ± 1 Nm	15 ± 1 Nm			
	Maximum Allowable Current			2 Amp		
	R Terminal Calculation			RPM = (Hz) * 10		

Part Number	Group Name
107-7977	Group D
112-5041	Group E
117-1379	Group C
121-4134	Group C
125-9597	Group C
132-2156	Group D
148-6877	Group C
169-3345	Group J
177-9953	Group J
185-5294	Group J
197-8820	Group J
200-2232	Group F
200-8277	Group F
200-8281	Group F
204-7449	Group F
226-7683	Group J
229-2348	Group F
234-4906	Group F
235-7132	Group J
235-7133	Group J
249-0313	Group K
249-4332	Group F
249-7050	Group F

Part Number	Group Name
266-7224	Group G
266-7225	Group G
266-7226	Group G
266-7227	Group G
266-7228	Group G
272-1889	Group K
276-8899	Group F
298-8838	Group E
305-5530	Group F
305-8921	Group G
306-2172	Group L
306-2173	Group L
306-2174	Group L
316-7251	Group F
321-8902	Group A
321-8940	Group F
322-9743	Group H
329-2547	Group B
331-5717	Group G
333-1184	Group G
336-1558	Group L
344-5081	Group I
346-6147	Group I

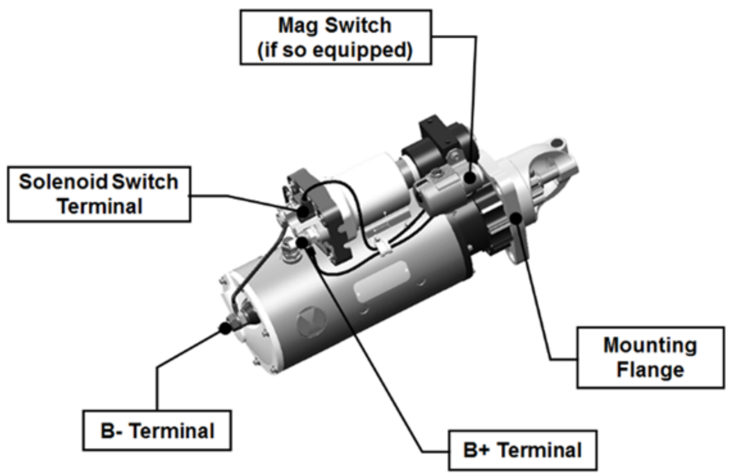
Part Number	Group Name
350-7073	Group J
352-4699	Group I
352-4700	Group I
362-0732	Group G
362-3375	Group G
366-0669	Group I
366-2756	Group I
3E-7577	Group E
3E-7892	Group E
421-7193	Group M
437-0124	Group M
437-0125	Group M
469-2859	Group G
485-7793	Group B
542-1228	Group N
561-2986	Group J
561-2998	Group J
561-2999	Group J
561-3000	Group J
561-3001	Group J
561-3002	Group K
566-9549	Group J
5N-5692	Group B
6N-9294	Group B
7G-7889	Group B

4 Electric Starting Motors

The following guidelines are for mounting, wiring, and control of electric starters that come with Cat engines. Recommendations are given to help the user achieve satisfactory life and function of the product. Applications with non-typical requirements may have special considerations beyond the scope of this document.

4.1 Customer Touch Points

Customer touch points consist of mounting points to flywheel housing and electrical connections. No other hardware should be modified or removed from starter. No additional brackets or devices should be attached to the starter. Any additional mass or improper tightening of fasteners may cause hardware to fail or introduce a leak path.

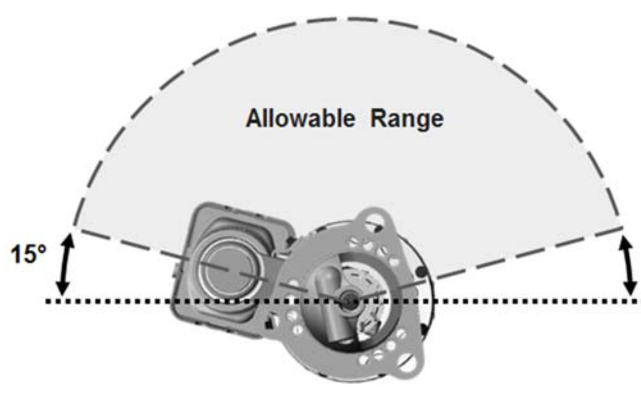


4.2 Mounting

4.2.1 Solenoid Orientation

Most starters have restrictions of how the solenoid may be oriented when starter is mounted to the engine. Temporary tilt during operation is normal and does not have to be considered.

Although specifications vary by starter design, a general rule of thumb is that the solenoid is oriented more than 15° above the horizontal plane. If the solenoid or motor body is equipped with a drain tube, then the tube should be facing downward within 15° of the vertical plane.



4.2.2 Bolted Joint

The starter can be mounted to the flywheel housing using bolts or studs. A 12-point flange bolt is often needed to give tool access. A stud is useful when the shape of the starter obstructs access of a bolt. Starters with aluminum mounting flange should have a hardened washer to prevent galling and yielding of aluminum flange material.

Fastener	Torque (N-m)	Strength
3/8” bolt	47 ± 9	Grade 8
5/8” bolt	215 ± 40	Grade 8
M10 stud M10 nut	18 ± 4.5 44 ± 11	Class 8.8
M12 stud M12 nut	25 ± 6.2 78 ± 19	Class 8.8
M10 bolt	55 ± 10	Class 10.9
M12 bolt	100 ± 20	Class 10.9
M16 bolt	240 ± 40	Class 10.9

4.2.3 Sealing and Oil Splash

The starter motor mounting flange is sealed to the flywheel housing using either a gasket or O-ring. The flywheel housing lead-in chamfer must not exceed 1.5 mm so that O-ring is seated to the flat surface beyond the chamfer.

Starters applied in applications with wet flywheel housing must use a starter that is rated for oil splash. Oil temperature at the starter should not exceed 100°C, and air pressure inside the flywheel housing must not exceed 5 psi (35 kPa). Oil level inside the flywheel housing must be below the line of the starter pinion gear. Failure to meet these guidelines will cause oil to be forced into the starter.

An air exchange does occur between flywheel housing and starter motor. High humidity inside the flywheel housing can foster corrosion inside the starter. Enclosed flywheel housings that are dry should have adequate measures to prevent accumulation of water inside the flywheel housing.

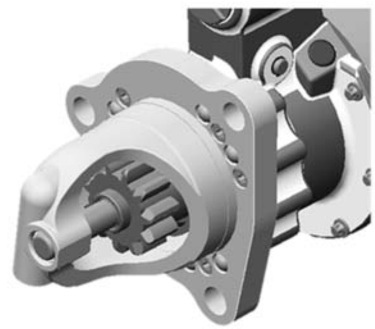
See Section 4.8 for list of part numbers by Class description

Starter Flange (SAE J542)	Seal Part No.	Use with Starter
Type 1	3K-3257	For general use
Type 1 (non-standard)	7N-6494	Class I, J
Type 2 and 3	9Y-6089	For general use
	303-2004	Alternative to 9Y-6089
	290-5728	Class S, T, U
O-ring	423-9049	Class R
	490-2370	Class M, N, O, P
	351-8955	Class H, J

4.2.4 Open Flywheel Housings

Applications with open (flywheel exposed) flywheel housing can expose the starter pinion gear to dusty conditions. Some types of starters have an external drive assembly that can develop restricted pinion movement due to dust accumulating on the shaft splines. In such cases it is recommended to use a starter with a noseless design where only the pinion gear is external to the starter.

Noseless Design



Nose Design
with exposed drive assembly

4.3 Starting Batteries

4.3.1 Battery Type

Use only flooded lead acid, or AGM type batteries. Alternative battery technology, such as Nickel-Cadmium and Lithium-Ion, have low internal resistance that can damage to the starter.

4.3.2 Battery Sizing

It is recommended in order to size batteries and validate performance that starting data be gathered from the complete machine system at cold rated temperature. The following general guidelines can be used if insufficient data exists to evaluate battery size. These guidelines are per starter in the engine system. Assumptions are 80% of rated current at 0°C, and 100% of rated current at -25°C. Using batteries with too high of CCA rating can cause damage to the starter motor.

See Section 4.8 for list of starter part numbers by Class description

	Starter Motor		**Battery CCA**	
	Starter Type	Maximum Rated Current	0°C Ambient	-25°C Ambient
12 Volt	Class S	1200 Amp	1800 CCA	--
	Class C	1650 Amp	2250 CCA	--
	Class G	2000 Amp	3000 CCA	--
24 Volt	Class T, U	700 Amp	900 CCA	2000 CCA
	Class R	850 Amp	1000 CCA	2000 CCA
	Class D, F	850 Amp	1000 CCA	2000 CCA
	Class N, P	710 Amp	1000 CCA	2000 CCA
	Class M, O	825 Amp	1300 CCA	2000 CCA
	Class H, I, J	1000 Amp	1300 CCA	2600 CCA

4.4 Wiring of Starter B+ and B-

4.4.1 Cable Size

The starter is an intermittent device not rated for continuous use. Battery cable is sized for maximum allowable circuit resistance or maximum allowable temperature rise, whichever results in larger cable size.

1. **Resistance**: The total resistance of the crank circuit, from Battery B+ to Battery B-, should not exceed 0.002 Ohm for 24V systems, and 0.001 Ohm for 12V systems. Include all cables and connections in the calculation or measurement.

2. **Temperature Rise**: The short-term rating of a conductor is far greater than the long-term steady state current rating. The 90 second rating of a conductor can be calculated by,

   $$I_{100} = 12.56\ (CCSA)$$

   Where I_{100} is the current to raise the conductor temperature by 100°C, and *CCSA* is the conductor cross-sectional area in units of mm^2.

The ground conductor should be of equal cross-sectional area as the B+ cable and connected to a primary ground for the machine. See Section 4.4.6, *Ground Path* for explanation of a primary ground.

4.4.2 Terminal Stack

The number of connections at starter B+ or B- terminal should not exceed a maximum of three (3) cable or wire terminals, and no more than two (2) cables of 0 AWG size or larger.

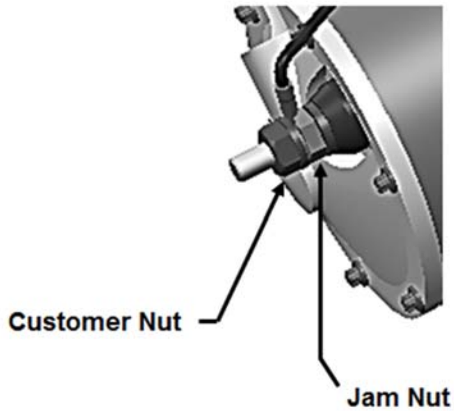
All required nuts and washers are included with the starter. No spacers or threaded extension devices shall be attached to, or cantilevered off of, the B+ terminal. The starter main battery cable should be placed on the post first in the sequence of assembly before stacking additional wire leads.

4.4.3 Terminal Strain Relief

Cable routing and clipping points should be prepared in a way that does not impart a physical load on the starter terminals. The cable must be supported at a location on the engine, within 12 inches (300 mm) of the terminal that moves in sync with the starter motor. Avoid tight bends in the cable that place stress on the terminal. Flexible ground straps offer an advantage because it does not require strain relief.

4.4.4 Fastener Torque

All electrical terminals have special low-torque specifications because of the soft materials used in the terminal stud. A 'customer nut' is provided to tighten against the cable terminals. An inner jam nut secures the terminal to the starter and must not be disturbed. See Section 4.8 for terminal torques of starter motors.



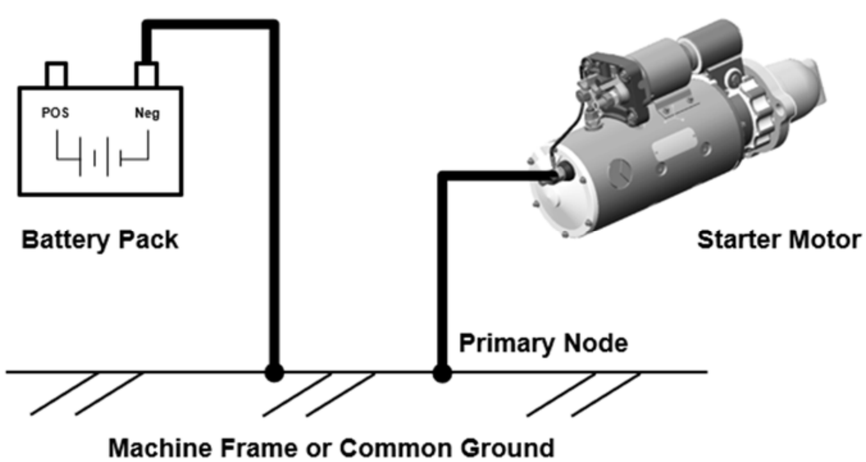
4.4.5 Terminal Protection

A protective boot should be used to prevent short circuit of B+ terminal. The boot should be oriented to not trap fluids or be equipped with a drain hole.

4.4.6 Ground Path

Most starters are fitted with a B- terminal that carries current of the cranking motor and solenoid. If a B- terminal is provided, then it is expected that the terminal be used. Insulated ground starters must have a B- cable or the starter will not function. Case grounded starters have parallel ground path by physical contact with the engine, but a solid and reliable ground path should be made at the B- terminal.

The ground cable should be connected to a primary ground node. An example of primary ground is machine chassis or other members connected directly to the battery B- cable. Engine and other members bolted to the frame are secondary ground and should not be part of the starter grounding circuit.



4.4.7 Ground Isolation

Some applications require the starter B- to be isolated from the electrical system when not in use. In such cases an insulated ground starter is needed in conjunction with a starter isolation switch on the starter B- cable. Guidelines are given in document LEDM0010, *Starting Motor Wiring for Vessels with High Isolation Requirements.*

4.5 Wiring of Starter Control

The starter control circuit governs the action of the starter solenoid, throw of pinion gear, and closing of electrical contacts for the cranking motor.

Some types of starter have the customer connection at the starter solenoid, whereas other types of starter have the customer connection at the starter mag switch. The following guidelines address both methods.

4.5.1 Method 1: Direct Solenoid Control

Starters with customer connection at solenoid need a single wire connection to the solenoid Switch terminal. The circuit ground path is integral to the starter. The starter is switched ON when system voltage is applied; and switched OFF when voltage is removed

Voltage at the solenoid Switch terminal must be within 1.0 Volt of the solenoid B+ terminal for 12V systems, and within 2.0 Volt for 24V systems. Excessive voltage drop in the solenoid switch circuit can induce a high rate of tooth abutment to the engine ring gear (also known as click no crank, or blind start). See Section 4.8 for electrical specifications and assembly torques of starter motors.

4.5.2 Method 2: Mag Switch Control

Most starters with mag switch require the electrical system designer to provide power and ground wires for the mag switch field coil. Starters controlled directly by an ECM sourcing driver should return the mag switch ground back to the ECM. High side switching is recommended to avoid unintentional cranking of engine in the event of short to ground.

The designer must account for total current draw when operating multiple starters in parallel. See Section 4.8 for electrical specifications and assembly torques of starter motors.

Connection Style	Method
Connector, 2 pin	Pin 1 for switch, Pin 2 for ground.
Connector, 6 pin	See wiring diagram for Class O, P starters in Section 4.5.3.
Ring Terminal, 2 post	Customer makes ring terminal connection for switch and ground. Not polarity sensitive. See Section 4.8 for tightening torques.
Ring Terminal, 1 post	Customer connects only to the switch terminal. Mag switch is already grounded through the starter. See Section 4.8 for tightening torques.

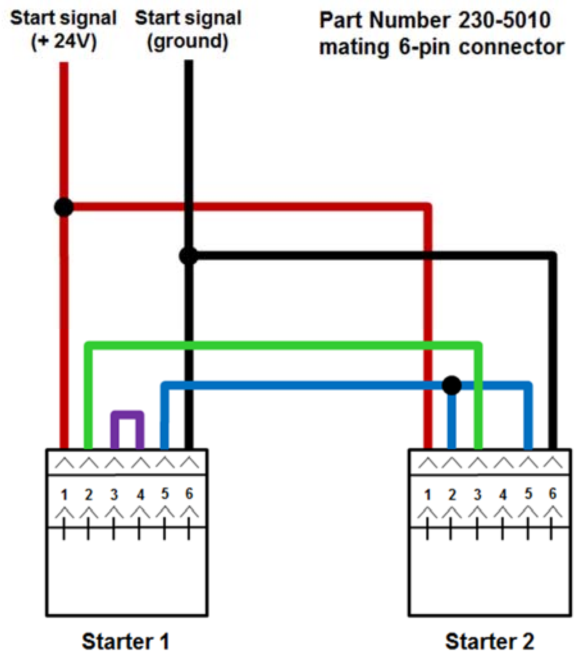
4.5.3 Control of Multiple Starters

Only certain types of starters can operate in multiples at same time. Current draw of the solenoid control circuit is the rated current of the starter solenoid multiplied by the quantity of starters. See Section 4.8 for parts numbers belonging to each class of starter, and for electrical specifications and assembly torques of starter motors.

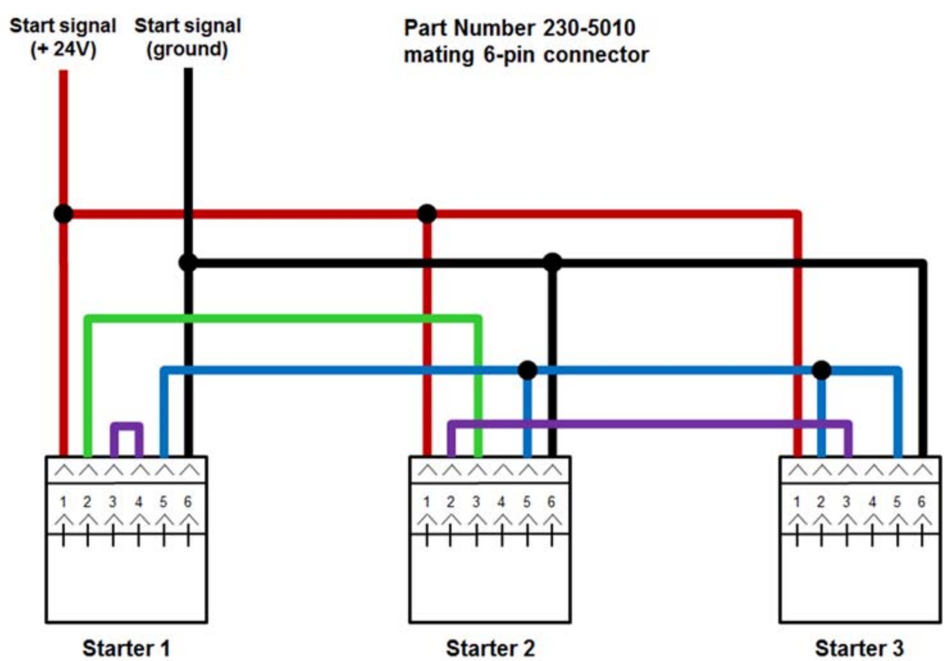
- **Starters, Class C, D, E, F, G, H, I, J:** Maximum of two starters at the same time. Each starter must have a separate start relay operating the solenoid switch terminal. Versions of the starter that are equipped with a Mag Switch can be operated by a single start relay or power source.

- **Starters, Class O, P:** This type of starter can be operated in dual and triple configuration. Switch control is delivered to all starters simultaneously, while an internal cascading interlock waits to crank the engine until all starters are engaged to the ring gear. A special jumper harness is needed between starter motors, as shown below.

Wiring of **dual** Class O and P type starters



Wiring of **triple** Class O and P type starters



4.6 Software Control Strategy

Proper control of the starter is vital to not damaging the starter and engine ring gear. The starter controls should:

- Prevent starter from throwing into a moving engine.
- Disengage the starter at an appropriate engine speed to prevent high speed over-run of pinion gear.
- Limit crank time so the starter does not over heat.
- Detect tooth abutment with engine ring gear and prevent the starter solenoid windings from overheating.

The following methods are recommended when operating the starter motor.

4.6.1 Crank Duration and Rest

An electric starter should not be used more than it can withstand before overheating. Electric starter rated duty cycle is 3 x (30 second crank + 2 minute rest). Carrying out additional crank attempts or circumventing the rest time may cause irreversible damage to the starter motor.

Gas engine purge uses the starter to crank the engine and the purge time counts toward the 30 seconds of total crank time before starter should be rested.

4.6.2 Starter Over Run

The starter must be disengaged at an appropriate moment during engine start up. Excessive run time with engine at operating speed will cause catastrophic failure of the starter. Starter should be disengaged between 400 to 500 rpm engine speed.

If the engine stumbles badly or stops running when the starter is disengaged during cold start conditions, then a 0.5 second de-bounce may be added before starter disengagement. However, the de-bounce is inappropriate for a normal engine starting, so another tier of logic must be added to the software to disengage starter immediately when detecting engine speed of >600 rpm.

4.6.3 Engage to Running Engine

The starter must never be engaged into a running engine. Verify engine speed is 0 rpm before allowing a crank event.

4.6.4 Rapid Re-Engagement

The starter should not be allowed to execute a repeat start attempt before the engine flywheel and starter pinion gear have time to come to rest. It is not sufficient to rely only on checking for 0 rpm engine speed because some speed sensors can lose speed pattern at 60 rpm. A time delay should be imposed between start attempts to allow the starter to coast to a stop. Air starters in particular need a long time for the turbine to coast to a stop.

Electric starter:	5 second delay
Air starter:	20 second delay

This time delay is a separate concept from the starter Rest Time between crank attempts. The Rest Time is used to manage temperature rise in electric starters, while the Rapid Re-Engagement Time is used to prevent damage to engine flywheel.

4.6.5 Tooth Abutment Detection

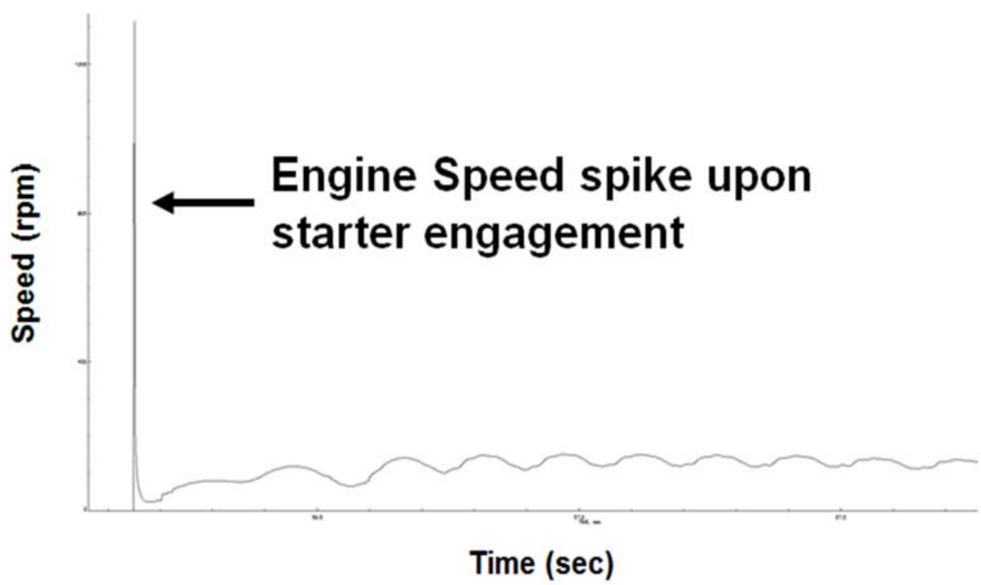
It is possible that a starter may not clear a tooth abutment with the engine ring gear. In those circumstances the solenoid should be disengaged quickly to prevent over heating of solenoid windings.

Disengage the starter motor if engine speed is not greater than zero for more than 2 seconds after the beginning of the start command. A follow up start attempt will usually clear the tooth abutment and allow the starter to crank the engine. If the starter has not cranked the engine after 3 start attempts, then the problem should be investigated.

Continuing to make further start attempts with the pinion gear stuck in tooth abutment can damage the starter motor by overheating the solenoid coils.

4.6.6 False Speed Readings

It is sometimes the case that a speed sensor will report a momentary false high-speed reading at the beginning of a start attempt. This is due to the edge of a gear tooth rapidly moving in front of the speed sensor as the starter engages the engine flywheel. An engine speed of >0 rpm should be ignored for 200 milliseconds at the beginning of the crank event in order to prevent the starting software from disengaging the starter. This debounce time is likely built in to the engine software that reports engine speed, but in some cases the debounce might need to be added to the starting logic.



4.7 Environment

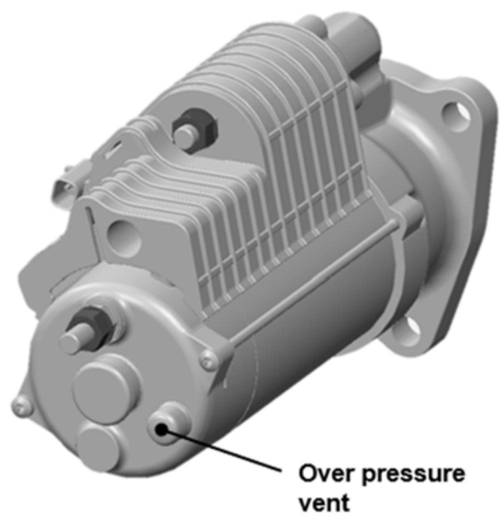
4.7.1 Hazardous Operating Environment

Conventional starters and alternators may not be suitable in hazardous operating environments. Contact a Cat dealer for assistance if the application has such kind of requirements.

4.7.2 Paint

Most starters can be painted if desired. “Class A” type starters (see Section 4.8) should not be painted due to the vented slots at both ends of the motor frame. When painting starters,

- All electrical terminals should be masked.
- “Class F, G, H, I” starters must have the over-pressure vent masked.



4.7.3 Pressure Wash and Submersion

No vented starter is approved for submersion. Even if a starter is fully sealed it is still not possible to completely prevent moisture from entering the starter, so best practice is to place the starter above the water fording depth of the machine. Temporary submersion is acceptable only if the starter is rated to be submerged and the solenoid is oriented within specification, as described in Section 4.2.1, *Solenoid Orientation*.

It is advisable to use shielding to deflect water away from the starter solenoid, especially for applications that use water cannons as part of cleaning process.

The submersion pressure rating is far less than the pressure wash rating and specifications are not interchangeable.

4.7.4 Temperature

The ambient temperature in vicinity of the starter solenoid should not exceed 120 °C.

4.8 Tables of Starter Technical Data

Table 4.8-1, Starter Electrical Terminal Specifications and Tightening Torques

		B+ and B- Terminals		Start Control			
	System Voltage	Stud Size	Tightening Torque	Current Draw	Connection Type	Tightening Torque	Mating Connector
Class A	24 V	M12	24.5 - 27.5 Nm	2:00 AM	M5 stud	15 -30 in-lb	--
Class B	24 V	½ inch	27 - 34 Nm	70 A	#10 stud	16 -38 in-lb	--
Class C	12 V	½ inch	27 - 34 Nm	115 A	#10 stud	16 -38 in-lb	--
Class D	24 V	½ inch	27 - 34 Nm	73 A	#10 stud	16 -38 in-lb	--
Class E	12 V	½ inch	27 - 34 Nm	4:00 AM	M5 stud	15 -30 in-lb	--
Class F	24 V	½ inch	27 - 34 Nm	2:00 AM	M5 stud	15 -30 in-lb	--
Class G	12 V	½ inch	27 - 34 Nm	111 A	#10	16 -38 in-lb	--
Class H, I	24 V	½ inch	27 - 34 Nm	56 A	#10	16 -38 in-lb	--
Class J	24 V	½ inch	27 - 34 Nm	2:00 AM	M5	15 -30 in-lb	--
Class K	32 V	½ inch	27 - 34 Nm	50 A	#10	16 -38 in-lb	--
Class L	64 V	½ inch	27 - 34 Nm	50 A	#10	16 -38 in-lb	--
Class M, N	24 V	M12	24 - 28 Nm	2.4 A	Plug	--	230-4011
Class O, P	24 V	M12	24 - 28 Nm	2.4 A	Plug	--	230-5010
Class R	24 V	M12	24.7 - 27.5 Nm	2:00 AM	Plug	--	230-4011
Class S	12 V	½ inch	20 - 30 Nm	2:00 AM	#10 stud	2 - 3 Nm	--
Class T	24 V	½ inch	20 - 30 Nm	2:00 AM	#10 stud	2 - 3 Nm	--
Class U	24 V	½ inch	20 - 30 Nm	2:00 AM	Plug	--	3E-3364

Part Number	Group Name
104-7041	Class D
104-7044	Class D
107-0997	Class K
108-1876	Class D
117-8846	Class K
145-2413	Class D
150-8867	Class G
151-8090	Class C
165-4619	Class D
193-9185	Class C
193-9186	Class D
198-7746	Class E
200-6962	Class C
200-6963	Class D
204-9742	Class B
205-7687	Class E
207-1513	Class B
207-1514	Class B
207-1516	Class B
207-1517	Class B
207-1519	Class B
207-1520	Class C
207-1521	Class E
207-1523	Class C
207-1524	Class C
207-1525	Class C
207-1527	Class C
207-1529	Class C
207-1532	Class C
207-1533	Class C
207-1537	Class C
207-1539	Class E
207-1541	Class D
207-1546	Class D
207-1547	Class D
207-1548	Class D
207-1549	Class D
207-1551	Class D
207-1555	Class D
207-1556	Class D
207-1558	Class D
207-1561	Class D
207-1562	Class D
207-1564	Class D
237-1962	Class H

Part Number	Group Name
249-3681	Class S
266-7229	Class B
267-9535	Class C
269-2757	Class H
276-8900	Class H
276-8901	Class H
287-7136	Class C
296-5688	Class F
330-3123	Class U
333-2082	Class P
333-2083	Class P
333-8998	Class A
338-3454	Class H
338-3455	Class I
338-3456	Class I
338-3457	Class H
339-5406	Class A
343-6505	Class H
345-1354	Class J
348-7651	Class H
349-6519	Class J
349-6523	Class J
349-6530	Class J
349-6536	Class J
349-6542	Class J
349-6554	Class J
349-6565	Class J
349-6571	Class J
349-6601	Class J
349-6606	Class J
350-1614	Class J
352-9765	Class G
352-9767	Class H
352-9848	Class H
353-7274	Class I
357-7354	Class H
358-9034	Class J
362-9582	Class S
363-9837	Class H
363-9838	Class H
363-9839	Class H
372-7792	Class J
373-1665	Class S
390-0788	Class R
3T-8950	Class H

Part Number	Group Name
415-1804	Class T
422-7553	Class O
422-7554	Class O
422-7555	Class O
422-7560	Class O
422-7567	Class O
423-4163	Class J
423-5916	Class J
435-1239	Class D
435-1240	Class H
436-9102	Class N
436-9103	Class N
436-9104	Class N
436-9105	Class M
436-9106	Class M
440-3361	Class D
441-8378	Class K
461-6549	Class P
461-6550	Class N
465-9083	Class H
475-7412	Class N
478-9866	Class H
478-9867	Class J
494-6414	Class J
496-4960	Class P
500-7312	Class M
502-3919	Class N
516-2856	Class M
516-2857	Class O
520-6648	Class R
539-7216	Class D
541-1720	Class G
5R-9846	Class D
6V-0500	Class K
6V-0501	Class K
6V-0508	Class K
6V-0509	Class K
6V-0511	Class H
6V-0512	Class H
6V-0513	Class I
6V-0516	Class H
6V-0588	Class H
6V-0885	Class H
6V-0927	Class H
6V-4215	Class C

5 Pneumatic Starting

Pneumatic starting, either manual or automatic, is highly reliable. In general, pneumatic starting motors have higher power-to-weight and power-to-size ratios than electric starters.

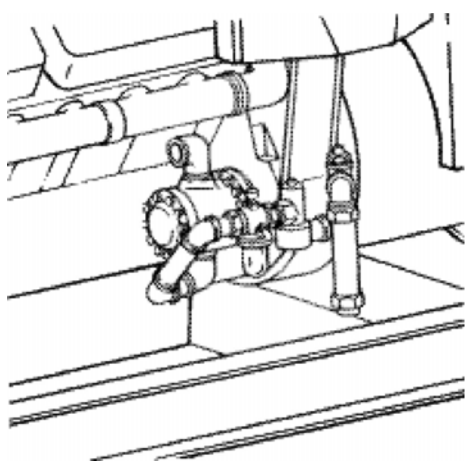
Pneumatic starting is widely used in mining, marine, oil-field, natural gas pumping, and other applications for starting large diesel and gas engines. Although compressed air is a most common source of energy in pneumatic starting, natural gas, nitrogen and other gases can be applied as a starting media as well.

The pneumatic system can be quickly recharged; but gas storage tanks are prone to condensation problems and must be protected against internal corrosion and freezing.

5.1 Typical Pneumatic Starter

Air is usually compressed to 758 to 1723 kPa (110 to 250 psi) and is stored in storage tanks. Stored air is regulated to from 620 kPa (90 psi) to a maximum of 1550 kPa (225 psi) depending on the engine and starter and piped to the air motor. Consult the Owner's manual for the recommended regulation pressure for the engine model you are using. A check valve between the compressor and the air receiver is good practice, to protect against a failure of plant air that might deplete the air receivers' supply.

The air compressors that supply pneumatic starters are driven by external power sources such as electric motors and diesel or gasoline engines. A small emergency receiver (not supplied by Caterpillar) can be hand pumped to starting pressure under emergency conditions. A more common emergency backup will include an auxiliary diesel engine-driven air compressor package.



5.2 Air Tank

Air tanks are required to meet specific characteristics, such as the specifications of the American Society of Mechanical Engineers (ASME). Compressed air storage tanks must be equipped with a maximum pressure valve and a pressure gauge. Check the maximum pressure valve and pressure gauge often to confirm proper operation. A drain cock must be provided in the lowest part of the air receiver tank for draining condensation.

5.2.1 Air Storage Tank Sizing

Many applications require sizing air storage tanks to provide a specified number of starts without recharging. This is accomplished using the following formula:

$$V_T = \frac{(V_S)(T)(P_A)}{P_1 - P_{min}}$$

Where:

V_T = Air storage tank capacity (cubic feet or cubic meters)

V_S = Air consumption of the starter motor (m ^{3}/sec or ft^3/sec). Air Starting Requirements are in the TMI for model engine used. If prelube is used its consumption must be added to V_S also.

T = Total cranking time required (seconds): If six consecutive starts are required, use seven seconds for first start (while engine is cold), and two seconds each for remaining five starts, or a total cranking time of seventeen seconds.

P_A = Atmospheric pressure (psi or kPa): Normally, atmospheric pressure is 101 kPa (14.7 psi).

P_T = Air storage tank pressure (psi or kPa): This is the storage tank pressure at the start of cranking.

P_{min} = Minimum air storage tank pressure required to sustain cranking at 100 rpm (psi or kPa). Air Starting Requirements are in TMI for model used.

Example:

A 3516 Diesel Engine with electric prelube has the following:

Maximum air tank pressure = 1241 kPag (180 psig)

Minimum air to starter pressure = 620.5 kPag (90 psig)

Expected air line pressure drop = 207 kPag (30 psig)

Six consecutive starts. First start = 7 seconds; the other 5 starts = 2 seconds

Average barometric pressure at this location = 100 kPa (14.5 psi)

Preconditioned engine installation.

(cfm x 0.02832 = m ^{3}/min)

Solution:

V_S = 0.40 m^3/sec (14.1 ft^3/sec)

T = 7 + (5 x 2) = 17 sec

P_A = 100 kPa (14.5 psi)

P_T = 1241 – 207 = 1034 kPag (180 – 30 = 150 psig)

P_{min} = 620.5 kPag (90 psig)

Therefore,

$$V_T = \frac{(0.4)(17)(100)}{1034 - 620.5} = 1.64 \text{ m}^3$$

$$V_T = \frac{(14.1)(17)(14.5)}{150 - 90} = 57.93 \text{ ft}^3$$

5.3 Air Starting Motor

5.3.1 Cranking Time Required

The cranking time depends on the engine model, engine condition, ambient air temperature, oil viscosity, fuel type, and design cranking speed. Five to seven seconds is typical for an engine at 26.7°C (80°F). Restarting hot engines usually requires less than two seconds. Most marine societies require a minimum of six consecutive starts for propulsion engines. Refer to the applicable marine society rules for current requirements for propulsion and other applications on marine vessels.

Note: Gas engines are generally a little harder to start. Even during hot starts, 10 second start attempts are sometimes needed. See Operation and Maintenance manual for starting recommendations.

Note: Some gas engine applications require purge cycles to vent unburned fuel before the next start attempt. Refer to local code or industry recommended practice.

5.3.2 Air Consumption of the Starter Motor

The starter motor air consumption depends on the same variables as mentioned in cranking time. The air pressure regulator setting also affects consumption. Normal pressure regulator setting is 759 kPa (110 psi). A higher pressure can be used, up to a maximum of 1550 kPa (225 psi), to improve starting under adverse conditions. Specific requirements for air starter consumption on various engine models are available from the TMI. This data assumes a bare engine (no parasitic load) at 10°C (50°F).

5.3.3 Operation

The supply of compressed air to the starting motor must be shut off as soon as the engine starts. This will prevent wasting starting air pressure and prevent damage to starter motor by over-speeding.

5.3.4 Starting Motor Torque Calculation

It is important when selecting the starting motor to ensure the motor produces enough torque to overcome the breakaway and rolling torque of both the engine and driven equipment. The motor selection and the air/gas pressure supplied to the motor are both factors in how much torque is produced.

An example calculation is provided below for a G3516 engine:

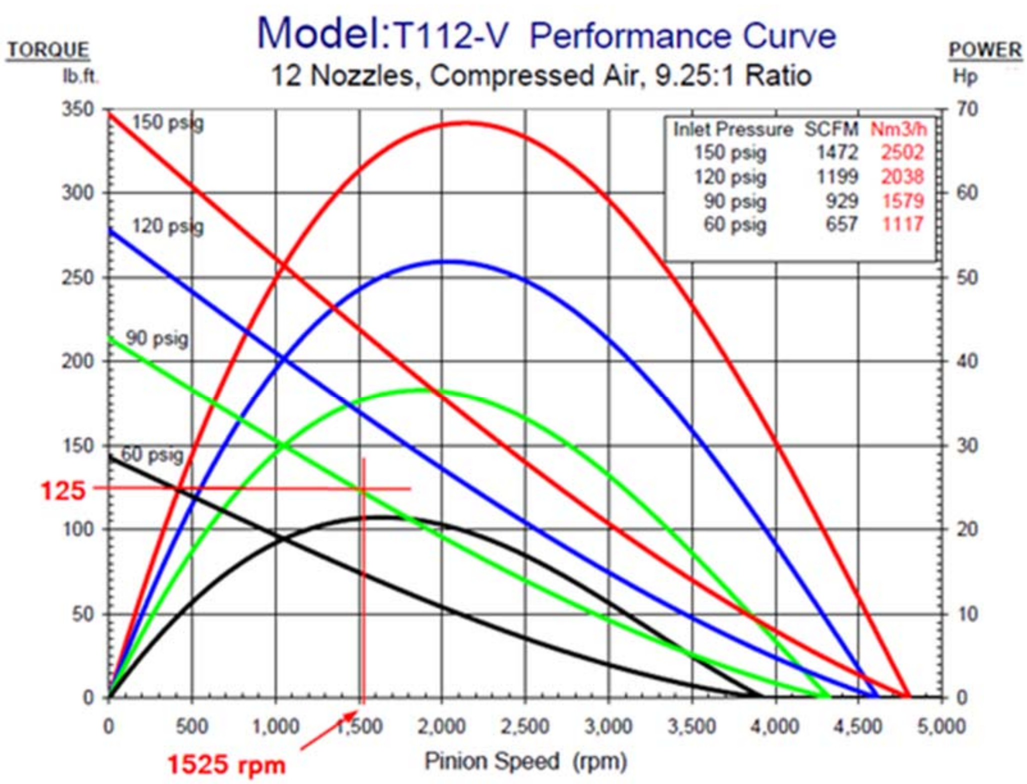
Engine torque values are found in their respective Technical Information A&I Guides.

- Engine Cranking Torque = 950 ft-lb
- Engine Breakaway Torque = 1140 ft-lb
- Engine Cranking Speed= 100 rpm
- Starter motor is TDI T112V, 150 psi turbine starter (Cat part number 301-4526) using compressed air at 90 psi.
- Starter motor has 12 pinion teeth.
- G3516 flywheel has 183 teeth.

$$Gear\ Ratio = \frac{(Flyhweel\ Teeth)}{(Pinion\ Teeth)} = \frac{183}{12} = 15.25$$

$$Pinion\ Speed\ = (Engine\ Crank\ Speed)(Gear\ Ratio)$$
$$Pinion\ Speed\ = (100)(15.25) = 1525\ rpm$$

Read the starter motor torque (SMT) off the torque curve provided in the Technical Information A&I Guide. At a pinion speed of 1525 RPM and air pressure of 90 psi, the starter motor produces 125 ft-lb of torque.



The starter motor torque needs converted back to engine crank torque (ECT). If a safety factor (SF) is desired, it must be considered in the ECT calculation. If no safety factor is used, then the value is 1.

$$Available\ ECT = (SMT)(\#\ of\ starters)(Gear\ Ratio)(Safety\ Factor) - ECT$$
$$Available\ ECT = (125)(1)(15.25)(1) - 950 = 956 \text{ ft-lb}$$

The driven equipment cranking torque must be less than this value. The calculation must also be done for the available breakaway torque.

5.3.5 Prelubrication Systems

3600 Engines require prelubrication. For all other models check Operation and Maintenance Manual. Figure 5.3.9-1 shows a 3516 oil-field engine with an optional air starter and air prelubrication system. The system schematics in Figures 5.3.9-2, -3, and -4 show the included prelubrication system on 3600 engines. The prelubrication system is designed to provide lubricating oil to critical components before cranking and starting the engine.

Caterpillar furnishes an air cranking/air prelubricating system. This consists of an air-driven prelubrication pump that draws oil from the engine sump and forces it into the engine. This pump is driven by an air motor, through sequence valving runs, until a predetermined engine oil pressure shuts it off and turns on the air cranking motor. The additional air consumed by the prelube pump must be added to the starter motor air consumption to properly size the air receiver and air storage tank needed.

Oil-field engine applications that use the 2301A Electric Governor do not require prelubrication pumps because a properly wired 2301A Governor maintains engine speed at low idle speed until adequate oil pressure is in the lube system. When the engine starts and accelerates to low idle, it will stay at that speed until an electric switch is closed by engine oil pressure. The engine will then accelerate to rated speed.

The prelube system's solenoid valve may require venting. Please see the notes on solenoid valve venting in the next section on "Piping".

Any solenoids used in the starting system must be DC to ensure starting during an AC power outage.

5.3.6 Piping

Air starter air supply piping should be short, direct and at least equal in size to the motor intake opening. Black iron pipe of seamless steel AS TMA106 grade is preferred to prevent vibration induced fatigue from the starter to the piping. The piping requires flexible connections at the starter.

In some larger engines, a flexible hose is included from Caterpillar. Deposits of oil and water will accumulate in the air receiver and at low spots in the piping. The accumulation of oil and water must be removed daily to prevent damage to the starting motors. Manual or automatic traps should be installed at the lowest parts of the piping and all piping should slope toward these traps.

Air starting motors are required to have a 40 micron filter screen installed before the air pressure regulator of the supply line to the air starter motor.

If the engine operates at ambient air temperature below 0°C (32°F), and operates in a high humidity environment, an air dryer is needed to prevent condensed water from freezing in piping. When the same air is used for other purposes, e.g., engine controls, the air dryer is essential. A small quantity of alcohol in the starter air tank also prevents freezing if a dryer is not used. At temperatures below –18°C (0°F) consult the supplier.

During starting, an air pressure drop is associated with each air supply component. These components include the lubricator, strainer, relay valves and others.

Note: Vane-type air starters may also freeze during high humidity and low temperatures. Applications equipped with turbine-type air starters may also freeze in some low ambient conditions; they are less susceptible to motor freeze than vane-type air starters.

Dynamic losses range from 207 to 414 kPa (30 to 60 psi) depending on the engine model and supply line pressure. A minimum 759 kPa (110 psi) supply pressure is recommended for proper operation of the starting motors.

Starter/prelube supply and exhaust piping practice is critical when installing the engine. If restricted in excess the starter motor performance will be negatively impacted. Proper pipe diameter, length and directional changes such as elbows, tees and the like, all must be accounted for in the piping design. As with any site piping, industry standards and regulations for each application come into play and will define the appropriate piping material and safeguards necessary for the application. Combustible gas exhausting from starter motors must be piped away to designated area or to the atmosphere especially in gas service applications.

Air or gas starting systems may include solenoid-actuated valves to enable automated control by the engine management system. Some such valves require venting for proper operation; check the installation information published for your specific engine model to see if valve venting is a requirement for your installation. Just as with the starter motor exhaust, valve vent lines on systems using combustible gas must be piped away from the engine to a safe location.

Caution must be exercised when designing exhaust and venting systems for pressurized gas or air. Piping systems which may see high pressure should not be connected to systems that include devices rated only for lower pressure. These high-pressure gases can back flow through the low-pressure piping and cause damage to the lower pressure rated devices. One-way check valves may be helpful in preventing such back flows, but care must be taken to ensure the valves are rated for the pressures and flows involved. Improperly sized check valves will restrict flow, creating back pressure. In many cases the safer approach is to keep high pressure exhaust systems completely separated from low pressure systems.

Hazardous locations will require CSA rating and regulations for starter/prelube attachment solenoid valves for control switching.

Blocking valves that positively disconnect the main air/gas supply when the starting/prelube cycles are completed may be necessary in come applications.

5.3.7 Cleanliness

Purge the compressed air lines of debris and loose weld material prior to initial startup. Dirty supply lines can damage starters and cause malfunctions of the relay valve. A damaged valve can open or keep open the main air supply lines and cause pinion and flywheel ring gear teeth damage (pinion spinning while engaging).

5.3.8 Testing

Hydrostatically test the compressed air lines to at least 1.5 times the system working pressure, or to the requirements of the applicable regulatory agency.

5.3.9 Figures for Prelubrication

Figure 5.3.9-1, 3516 Oil-Field Engine with Optional Air Starter and Air Prelubrication

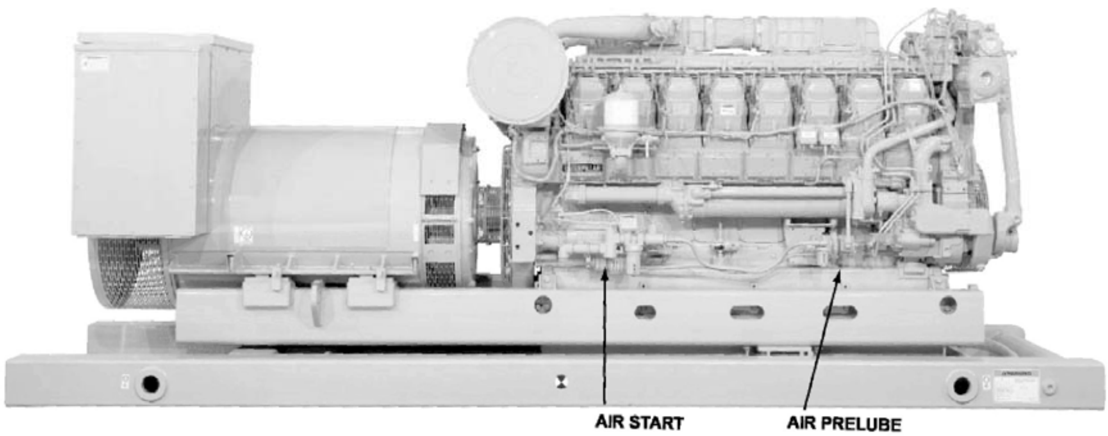


Figure 5.3.9-2, Typical Air Starting System

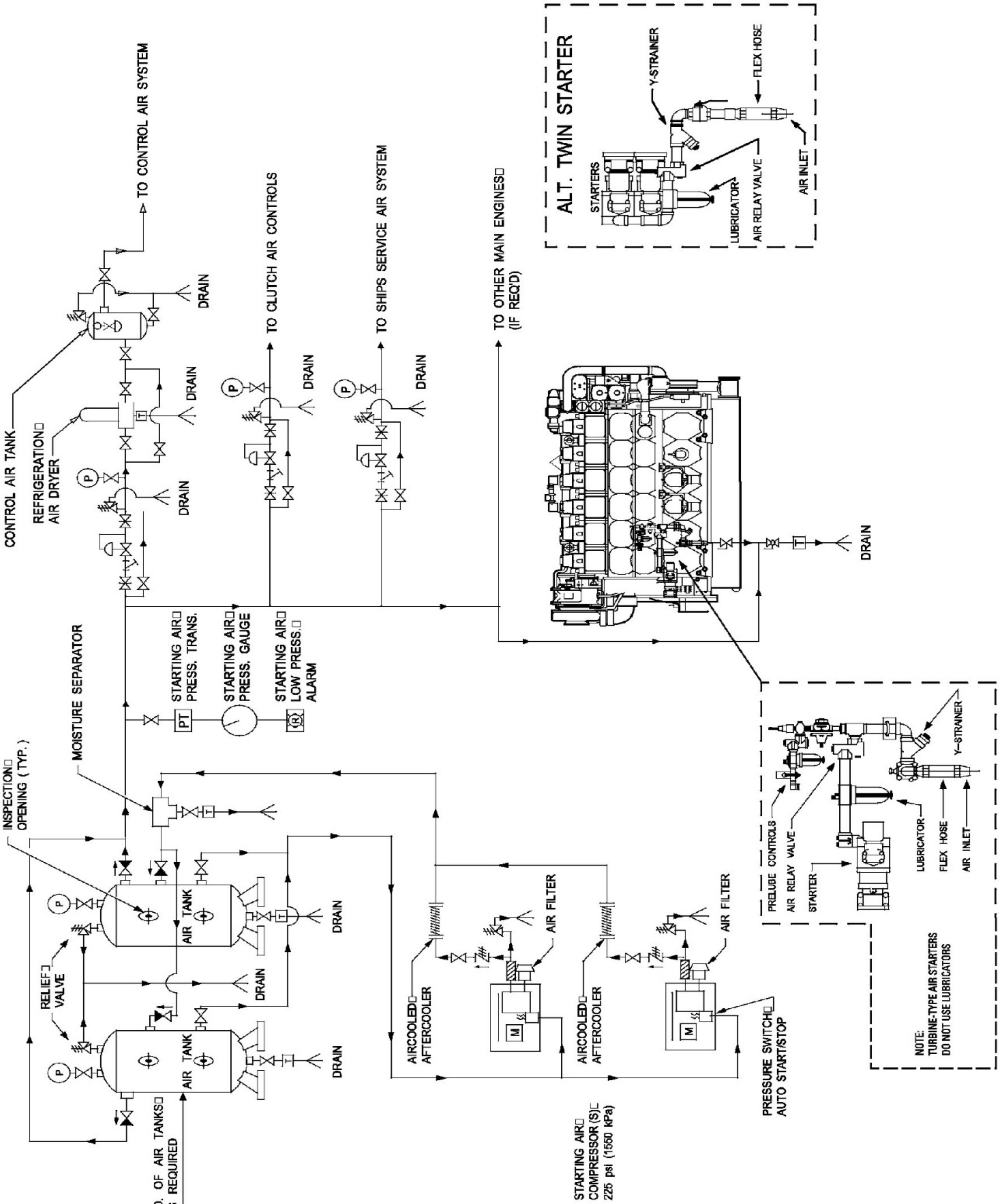


Figure 5.3.9-3, Turbine Air Starting Motor with Electric Prelube Pump and Electric Controls

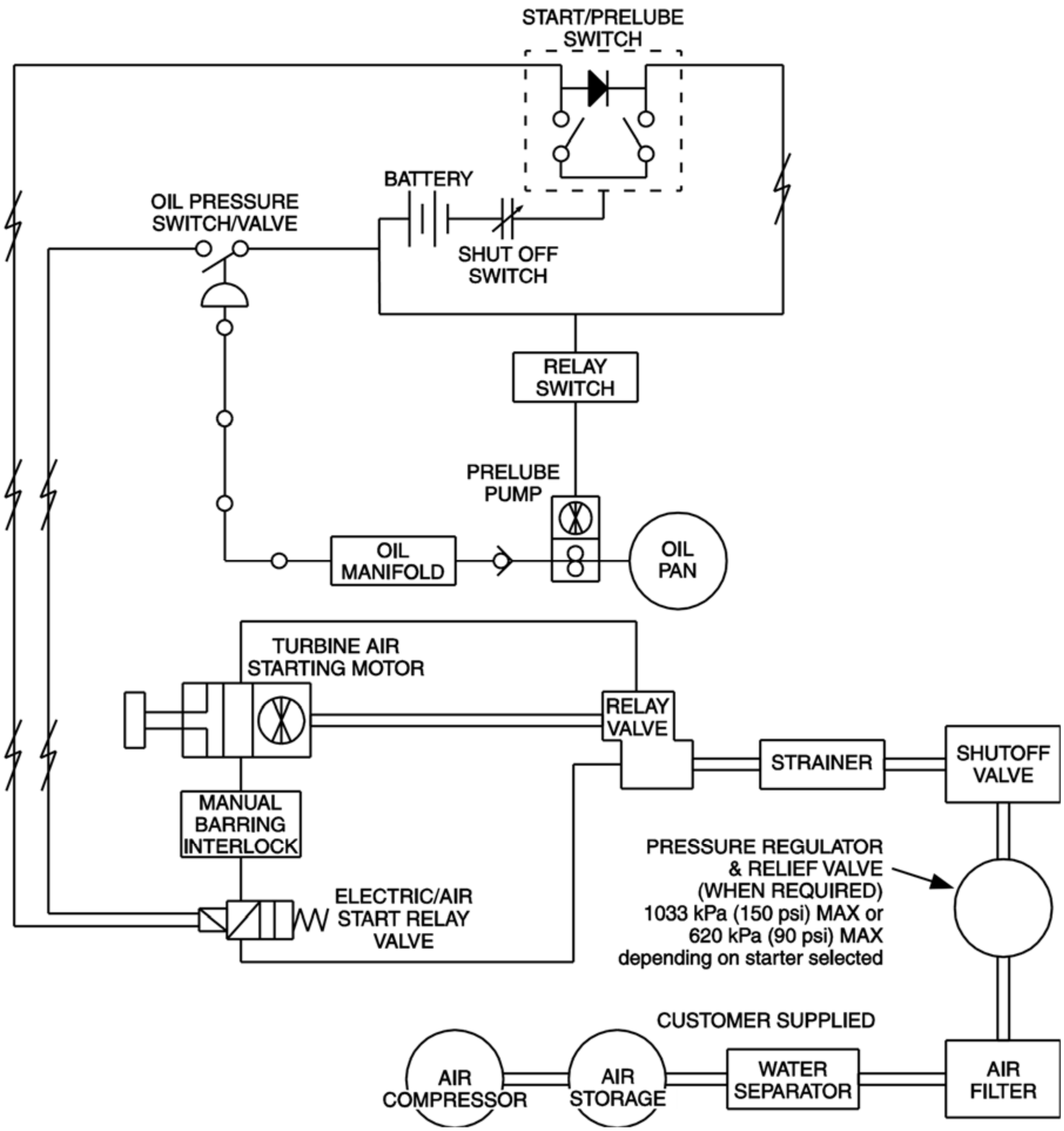
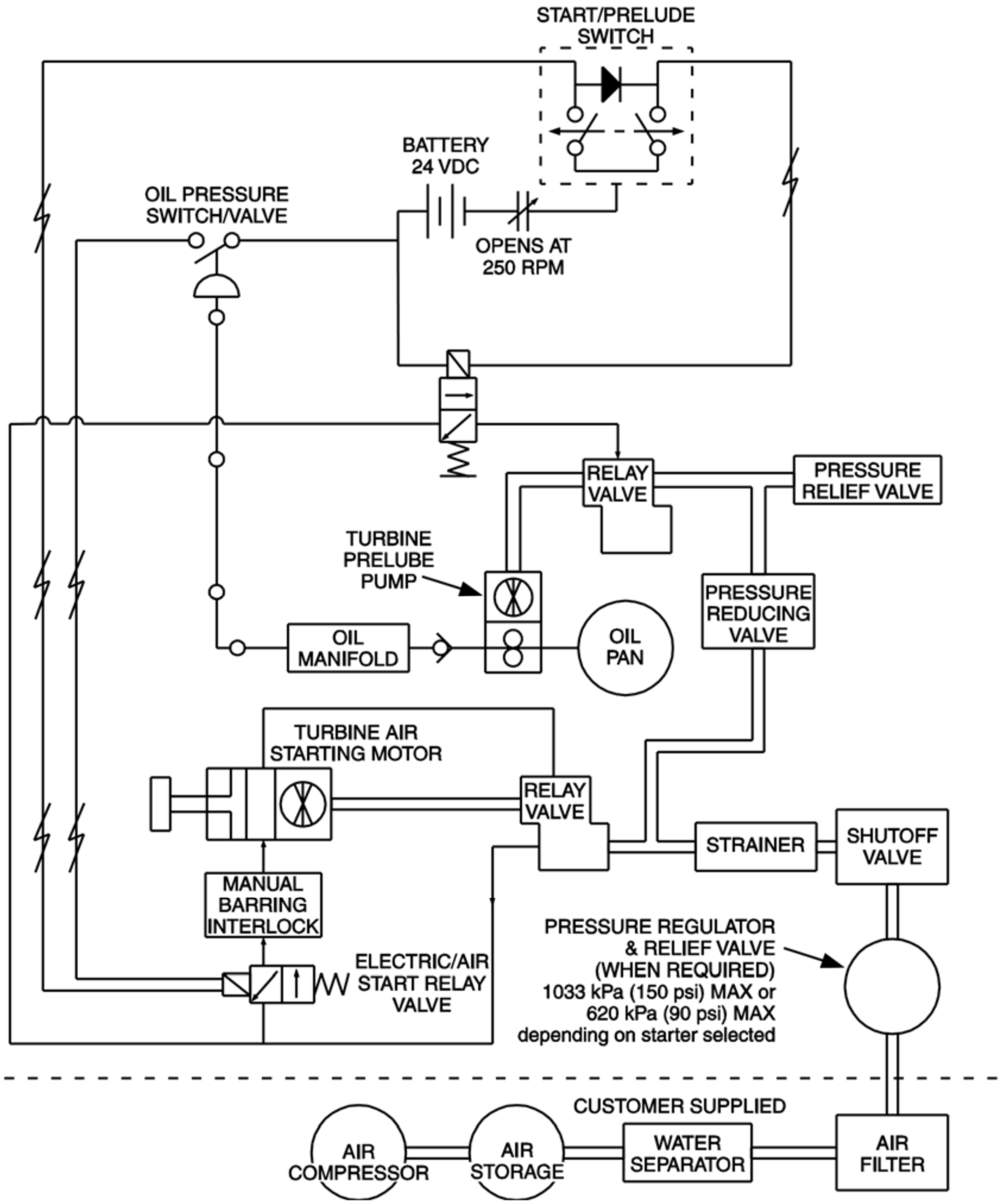


Figure 5.3.9-4, Turbine Air Starting Motor with Air Driven Turbine Prelube Pump and Electric Controls



6 Hydraulic Starting

Hydraulic starters provide high cranking speeds, fast starts and, are relatively compact. Recharging time, using the small engine-driven recharging pump, is fast.

Hydraulic systems can be recharged using a special hand pump, but process is very laborious.

The high pressure of the system requires special pipes and fittings and extremely tight connections.

Oil lost through leakage can easily be replaced, but because of high pressures in the accumulators, usually 20,700 kPa (3000 psi) when fully charged, recharging the accumulator(s) requires special equipment.

6.1 Hydraulic System Considerations

- Repair to the system usually requires special tools.
- Hydraulic starting is most often used where the use of electrical connections could pose a safety hazard.
- Hydraulic starting systems are not available from Caterpillar for most models. They are available for 3508 and 3512 engines. Contact your local Cat dealer for the nearest available supplier of other models.
- If hydraulic accumulators are used, it must be very carefully protected from perforation or breakage. Hydraulic accumulators contain large amounts of stored mechanical energy.

7 Starting Aids

Diesel engines require the heat of compressed air in the cylinder to ignite the fuel. Below certain temperatures, the cranking system will not crank the engine fast enough or long enough to ignite the fuel. One or more commonly used starting aids, such as jacket water heaters and/or ether may be required to start the engine. In addition, engines with prelube requirements may require oil heaters. Refer to Operation and Maintenance manual for the engine model selected for cold weather procedures.

7.1 Jacket Water Heaters

Jacket water heaters are electrical heaters that maintain the jacket water at a temperature high enough to allow easy starting of the engine. More heaters of higher ratings may be required in areas of extremely cold temperature.

Jacket water heaters are used on both manual and automatic starting systems and are essential for automatic starting below 21°C (70°F). Heaters precondition engines for quick starting and minimize the high wear of rough combustion, by maintaining jacket water temperature during shutdown periods.

Heaters thermostatically control jacket water temperature near 30°C (90°F) to promote fast starts. Higher temperatures accelerate aging of gaskets and rubber material.

7.2 Battery Heaters

Battery heaters are usually recommended in cold ambient temperatures. The heaters should be set to maintain battery temperature in the range of 21 to 32°C (70 to 90°F) for maximum effectiveness.

7.3 Ether

Ether is a volatile and highly combustible agent. Small quantities of ether fumes added to the engine's intake air during cranking reduce compression temperature required for engine starting. This method can be used for starting of an engine at practically any ambient temperature. Ether starting aids are available on the smaller Cat engines.

CAUTION: When other than fully sealed ether systems are used, ensure adequate ventilation for venting fumes to the atmosphere to prevent accidental explosion and danger to operating personnel.

The high-pressure metallic capsule-type is recommended for mobile applications. When placed in an injection device and pierced, ether passes into the intake manifold. This has proven to be the best system since few special precautions are required for handling, shipping, or storage.

Ether must be used only as directed by the manufacturer of the starting aid device. The ether system must be such that a maximum of 3.0 cc (0.18 cu in) of ether will be released each time the button is pushed. Cat ether systems are designed to release 2.25 cc (0.14 cu in) of ether each time the system is activated. Excessive injection of ether can damage an engine. Ether should not be released into a running engine.

Lighter fuels, such as kerosene, can ease the unaided cranking requirements slightly by lowering the compression temperature required for starting. These lighter fuels also slightly reduce horsepower delivered at any given fuel rack setting.

Excessive parasitic loads should be disconnected during engine cranking.

CAUTION: Under no circumstances should ether be used on any 3600 model engines or any engine that has an air inlet heater. Warning labels may be necessary if remote air intakes are used and the engine has an inlet heater. Labeling when remote air inlets are used is the responsibility of the customer or end user.

7.4 Manifold Heaters

Heat added to the intake manifold of an engine during cranking will significantly improve startability and reduce any white start-up smoke.

Manifold heaters are used on small engines available from Caterpillar. Caterpillar does not offer manifold heaters on larger marine engines.

7.5 Starting Smoke

High performance engines are prone to have some white start-up smoke. The white smoke is composed of unburned fuel. Cat engines have been designed to minimize this problem. Electronically controlled engines have a cold mode strategy built into the software to reduce start-up smoke. Operators can do several things to improve the situation:

- Use jacket water heaters to raise the engine water temperature to 32 to 49°C (90 to 120°F) prior to starting.
- Keep warm-up idle speeds (rpm) low.
- Warm the air to the air cleaners and intake manifold.
- Diesel engines that are designed to have high output power, yet still be relatively lightweight, generally have low compression ratios; i.e., in the range of 12.5 to 16:1. This design factor makes them prone to misfire and run rough until the engine reaches normal operating jacket water temperatures of 80 to 93°C (175 to 200°F).

7.6 Driven Load Reduction Devices

Effect of driven equipment loads during cold weather engine starting must be considered. Hydraulic pumps, air compressors, and other mechanically driven devices typically demand more horsepower when they are extremely cold at start-up. The effect of this horsepower demand may be overcome by providing a means of declutching driven loads until the engine has been started and warmed up for a few minutes. This is not always easy or practical, so other means of relieving the load at cold startup may be required if the engine-load combination cannot be started with sufficient ease using the engine starting aids described earlier.

Some engine driven air compressors provide for shutoff of the air compressor air inlet during cold starting. This greatly decreases drag on the engine and improves cold startability. This approach can only be used when the air compressor manufacturer provides this system and fully approves of its use. Air compressor damage could result.

8 Emergency and Fast Starting

Some emergency and standby power applications require the ability for fast starting. Certain engine configurations can support emergency power supply systems such that loads can be accepted within 10 seconds of a power outage. The following list offers recommendations to achieve faster starting.

Note: If a project has a start time requirement, it is highly recommended that a **Start Time Analysis (STA)** is completed for the overall system. The STA provides a systems analysis based on detailed input relating to the site conditions, intended electrical system components and the overall design of the critical power path. A factory supported start time analysis will be available only for C175, through the ASC inquiry system.

Note: The parameters listed below will improve starting but cannot guarantee starting in a certain number of seconds. Contact your Cat dealer if a specific fast start time is required for your application.

- Maintain jacket water temperature at 49° C (120 ° F).
- Combustion air requirement of 21C minimum.
- Use dual jacket water heaters, if not circulating type or redundant.
- Starter must be able to crank engine above 110 rpm for ten seconds.
- Use dual heavy-duty electric starters.
- Fully charged batteries.
- Heated batteries, if ambient temperatures are below 0°C.
- Depending on engine model, air starters may increase **or decrease** cranking speeds and thus **affect the** overall start time. Please consult your Cat dealer for starter recommendations for your package.
- Use backup battery charger.
- Optional air starter.
- Air pressure adequate to crank engine above 110 rpm.
- Air tank and line volume large enough to crank engine above engine starting RPM.
- Set purge cycle time to zero for EMCPII engines.
- Continuous engine oil prelubrication must be installed and operating, if available on engine model.
- Fuel pressure must be up to the engine shutoff valve.
- The engine fuel shutoff must be installed as close the engine regulator as possible.
- Some gas gensets are designed specifically for standby applications. Gas trains provided with these gensets should be installed as supplied with the gas train components and flexible hose installed directly to the engine fuel inlet. This ensures fastest starting capability.
- The fuel shutoff valve must be energized at the same time as the starters.
- High-pressure gas systems will reach high idle faster than low pressure gas systems.
- Low-pressure systems are more stable at high idle.
- Spark plugs and transformers must be properly maintained and operational.
- Oversized and high voltage generators increase the rotational inertia of the package and will slow start times.
- Engine driven radiator fans will slow package start times. Using oversized or high voltage generators in conjunction with engine driven fans may increase start times such that a 10 second start will not be achievable. If using an oversized or high voltage generator, consider using a remote radiator with electric driven fans.

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