Starting Systems

and Batteries/Charging Systems

Application & Installation Guide

LEBW4980-15

Caterpillar: Confidential Green

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1 Introduction

This section of the Application and Installation Guides describes the requirements and options available for the engine starting and charging systems. Additional engine systems, components and dynamics are addressed in other sections of the Application and Installation Guides.

Systems and components described in this guide may not be available or applicable for every engine. Consult the applicable engine model price list and/or parts reference guide for information on specific model option availability or compatibility.

1.1 References

The following information is provided as an additional reference to subjects discussed in this guide. Please note the information in these publications is subject to change without notice.

- None currently noted.

1.2 Changes since last revision

- Section 4.2.1: Added information on cyclic starting, with a reference to a service publication providing instructions for specific applications.

2 Starting Systems - Overview

The combustion cycles used in reciprocating piston engines, be they compression-ignition or spark-ignited, have in common that they are continuously operating processes. In each case, fuel and air are carried into combustion chambers where they are compressed, ignited, and then directed to expend the released energy to push pistons in their cylinders to ultimately turn the crankshaft. Once in motion, the engines that operate by these cycle models will continue to repeat the cycles, over and over, until the process is stopped.

The conventional method for starting these continuous processes is to temporarily apply a motor to the crankshaft to rotate the machinery until the combustion cycles can take over and do what they are designed to do. These starting systems, and any related equipment, are the focus of this guide.

2.1 Anatomy of a starting system

Just as the physical construction of the reciprocating piston engine has become fairly standardized, the location and configuration of an engine starting system has also been standardized. The almost universally accepted starting system for a piston engine places a ring gear on the outer diameter of the engine's flywheel, as the means to turn the crankshaft while the engine is not yet operating (a process referred to as "cranking" the engine).

A starter motor is then mounted to the engine in such a way that a small pinion gear on the starter can engage the ring gear on the flywheel. The pinion gear engagement is arranged such that the pinion can engage the ring gear at the start of the cranking cycle and then can release that engagement when the combustion processes are able to take over the task of turning the crankshaft themselves. An illustration of one type of starter motor installation is shown in Figure 2.1 below.

There are many ways a starting system can be incorporated onto an engine, but the vast majority of starters are in this format. However, the nature of the starter motor itself can be vastly different on one engine versus another, with those differences exploited to serve the particular needs of each specific engine installation. The example starting system in Figure 2.1 happens to use an electric starter motor, a very common and convenient starting system design. This illustration also calls out one of the requirements for electric starting in that it shows storage batteries and a charging system, both essential items to make the electric starter design practical. There can be circumstances that make this electric starter solution impractical, and for those applications other types of starters may be a good fit.

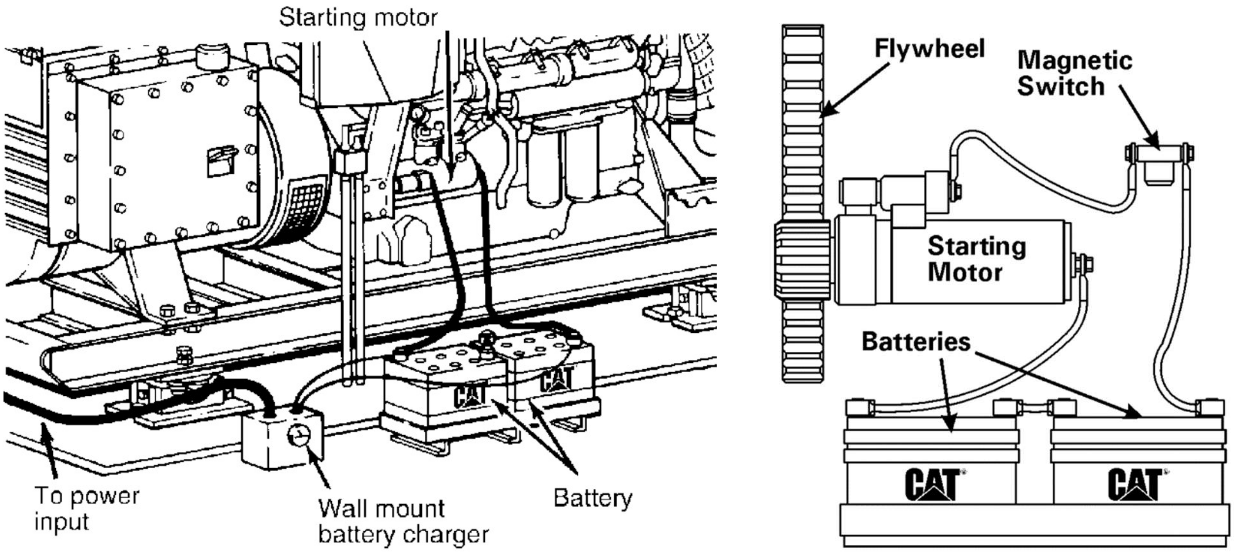

Figure 2.1 **Example of a starter motor installed on an engine**

There are three types of starters most commonly used with Cat® engines. They differ in the method by which the cranking energy is stored, delivered, and recharged.

- Electric starters rely on chemical energy stored in batteries. Switches connect the batteries to the starter motor to start and stop cranking. Because the energy in the batteries is finite and will become depleted over repeated cranking cycles, most electric start systems will use an engine driven alternator or an external battery charger to recharge the batteries while the starting system is not in use.
- Air or pneumatic starters use pressurized air as the driving medium. Remotely controlled valves direct compressed air to the starter motors to initiate the cranking cycle. The pressurized air is stored in pressure tanks that replicate the function of the batteries for the electric starting system – to store the potential energy needed to crank the engine. But, in this case the energy is captured as elevated pressure in the air storage tank. Air storage tanks are recharged by an air compressor, which can be driven by the engine or by an external electric motor.
- Hydraulic starters also rely on stored pressure as the driving medium for cranking, but instead of air they use incompressible hydraulic fluid to direct that energy to the starter motor. Like the air system, a hydraulic starter system must have a pressurized fluid storage tank to hold the energy needed for engine cranking. Hydraulic pressure tanks are also recharged by pumps, either engine driven or externally driven by a motor.

2.2 Starter sizing

Cranking the engine is a relatively straightforward process – in order to get the engine to "turn over" (getting the crankshaft to turn) the starter must apply more torque to the flywheel than the resistance present on the engine prior to cranking. This resistance to cranking comes from several possible sources, and the starter must be sized to have the torque capability to overcome the combined resistance of all such sources present on a given installation.

2.2.1 Breakaway torque

A non-operational engine requires an initial "push" of cranking torque to get the components moving. This is a consequence of the static friction present in the various component interfaces in the engine combined with the combined inertias of all of those parts. The starter must have sufficient torque at 0 RPM (not yet rotating) to overcome this breakaway torque to get the engine's parts all moving. In that sense, the breakaway torque is considered to be characteristic of the engine and is not typically dependent upon external attributes such as ambient temperature. Caterpillar® does publish breakaway torque data for each engine.

2.2.2 Cranking torque

Even after the crankshaft begins to turn, the engine offers resistance to cranking. This, too, is a function of the friction between parts in the engine and to a lesser extent the inertias of the moving parts, but generally speaking the dynamic friction of moving parts is considered to be less than the static friction of those parts before they move. This generalized notion can be turned on its ear by the effects of low temperatures on the engine's lubricating oil. The viscosity of lube oil tends to increase to lower temperatures, and the increased viscosity of very cold oil can actually result in cranking torques that are greater than the breakaway torque. Caterpillar publishes cranking torque data for its engines, and in many cases those data will include values for various temperatures for the oil fill to account for the viscosity changes.

2.2.3 Connected equipment

Also a consideration for cranking is the torque contributed by any machines or devices that are directly (mechanically) connected to the engine. The inertia of a generator, or the compression loads on a gas compressor, will certainly add to the total load that must be turned by the starter. Even ancillary components such as belt-driven cooling fans or other accessories can contribute incremental loads to the total. This presents the challenge faced on each installation, that of estimating the total cranking torque requirement of the driveline

("driveline" = the rotating system of all of the machinery connected to the engine). These connected equipment loads are entirely dependent on the design for each installation and thus will require input that is not in Cat-published guides.

2.3 Starter gearing and starter performance

As described above, the starter motors and their energy storage and delivery systems become relatively interchangeable components. However, their point of interface with the engine ends up looking very similar across the range of these very different starter types. The pinion gear-ring gear power transmission scheme creates consistency among the various starter system types, and it defines the calculations that are needed to properly size the starter to the task at hand.

2.3.1 Gears, tooth counts, and gear ratios

Gears are the rotational equivalent of levers; they are components that create mechanical advantage for a rotational system the same way that a lever gives mechanical advantage for a linear (straight-line) system. This mechanical advantage takes the form of trading distance traveled for effort required to make things moves. On a lever system when the input end must move 3x farther than the output end of the lever, the effort at the output end is 3x greater that the force applied at the input end. For gears the concept is the same except the linear motion is changed to rotation. Using a similar illustration to the lever example above, a gear interface that produces a 3x reduction in RPM also imparts a 3x increase in torque.

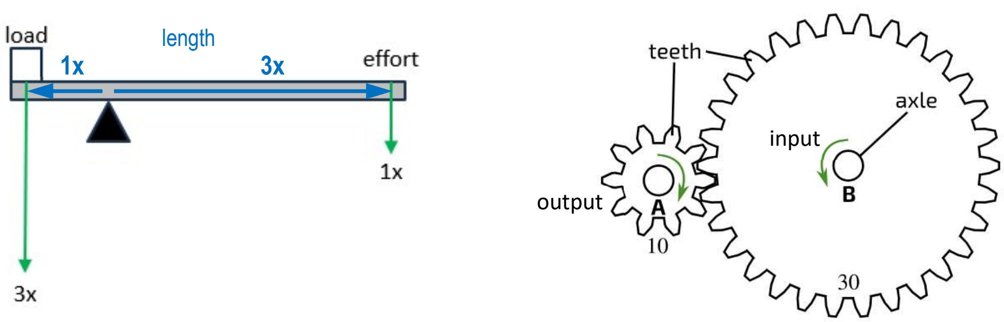

Figure 2.2 **Examples of 3:1 advantage for lever and gear**

In the example above, the length of the input arm of the lever is 3x longer than the end carrying the load. This allows the effort force on the input of the lever to be 1/3 the weight of the load on the other end of the lever while the lever remains stationary. For the gear system, having the input gear be 3x the size of the output gear accomplishes a similar outcome. The input gear will have to rotate 3x as far to turn the output gear a given amount, but the torque effort required at the input gear will be 1/3 the torque load present on the output gear. Inherent to the design of gears is the notion that the teeth on each gear must have a matching design in order to mesh (or fit) together. This similarity in tooth design makes establishing the gearing ratio very simple: the ratio of the teeth on the gears is their ratio of diameters, and that ratio is what is used to determine the changes in speed and torque that result.

Starter motors take full advantage of this gearing ratio, using high pinion speeds on the starter motor to enable the use of a smaller motor (with a lower torque rating) to accomplish the task of cranking. In fact, larger engines tend to have larger diameter flywheels, which in turn means a larger tooth count ring gear. That larger ring gear, when meshed to the same small starter pinion gear, will produce much greater torque multiplication, but of course at the cost of equally greater speed reduction.

2.3.2 Using starter performance data

Knowing the gear ratio and how to use it is a key step in starter sizing, regardless of the type of starter being used. And you will need to know the target cranking speed for your engine model, and the aforementioned breakaway and cranking torque requirements for your installation. Then there is one more piece of information needed – the torque-speed performance of the starter you intend to use. This can be in the form of a graph or a table.

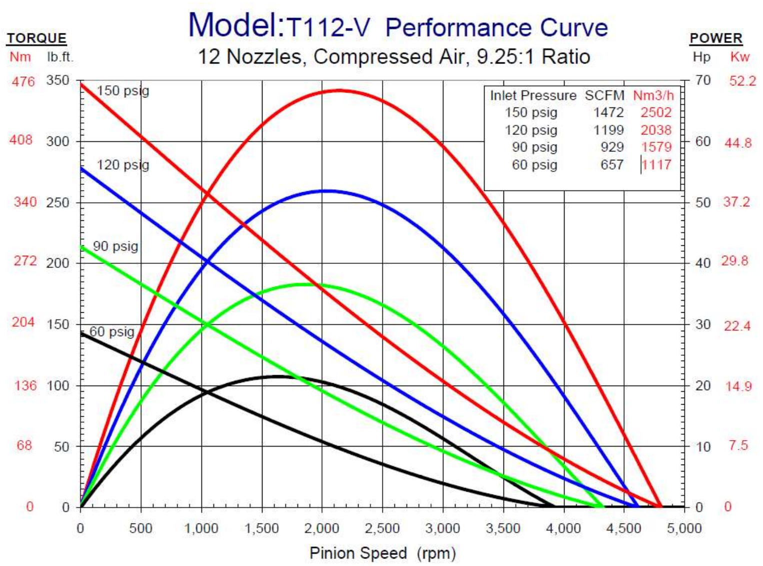

Figure 2.3 **A torque-speed starter performance chart (air starter)**

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The figure above presents a starter motor performance chart, showing both torque and power as a function of starter RPM. Our focus is on the torque plots, which are the curves that start high on the left and decline as they move to the right. This chart is for a turbine-type pneumatic starter, but it is pretty typical of a torque-speed chart for a starter motor, regardless of type. Perhaps the key thing to remember while working with this chart is that everything shown is AT THE STARTER. Both the speed and torque must be converted before you attempt to compare them to the engine values, and that conversion is where the gear ratio comes into play.

Here is an example to illustrate how these pieces come together. The engine used here is an older G3516, and the values shown were retrieved from the Technical Information A&I Guide section.

- 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.

First, calculate the gear ratio that will be used in the conversion:

$$gear\ \mathrm{ratio} = \frac{(flywheel\ \mathrm{teeth})}{(pinion\ \mathrm{teeth})} = \frac{183}{12} = 15.25$$

Next, use the gear ratio to calculate the speed the starter will be turning to reach the target cranking speed for the engine:

$$starter\ speed = engine\ speed \times gear\ ratio = (100) \times (15.25) = 1525\ rpm$$

Now, use that starter speed to determine the available torque from the starter at that speed. This requires the starter performance curve for the starter type to be used, and the air supply pressure available on the site. On the starter performance chart, locate the starter speed (1525 rpm) on the horizontal axis and follow it upward until it intersects the performance curve for the site supply pressure (90 psig). As shown in the figure below, this results in a starter torque value of 125 lb-ft at 1525 starter RPM.

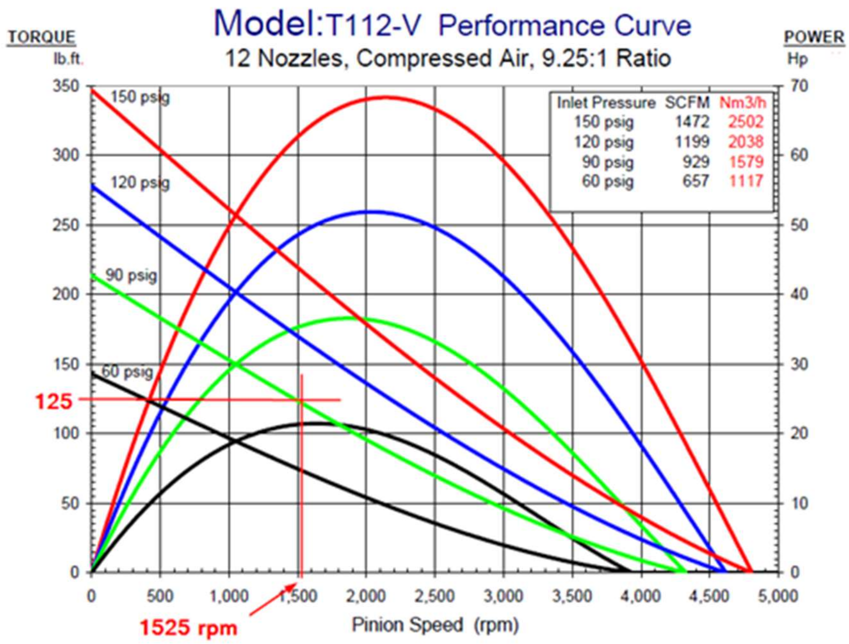

Figure 2.3 **Evaluating cranking torque from cranking speed**

In order to evaluate this starter capability versus the engine's requirements, the numbers must be converted to engine values. The engine RPM here is the target cranking speed used to determine the starter torque at that speed (100 engine RPM). The starter torque must be converted to flywheel torque, once again using the gear ratio:

$$flywheel\ torque = starter\ torque \times \#\ of\ starters \times gear\ ratio$$

$$= (125) \times (1) \times (15.25) = 1906\ lb \cdot ft$$

For this example, we have no additional cranking torque specified for the driven equipment or attachments. Comparing this starter capability to the engine-only requirements shows this starter has adequate capability for both the breakaway and cranking torques. In fact, because the starter torque is greater than the engine cranking torque, the engine will crank at a higher RPM than the target value. This is not necessarily a bad thing, but it is a good idea to evaluate just how much higher the cranking speed to will be to get an idea on whether it may be too fast. Simply divide the 950 lb-ft engine cranking torque by the 15.25 gear ratio to get the starter torque equivalent value of 62.3 lb-ft. Referencing this on the chart shows 62.3 lb-ft intersects the 90 psig performance curve at ~2800 starter RPM. Dividing that by the 15.25 gear ratio tells us this cranking speed is equivalent to 183 engine RPM. This speed is most likely a reasonable speed to crank a G3500, but if there are any questions it is also a detail that can be checked with the technical help staff, either at the dealer or with the Cat factory.

Another thing you should notice is this starter is capable of using air pressures within the displayed range of 60 psig up to its rated operating limit of 150 psig. It would also be possible to reduce the cranking speed by reducing the supply pressure for the air to the starter. Because it is still necessary to meet the breakaway torque requirement, that is a good next cranking point to evaluate. Following those same steps as above, the 1140 lb-ft of engine cranking torque is equivalent to 74.8 lb-ft of starter torque. For the 90 psig supply pressure this torque is achieved at ~2400 starter RPM, or 157 engine RPM. Or, if the supply pressure were regulated down to 60 psig, this torque would be achieved very close to the target cranking speed of 100 engine RPM (1525 starter RPM). From this extension of the example you should understand the pressure curves may be interpolated to estimate operating points that fall between them.

This example goes into some detail specific to an air starter, with the intent on being sufficiently thorough to give you a broader understanding of how this process works. Hydraulic and electric starters will have their own details to consider, such as fluid condition for the hydraulic system or battery bank size for the electric system. Be certain to review all of the details for a particular starter type before moving forward on a starter system selection.

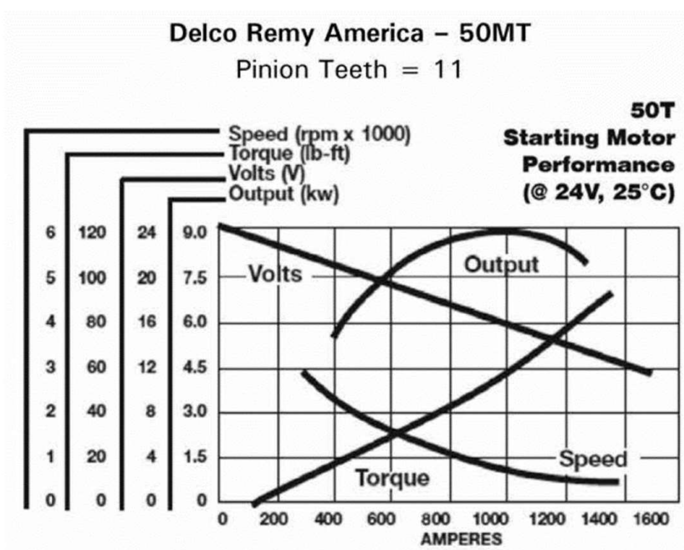

Figure 2.4 **An electric starter torque-speed performance chart**

The performance chart for an electric starter can look a bit different than that shown for the example, but it does include the same information. Torque, speed, and electrical current draw (Amperes) are somewhat interrelated, so they must be read simultaneously on the chart. Note also that the input voltage is fixed, so the electric starter does not offer that as an input that may be adjusted to suit a specific scenario.

Hydraulic starter performance charts can be quite simple by comparison. The hydraulic motor inside the starter is a positive displacement machine, so fluid flow is determined by the starter's turning speed. The one variable available to adjust performance is the input pressure of the hydraulic fluid.

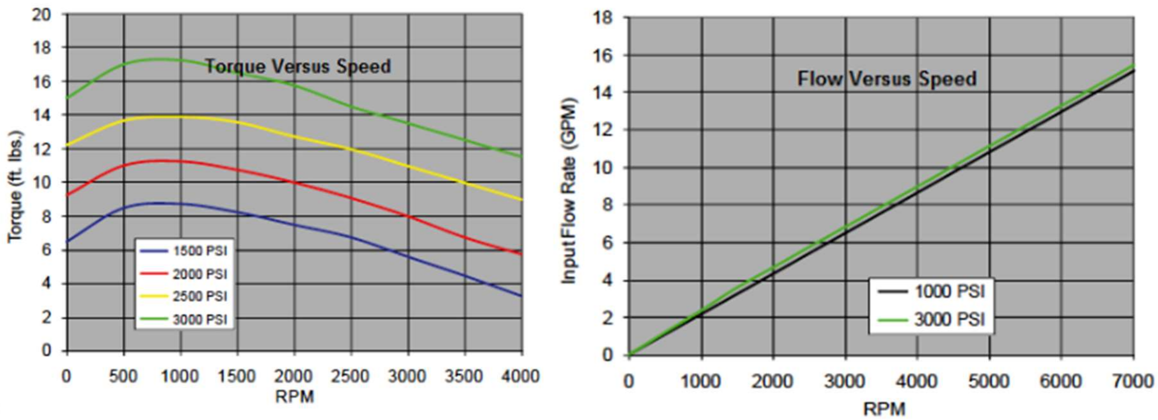

Figure 2.4 **A hydraulic starter torque-speed performance chart**

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3 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.

3.1 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 but 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.

3.2 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.

3.3 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. Caterpillar 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.

3.4 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.

3.5 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).

3.6 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.

4 Special Starting Cycles

4.1 Emergency and Fast Starting

Some emergency and standby power applications require the ability for fast starting. Certain engine configurations are capable of supporting 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 on the basis of 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).
- For gas standby gensets, minimum engine room temperature of 4.5° C (40° F) or greater in addition to the use of jacket water heaters and prelube when required.
- Combustion air requirement of 21° C 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.

4.2 Cycle Cranking

The cycle cranking feature (when present on the engine) enables an automated repeated cranking sequence. This may be useful when the application or environment creates a challenge in achieving a successful start in just one cranking sequence.

Cycle cranking enables the operator to define the number of repeated start attempts, the duration of each attempt, and the duration of the rest interval in between each attempt. Care should be exercised in defining these parameters – by its nature, the starter is a highly loaded device and a demanding cycle crank sequence can lead to increased temperature and stress in the starter motor and its power transmission.

4.2.1 Cranking instructions for the 45M turbine starter

The 45M turbine starter carries specific instructions for cyclic cranking for just this reason. Proper management of the duration of the cranking and rest cycles helps to address heat build-up in the internal gearing of the starter. Those specific instructions for cyclic cranking using the 45M turbine starter may be found in the service publication “Special Instruction – Limiting Cranking Cycles to Allow Cool Down Periods on Certain 3500 and C32 Engines”, service publication number M0183578.

5 Pneumatic (Air) Starters

Air starters are a readily available and highly capable starter type. Air starters generally respond very quickly to air flow inputs, making them capable of accelerating the engine very quickly as compared to electric starters (as much as twice as fast). However, because air starters require often bulky air storage tanks they typically are used on larger installations, such as large work boats, platforms, or land-based stationary applications. Air starters are the only factory option offered for larger engines (such as 3600/G3600) because there are few electric starters available that have the rated torque needed to crank such a large engine.

5.1 Pneumatic starter types

There are different designs available for air starters, and the starter design and construction contribute specific attributes to each offering.

5.1.1 Vane starters

The vane-type air starter uses vanes (paddles) fastened to a central shaft. Pressurized air admitted into the rotor housing must push the paddles to continue on a path to the exit port, thereby turning the rotor. This rotational motion is directed to the output shaft of the starter.

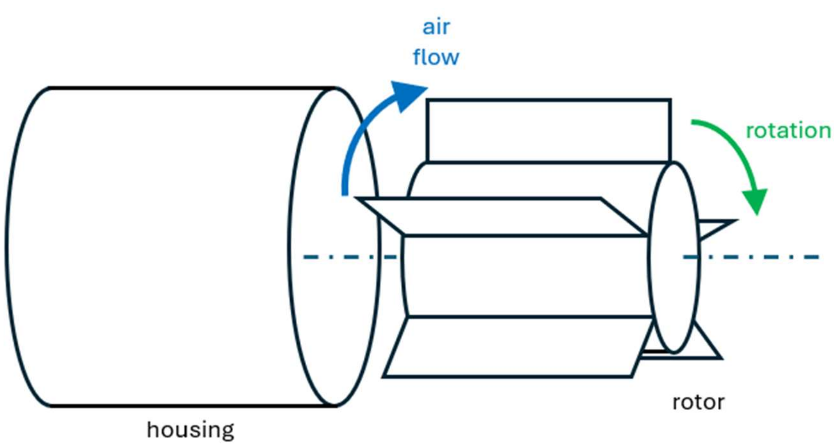

Figure 3.1 **Vane starter mode of operation**

The view in the figure above shows the vanes and rotor that form the core of the vane starter design. The inlet and outlet ports on the housing are arranged such that the air will push the vanes; this design makes the vane starter a positive displacement device. The vanes form a physical barrier to the free movement of the air, so the air must push them out of the way to proceed on its path from inlet to outlet on the starter housing. Some vane starter offerings are offered with high operating pressure capabilities, which can deliver higher torque outputs with less air flow required. The positive displacement design also puts a focus on seal life, as leakage past the vanes will lead to diminished performance.

The positive displacement design also causes the air flow rates during operation to be closely linked to the turning speed of the starter. Vane starter air flows increase with increased speed, so accurate estimation of air consumption during a single cranking cycle may require a detailed review of the case-specific torques and speeds the starter will experience during that cycle. Should the starter be loaded up to its rated torque, the rotor will simply not turn, and no air will flow.

5.1.2 Turbine starters

The turbine-type air starter, as the name suggests, uses a turbine to convert the input energy of the compressed air into shaft rotation.

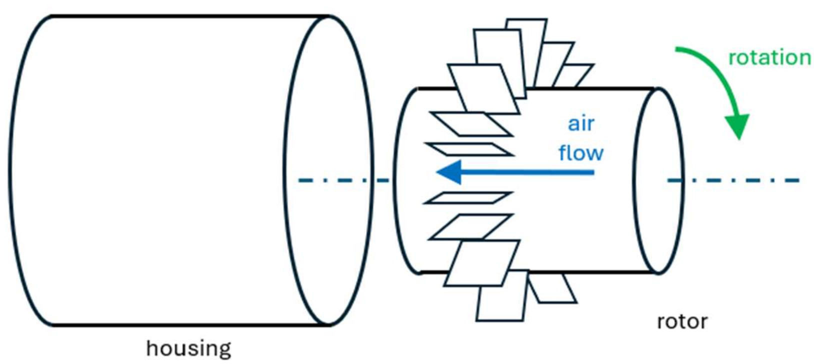

Figure 3.2 **Turbine starter mode of operation**

Unlike the vane-type design, the turbine starter is a “straight-through” design. The air inlet and outlet are at the opposite ends of the housing, and air flow is along the axis of the rotor. The turbine blades are shaped is a way that maximizes the rotational movement of the rotor as the air moves through.

Because there are no physical barriers to the air flow, it is free to move directly through the starter. This results in air flows that are nearly constant regardless of the turning speed of the rotor, a detail that can simplify the calculation of air consumption during a single cranking cycle. If this starter were loaded up to its rated torque, the rotor will not turn but the air will still be free to flow through the starter.

5.1.3 Starter pinion engagement

Starters rely on temporary engagement of the pinion to the engine's flywheel ring gear. The gear must be engaged to support cranking but must also disengage once the engine is successfully started. If the pinion remains engaged, the increased operating speeds of the engine will cause the starter to overspeed, causing damage.

Many smaller diesel engines can rely on the automotive-style inertial engagement mechanism, sometimes called a "Bendix" in reference to the company that became known for the design. Inertial engagement uses the inertial force of the accelerating shaft to drive the pinion outward on a steeply-pitched helical spline. The contact force between the pinion and ring gear keeps it engaged until the engine begins to accelerate, at which time a return spring on the engagement mechanism pulls the pinion back away from the ring gear.

Larger engines, and gas engines in particular, may be susceptible to some misfire during cranking. Such irregularities in rotation of the flywheel can release an inertially-engaged pinion prematurely, leading to multiple failed cranking cycles. To remedy this, many starters are offered with a "pre-engaged" pinion design. A pre-engaged pinion is extended outward to engage the ring gear before the starter motor is permitted to being cranking. For air starters, this is often accomplished by an intermediate air path which directs air pressure to a tap on the starter motor that pushes the pinion outward on a straight spline. Once the pinion is fully engaged the air pressure is then directed to a shuttle valve to "switch on" the main flow of air to the starter motor. Engine systems that monitor engine RPM will detect when the cranking cycle is complete can then release the pinion, allowing it to disengage and retract.

5.1.4 Prelubrication Systems

Prelubrication (or "prelube") is an oil pumping cycle performed before cranking to push oil into the engine's lubrication circuit. Prelube can avoid a significant amount of wear by minimizing the amount of time the moving components will be without the full pressurized oil flow from the main engine oil pump. In effect, prelube seeks to fill the oil passages so as soon as the main engine oil pump begins turning it will be delivering the proper lube oil flow and pressure. Large engine models (3600 family and larger, gas and diesel) require prelubrication. For other engine models it is at least recommended; check the Operation and Maintenance Manual to see if your particular engine requires prelube.

Prelubrication is discussed in greater detail in the Lubrication Systems A&I Guide (LEBW4957), including a description of various types of prelube systems and how they are comprised on the engine. The purpose of discussing prelube here is to raise awareness that it too is a system that will actuate during the cranking sequence. In many cases an engine that uses an air starter will also use air to drive the prelube system, and thus it should also be taken into account in the design of the supporting air system. The additional air consumed by the prelube pump must be added to the starter motor air consumption to properly size the air receiver/storage tank that will be needed.

5.2 Air supply systems for pneumatic starters

When pressurized air is the starting medium, there will need to be a system that provides the air so an air compressor must be involved in some manner. Often this will be in the form of a dedicated unit, part of what is often referred to as a "plant air" system. Consider too that there is much more to a compressed air system than just a compressor.

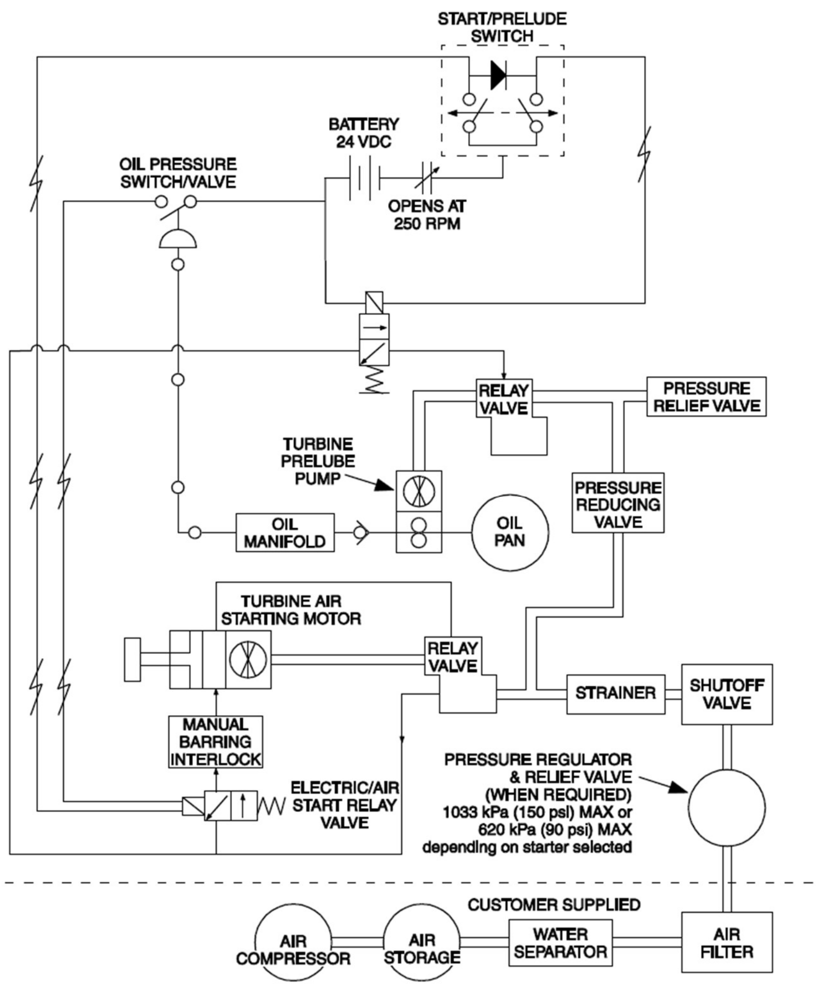

Figure 3.3 **Air start with air prelube system diagram**

PNEUMATIC STARTERS

- The air consumption rates for the starter system would require a very large compressor. Instead, an air storage vessel is used to make those large air volumes available on demand, and a much smaller recharge compressor is used.
- Air is readily available to be compressed into the system, but ambient air quality can very greatly from day-to-day and site-to-site. For this reason, the air system must have conditioning components included in the air path. Note the de-watering and filtration components in the diagram above.

Engines offered with price list air starting systems will typically include the integration components and air routings (hoses/tubes) as part of the system. However, as noted in the figure, the main air supply and conditioning remain part of the customer's scope of supply.

5.2.1 Air storage tank

The air storage tank is a pressure vessel, required to safely contain large volumes of air at high pressure. Such storage conditions often place such pressure vessels under the jurisdiction of regional or industry standards, such as the ASME Boiler & Pressure Vessel Code (BPVC). The BPVC is a standard that regulates the design and construction of boilers and pressure vessels to ensure they are of safe construction and have been inspected and tested to verify their integrity. Those sourcing an air start system should investigate what regulations cover pressure systems in their area to ensure their system will be constructed and installed in accordance with local codes. Operating such systems should include the necessary gauges to monitor system performance, and procedures for inspecting or testing all required overpressure relief devices and liquids drains.

5.2.2 Tank sizing

In general, the sizing of an air storage tank will be a function of the storage pressure and the volume of air to be stored. However, those numbers are further derived from the performance requirements of the devices the air will power, the real-world cranking behaviors of the engine, and any variabilities created by the local climate.

The basic calculation for required tank volume involves the air consumption rate of the air starter, the time duration the starter will operate, the nominal storage pressure the tank will be designed to, and the minimum pressure at which the required cranking condition can be sustained. These are the basic inputs. Because failure-to-start events do occur, the tank size should plan for multiple cranking cycles. The duration of those cranking cycles can also vary, based on the type of engine (diesel versus gas), the quality of the fuel (pipeline gas versus low energy landfill gas), the site environmental conditions (colder environments typically drive higher cranking torques and longer cranking cycles to achieve light-off). Also important is to include the added volume to support other systems also being operated using the pressurized air (such as an air-driven prelube system).

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 a diesel engine at 26.7°C (80°F), and restarting that engine hot usually requires less than two seconds. For reference, most marine societies require a minimum of six consecutive starts for propulsion engines. For such marine installations, refer to the applicable marine society rules for current requirements for propulsion and other applications on marine vessels.

Note that gas engines are generally a little harder to start than diesels. Gas engine initial (cold) cranking can last 20-30 seconds, and even during hot cranking 10 second start attempts are sometimes needed. The Operation and Maintenance manual may offer starting recommendations for your engine type and model. Note also that some gas engine applications require purge cycles to vent unburned fuel before the next start attempt. Such purge cycles involve cranking the engine with the fuel supply disabled, in order to pump air only through the intake and exhaust paths. Purge cycles can help minimize the risk of a combustion event occurring in the site piping due to residual fuel gas being present. Refer to Cat documentation for your engine, and to local codes or industry recommended practices for more information on this and other similar considerations.

The general sizing calculation follows this form:

$$V_T = \frac{(V_S)(T)(P_A)}{\mathrm{P}_T - P_{min}}$$

Where:

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

V_S = Air consumption of the starter motor (m3/sec or ft3/sec). Include prelube system air consumption if prelube is present on the engine.

T = Total cranking time required (seconds)

P_A = Atmospheric pressure (psi or kPa). A reference value for P_A is 101 kPa (14.7 psi).

P_T = Air storage tank pressure (psi or kPa). This is the starting tank pressure.

P_{min} = Minimum tank pressure required to sustain cranking at 100 rpm (psi or kPa).

There is some need to apply judgment to some of the values used for these variables. Prelube cycles may be longer for a first cranking cycle on a cold engine, but once the lube system passages have been filled by the prelube any subsequent prelube cycles should be quite short. Considering the consecutive starts requirement noted above, with each repeated cranking cycle the engine will get a little warmer, so for a diesel engine in a warm climate it may be OK to use 7 seconds for the first cycle and only 2 seconds for the remaining five cycles. For gas engines operating on low energy fuels (such as biogas), light-off can be more challenging and longer cranking cycles should be expected. And when failed start attempts occur a purge cycle should be run to chase any residual unburned fuel out of the exhaust piping.

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 m3/sec = 14.1 ft3/sec

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

P_A = 100 kPa = 14.5 psi

P_T = 1241 – 207 = 1034 kPag or P_T = 180 – 30 = 150 psig

P_{min} = 620.5 kPag = 90 psig

Therefore,

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

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

5.2.3 Air supply piping

The air supply piping must be robust enough to support the operating pressure of the system, and simplified enough to minimize the restriction to flow it induces. Restriction in the air lines simply reduces the performance of the air driven systems by lowering the real pressure seen at the starter or prelube motor. As an initial rule of thumb, the piping diameter should be no smaller than the inlet connection to the starter motor itself; larger diameter piping will contribute even lower restriction levels. Details such as total length of the air piping path and the quantity of bends, elbows, tees, and diameter changes all contribute to the flow restriction total. The air system designer should set a goal to minimize these sources of pressure loss.

Seamless carbon steel pipe (such as ASTM A106) is a preferred material for air system piping. Because this piping will connect to the engine, it will cross the invisible boundary between the low-vibration environment to the higher-vibration engine. A flexible coupling placed at the point of connection to the engine will add compliance and limit vibration-induced fatigue. Some engines may include such a flexible connection as received from the factory; check the consist for your engine to be clear regarding the sourcing of this important component.

Oil and water that are not removed by liquids separators will accumulate in the air receiver and at low spots in the piping. Any 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 just upstream of the supply line air pressure regulator to ensure solid particles do not damage the starter.

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.

Piping systems must comply with applicable local codes, including having safety pressure relief devices (PSVs) installed where they are required. Location and sizing of PSVs is important and should follow the codes as closely as possible. Blocking valves that positively disconnect the main air/gas supply when the starting/prelube cycles are completed may be necessary in some applications.

Purge the compressed starter supply 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). Hydrostatically test the compressed air lines to at least 1.5 times the system working pressure, or to the requirements of any applicable regulatory codes.

Caution must be exercised when designing exhaust and venting systems for air starters. Piping systems which may see high pressure should not be connected to systems that include devices rated only for lower pressure. High pressure air 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.

Air starting systems that are to be used in applications that require hazardous locations certification must be suited for such use. On an air starting system this will not involve the starting motor itself as is it driven by air, but such systems may use electrically-controlled solenoid valves to allow automated starting directed by the engine's control system. Any such electrical components in the air starting system must be covered by certification to the applicable hazardous locations standard. This can be for the component as received from its manufacturer or for that component as included as part of a whole system certification provided by Caterpillar.

5.3 Natural gas as a starting medium

It is worth noting that air starters often can be used with other media, such as compressed natural gas. Starter sizing for compressed gas follows the same general steps as above, but the starter performance may be different due to the physical differences between natural gas and air. Be certain to check for starter performance data to match the media you intend to use. Also, while it has been common to use the pressurized gas for starting engines in gas compression applications, this approach gets a more critical review when the gas emitted from the starter outlet is viewed as site hydrocarbon emissions.

Proper design and execution of starter and prelube supply and exhaust piping and venting are critical when installing the engine. 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 type of fluid in the piping. Natural gas piping can have different requirements than those that apply to air piping, so awareness of the codes is important.

Combustible gas exiting from starter motor exhaust outlets must be piped away to a safe location. This is also true of vent lines that may be necessary on certain control valves in the system. Such valves may include dedicated vent ports or even unused 3rd ports that may be critical to proper operation of the system. In some cases the unused port serves as an escape path to allow a particular line to depressurize when the starters are being disengaged. Keeping such vents open is critical to proper system operation. If combustible gas will be coming through those vents and ports, additional piping must be included to route those gases to a safe location.

6 Hydraulic Starters

As the name suggests, hydraulic starters use an incompressible fluid as the starting medium. More specifically, hydraulic fluid is used to transmit stored energy from a pressure source to the starter motor. Hydraulic starters are capable of high torque from a compact motor, so high cranking speeds are commonly achievable, which can translate to faster starting on many engines.

6.1 The hydraulic starter

Externally, a hydraulic starter can appear very similar to a pneumatic starter, except that is it likely to be visibly more compact than an equivalently rated pneumatic unit. The compact body is mated to a pinion drive system that may be essentially identical to those seen on pneumatic starters.

Internally the hydraulic starter uses a fluid drive that is suited to the incompressible fluid that drives it. The motor may use an arrangement of pistons, internally meshing gears, or some other arrangement by which the hydraulic pressure can produce rotary motion of the output shaft. Once the fluid has passed through this drive mechanism it is directed out of the motor and into a return path to the fluid storage reservoir.

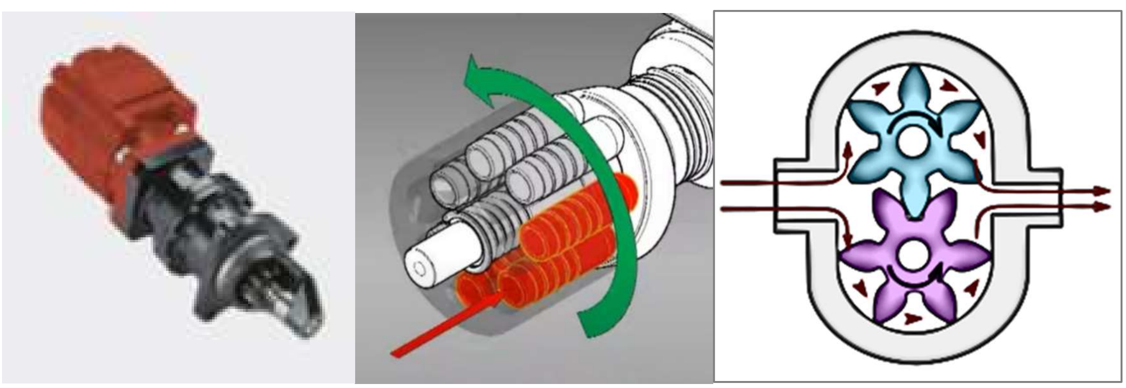

Figure 6.1 **A hydraulic starter motor**

6.1.1 Pinion engagement

Pinion engagement for a hydraulic starter is typically via the inertial engagement drive described in the earlier section.

6.1.2 Hydraulic starter details

Hydraulic starting can be an attractive option for applications where an electrical connection close to the engine may pose a safety hazard. While hydraulic starters are typically not offered as price list options for many Cat engines, they are readily available in the aftermarket from numerous vendors.

Hydraulic starters that include a case drain connection may extend the life of the starter by managing the backpressure on the starter's output shaft seal. A case drain connection should be routed back to the fluid reservoir on a low (near atmospheric) pressure line.

6.2 Hydraulic system

The hydraulic system needed to support hydraulic starting includes some basic components:

- A reservoir for storing the hydraulic fluid
- A pressure accumulator for storing the pressure used to drive the fluid
- A control valve for managing the operation of the starter
- Interconnecting lines to route the fluid to the various components

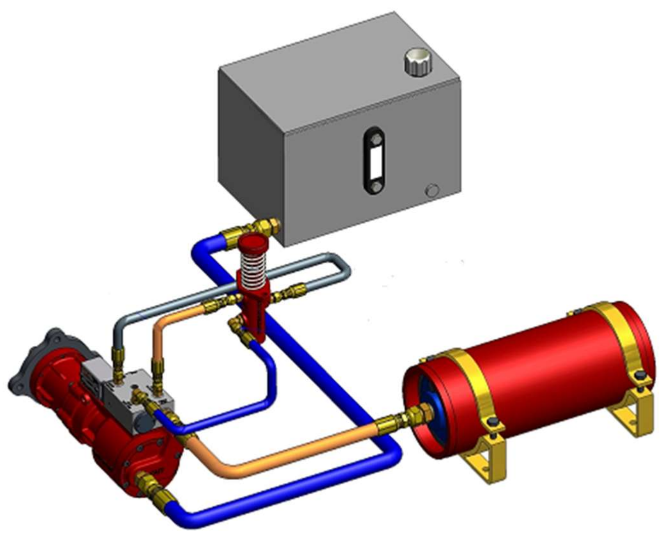

Figure 6.1 **A simple hydraulic starter system**

A powered pump is used to generate the pressure that drives the hydraulic fluid. Some systems will include a manually-operated pump to allow for recharging the pressure vessel when the powered system is unavailable. This can be an important feature for the system under non-standard conditions but be aware this process is quite laborious and should not be considered a standard method for pressurizing the system.

6.2.1 Hydraulic system requirements

Cleanliness is perhaps the key requirement for a hydraulic system. Maintaining the working fluid free from hard particles, or other debris or contaminants, is important for ensuring the best performance and longevity from the system.

The key standard for hydraulic fluid condition is ISO 4406:1999 (also SAE J1165). This standard presents a "code" for categorizing the particle content (by quantity of particle size) in a 100 ml sample of the hydraulic fluid in a system.

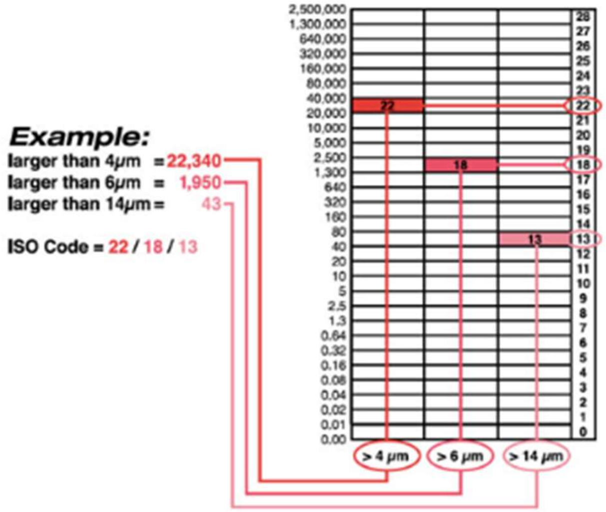

Figure 6.2 **ISO 4406 code explained**

By this ISO construct, the fluid sample is analyzed and the particles detected are counted and categorized by the micron sizes. Then, the particle count is parsed into the number of particles larger than three reference sizes, 4μm, 6μm, and 14μm. The total count for each reference size is then encoded using the scale seen in the figure above. In that example, the fluid analysis detected 22,340 particles larger than 4μm, and that number falls into the interval of 20,000-40,000 so it is assigned the code value "22". Similarly, the count for particles larger than 6μm is 1,950 which is assigned the code value 18, and the count for particles larger than 14μm is 43 which is assigned the code value 13. This result would be stated as "ISO code 22/18/13", which establishes a condition for that point in time. This code can now be compared against any other test results (earlier or later), with the understanding that each +1 increase in code value is essentially a doubling of the particles in that size range. Caterpillar recommends an ISO code of 17/15/12 for fluids used in hydraulic starting systems.

Managing this particle contamination requires effective filtration. Cat recommends filtration with a minimum 10 micron rating (3 micron is recommended), and with a beta ratio greater than or equal to 200. Beta ratio (β_x) refers to the number of particles measured upstream of the filter divided bt the number downstream of the filter, for the referenced minimum size “x”. In order to meet the β_{10}=200 performance reference, a filter presented with a fluid having 10,000 particles of 10 microns or larger would have to have an outflow containing no more than 50 particles of 10 microns or larger (10,000/50=200).

Working with this beta ratio construct in mind, the minimum recommended fluid cleanliness should comply with the following:

- Filtration to ISO 4406 (4µm/6µm/14µm)
- Cleanliness level 17/15/12
- Filter should have minimum 10 micron rating (3 micron recommended) with $\beta_{10} \geq 200$

In addition to these capabilities of the hydraulic fluid filtration system, the system cleanliness requires diligence in the installation phase. All hose assemblies should be cleaned prior to installation and commissioning. All hydraulic fluid put into the system should be adequately filtered to ensure it will not simply fill the engine’s hydraulic filters with debris (new fluid is recommended for a newly installed system).

The location of the filters in the hydraulic system must also be considered. It is recommended that the filters NOT be placed in the hydraulic fluid return path (downstream of the starters) because they will increase the backpressure in that fluid path. All fluid backpressure does detract from starter performance, so the fluid return path restriction should be kept to a minimum.

6.2.2 Hydraulic fluid recommendations

Caterpillar recommends the following for hydraulic fluids used in starting systems:

- Use premium quality hydraulic fluid with a viscosity range 32-65 cSt (Centistokes) (150-300 SUS (Saybolt Universal Seconds)) at 100˚F (38˚C).
- Normal operation viscosity range is between 16-220 cSt (80-1000 SUS).
- Maximum start up viscosity should not exceed 880 cSt (4000 SUS).
- Under no circumstances should the temperature exceed 180˚F (82˚C).
- Oil should have maximum anti-wear properties as well as rust and oxidation inhibitors.
- For fire resistant fluids, use those which are compatible with NBR sealing components such as water glycols or vegetable oil derived hydraulic fluid such as Cosmolubric B-220 and B-230.

6.2.3 Hydraulic hoses and fittings

The hydraulic system must contain high pressures, hence the hoses and fittings used in the system must be selected carefully. Hose materials must be specifically compatible with the fluid to be used. Hoses and fittings must be capable of the design pressure for the system. It is recommended all hoses and fittings carry a minimum capability of 3000 psig (207 barg).

The design of the fluid path must also consider the components selected. Tight bends can place stress on flexible hoses; as a rule of thumb, the hose bend radius should be no less than 12 times the nominal hose size.

On the supply side of the fluid circuit, an on/off control valve should be placed between the starter and the fluid pressure source. This valve needs to be able to limit the pressure in the supply line to the starter so that the starter motor is not subject to significant pressure when it is not operating. The fluid return path should be designed to be an “always open” path back to the fluid reservoir, with hoses and fittings sized to limit restriction to flow (backpressure) to no more than 150 psig (10.3 barg) as measured at the starter return port.

6.3 Hydraulic starter motor

The hydraulic starter motor is a specialized device that uses highly pressurized fluid as its driving medium. As with all such hydraulic systems, it is very important to read and understand the instructions pertaining to the starter before designing and installing the system to which it will be connected.

Installation to the engine typically uses the same SAE-spec mounting pads as do the pneumatic or electric starters. Inspect the general dimension drawings prior to installation to ensure the proper orientation of the starter connections.

A particular point of emphasis is in limiting the pressure placed on the output shaft seal for prolonged periods. This seal is a highly stressed component on the starter, such that preserving its condition can be a prime factor in extending the useful life of the starter itself. The aforementioned limit for backpressure in the fluid return lines is an important part of this effort. Having a case drain on the starter motor can also help, as this feature relieves excess pressure by allowing that fluid to drain back to the reservoir. Case drains work best with a dedicated line back to the reservoir, but if this is not possible it is acceptable to connect the case drain to the main fluid return line as long as the backpressure is kept below the pressure limit stated earlier.

Prior to initial operation of the motor, the hydraulic supply system should be cycled several times to purge air from the hydraulic lines. Note that all hydraulic starters will have their rated operating pressure indicated on their nameplate. As indicated earlier, hydraulic systems carry a large amount of energy so safe operation practices are critical. Hydraluic starters should NEVER be operated with supply pressures greater than the starter motor's rated pressure. The starter motor must never be operated with the outlet port plugged or obstructed in any way.

6.4 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 certain 3500 diesel engines, but those offerings are typically the starter motor only. The installer will still be responsible for the remaining portions of the hydraulic circuit.
- Care must be exercised to protect hydraulic pressure accumulators from damage. Hydraulic accumulators contain large amounts of stored mechanical energy when energized, so placing them where incidental damage may occur will likely represent a hazard to machinery and personnel.

7 Electric Starters

Electric starters are perhaps the simplest of the starting system options, and as such they are quite common as a factory starter offering. However, there are numerous details to the proper execution of starter installation and wiring that can determine the success of the installation.

The following guidelines are for mounting, wiring, and control of electric starters that come with Caterpillar 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.

7.1 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.

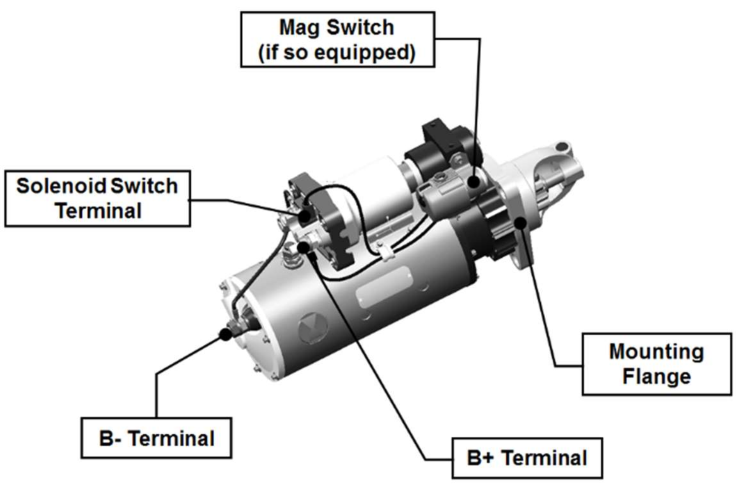

Figure 5.1 **Features of an electric starting motor**

7.2 Mounting

7.2.1 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.

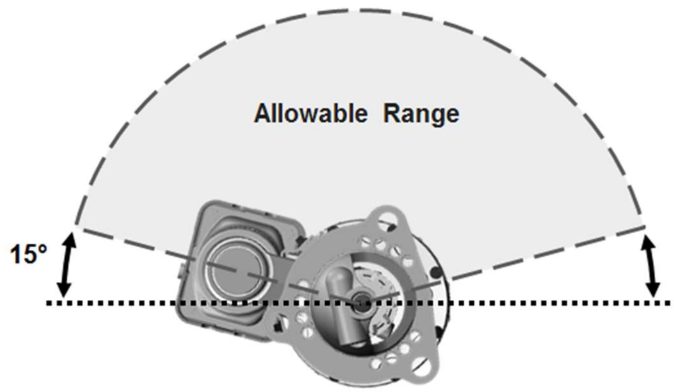

Figure 5.2 **Range of permissible solenoid angles**

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.

7.2.2 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.

Figure 5.3 **Starter mounting bolt torques**

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

ELECTRIC STARTERS

7.2.3 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.

Figure 5.4 **Starter seal part numbers**

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

Note: See Section 4.8 for list of part numbers by Class description

7.2.4 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.

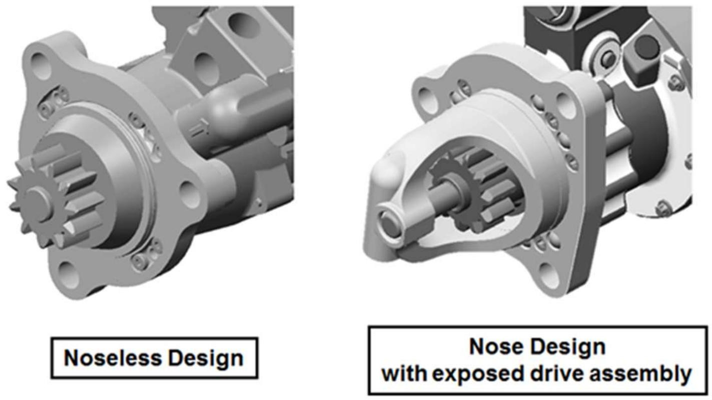

Figure 5.5 **Designs of the starter pinion “nose”**

7.3 Starting Batteries

7.3.1 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.

7.3.2 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 general guidelines in this table 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.

7.4 Wiring of Starter B+ and B–

7.4.1 Cable Size

Figure 5.6 **Starter batteries**

	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

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.

- 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.
- 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 the equation

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

  Where I_{100} is the current required 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.

7.4.2 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 from, 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.

7.4.3 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.

7.4.4 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 the Appendix for terminal torques of starter motors.

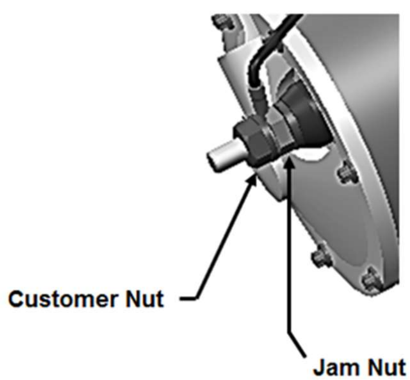

Figure 5.7 **Starter terminal detail**

7.4.5 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.

7.4.6 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.

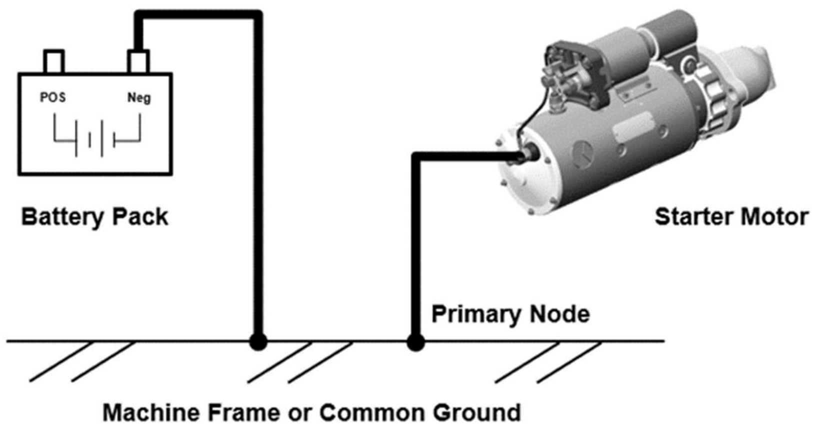

Figure 5.8 **Starter grounding**

7.4.7 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.

7.5 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.

7.5.1 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.

7.5.2 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 the Appendix for electrical specifications and assembly torques of starter motors.

Figure 5.9 **Starter grounding**

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.

7.5.3 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 the Appendix 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

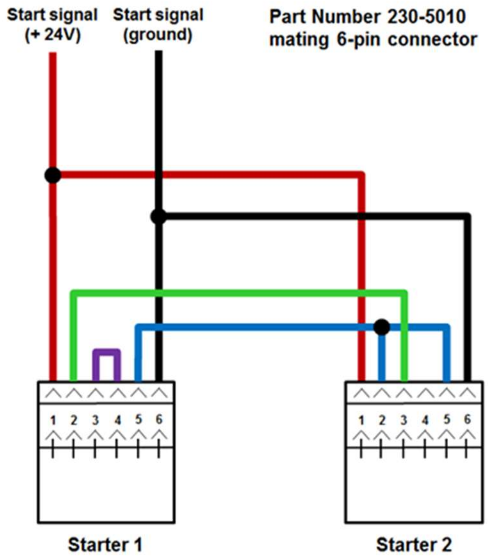

Figure 5.10 **Wiring dual Class O or P starters**

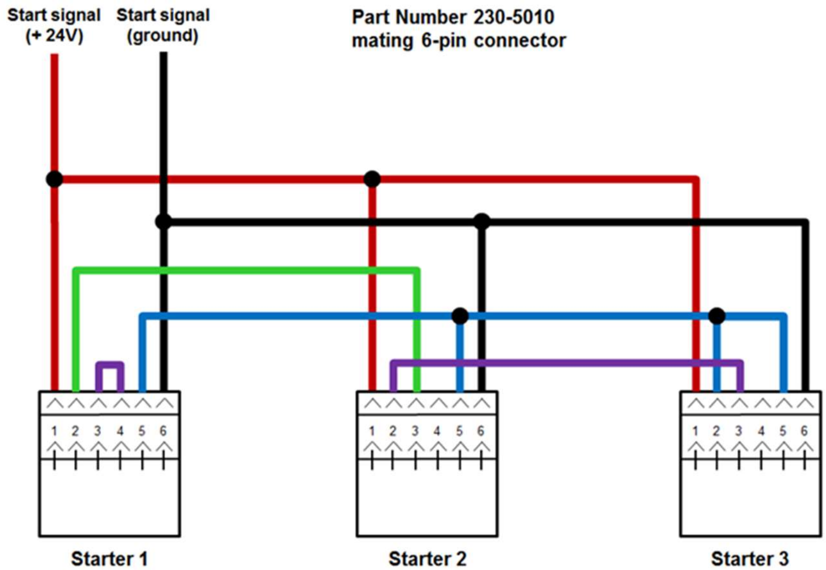

Figure 5.11 **Wiring triple Class O or P starters**

7.6 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.

7.6.1 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.

7.6.2 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.

7.6.3 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.

7.6.4 Rapid Re-Engagement

The starter should not be allowed 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.

7.6.5 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.

7.6.6 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.

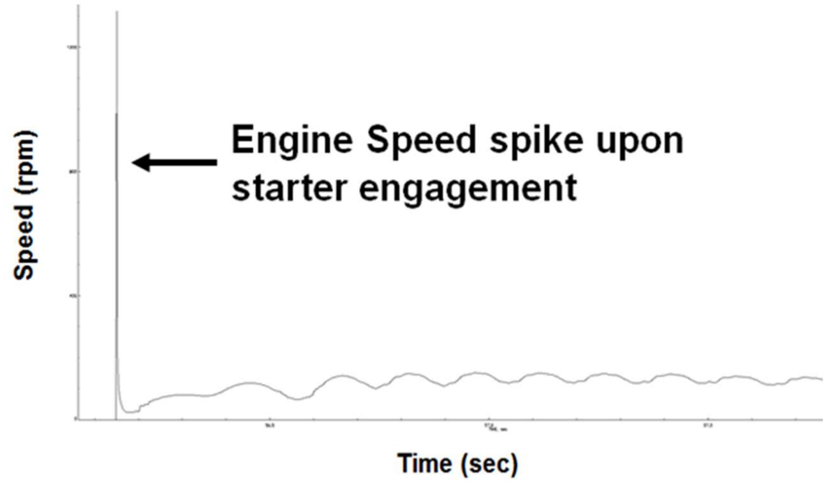

Figure 5.12

False starter speed spike

7.7 Environment

7.7.1 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

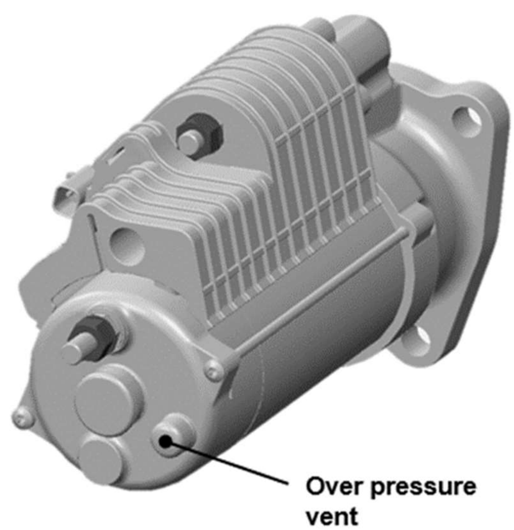

Figure 5.13

Over-pressure vent

7.7.2 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 5.2.1, 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.

7.7.3 Temperature

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

8 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.

8.1 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.

Figure 3.1 **Cat part numbers for various batteries**

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

8.2 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.

Figure 3.2 **Specifications for accessible batteries**

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%

8.3 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.

8.4 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.

8.5 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.

Figure 3.3

Optimum charging specs

Temp °F (°C)	Optimum Charging Volts for 12-volt Lead Acid Battery									
	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

Note: This table shows optimum charging volts for 12-volt battery vs. temperature for lead acid batteries, utilizing a charger. Use Caterpillar Data Sheet, PEHJ0073 to identify chemical construction of Caterpillar batteries to determine recommended charging voltages in the table.

9 Alternators

The following guidelines are for mounting and wiring of belt-driven charging alternators that come with Caterpillar 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.

9.1 Battery Compatibility

Most Caterpillar 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.

9.2 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.

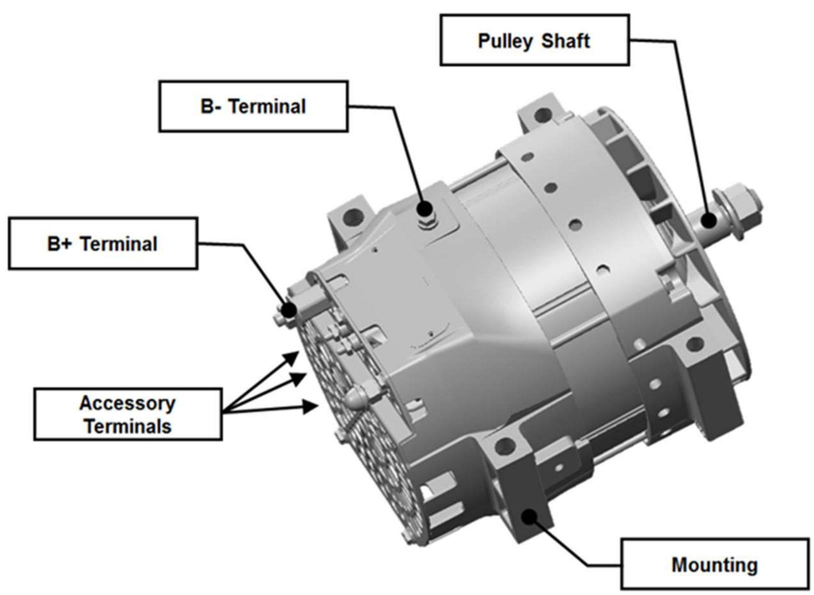

Figure 4.1 **Features of a typical charging alternator**

9.3 Alternator Mounting

Engine-driven alternators typically mount using one of two systems, described below.

9.3.1 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 in order 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.

9.3.2 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 through-bolt. There should be no clearance between the bracket and alternator pivot stays after hardware is tightened.

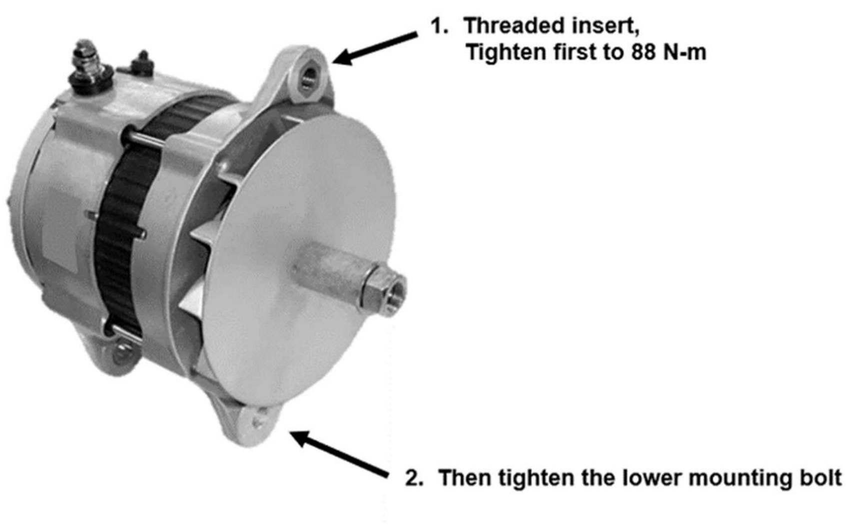

Figure 4.2 **A hinge mounted alternator**

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.

9.4 Pulley Shaft

9.4.1 Direction of Rotation

Most alternators are designed to rotate clockwise, 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.

9.4.2 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.

9.4.3 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 since 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.

9.4.4 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 the Appendix 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.

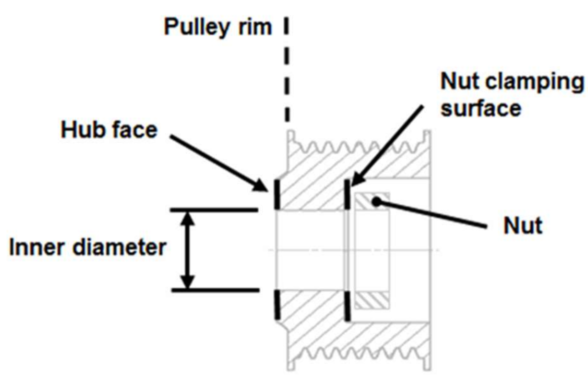

Figure 4.3 **The pulley and pulley nut**

9.4.5 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.

9.4.6 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.

9.4.7 Hand Guard

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

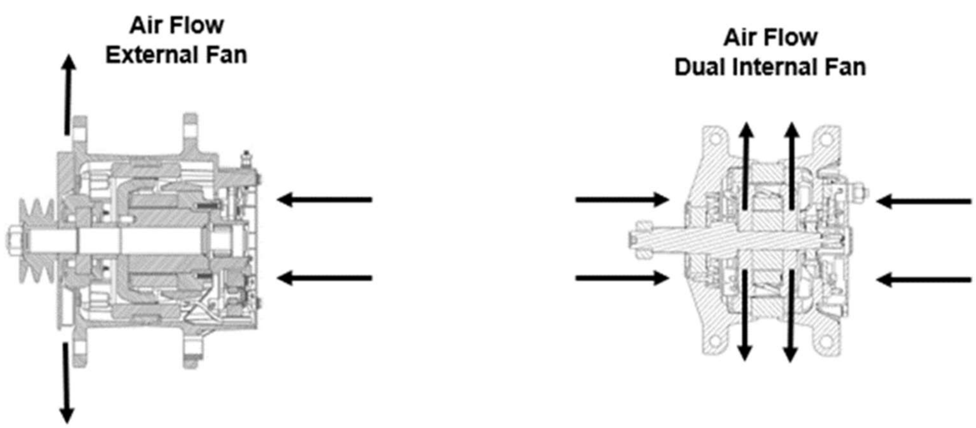

Figure 4.4 **Alternator cooling air flow**

ALTERNATORS

9.5 Wiring of Alternator B+ and B–

The charging alternator has positive and negative terminals for completing the charging circuit. These are often indicated as "B+" and "B-" respectively.

9.5.1 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 as long as 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.

9.5.2 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.

9.5.3 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 the Appendix for list of ring terminal sizes.

9.5.4 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.

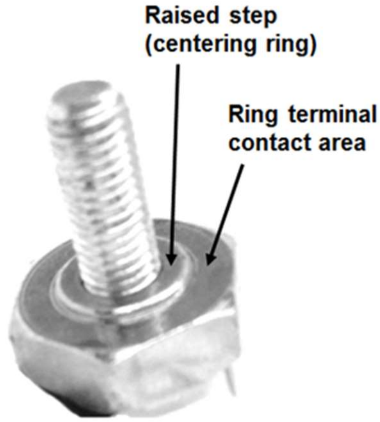

Figure 4.5 Detail of the alternator terminal fastener

9.5.5 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.

9.5.6 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.

9.5.7 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.

9.5.8 Dual Alternators

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

9.5.9 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 4.6.4, Sense Terminal (S, BS).

9.5.10 Operation Without a Battery

Applications without a battery in the charging circuit must use an alternator compatible with such an arrangement. Only certain types of alternators can accommodate this. Voltage peak during operation will increase when the charging circuit has no battery. Contact a Caterpillar dealer for assistance to select the correct alternator.

9.6 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.

9.6.1 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. The current must not exceed the maximum allowable or the alternator will be damaged. See the Appendix 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.

9.6.2 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 the Appendix 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.

9.6.3 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 the Appendix. Current must not exceed the limit or the 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 Caterpillar part number 9X-4997.

Caterpillar part number 9X-4997

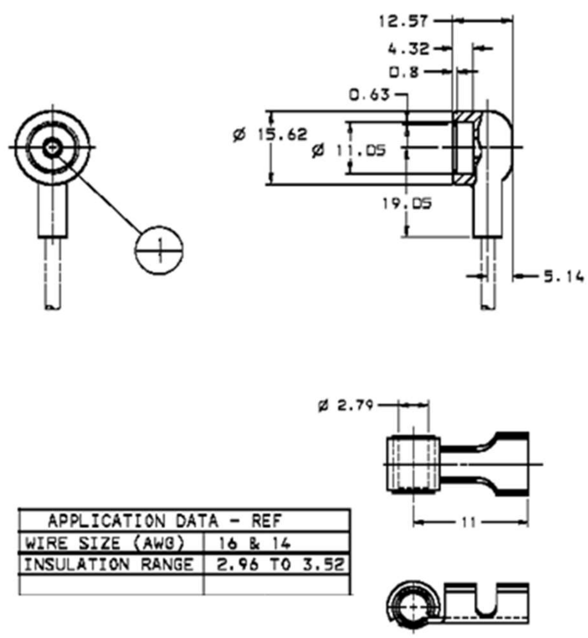

Figure 4.6 **Phase terminal connector**

9.6.4 Sense Terminal (S, BS)

The 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.

9.7 Environment

The following are some considerations for the environment in which the alternator will be operated.

9.7.1 Paint

The 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.

9.7.2 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.

9.7.3 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.

9.7.4 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 on a daily basis.

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.

Figure 4.7 **Screen/guard information for various charging alternators**

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

Note: See Section 3.8 for part numbers by group name

9.7.5 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.

10 Appendix – Alternator Technical Data

Figure 10.1

Alternator mounting and pulley tightening

	Continuous Speed Rating	Hinge mount threaded insert	Pulley Installation	
			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	128 ± 9 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

Figure 10.2

Alternator electrical terminal specs 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		

Figure 10.3

Alternator groups by part number

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
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

Part Number	Group Name
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
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

11 Appendix – Starter Technical Data

Figure 11.1 Starter electrical terminal specs 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 A	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 A	M5 stud	15 -30 in-lb	--
Class F	24 V	½ inch	27 - 34 Nm	2 A	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 A	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 A	Plug	--	230-4011
Class S	12 V	½ inch	20 - 30 Nm	2 A	#10 stud	2 - 3 Nm	--
Class T	24 V	½ inch	20 - 30 Nm	2 A	#10 stud	2 - 3 Nm	--
Class U	24 V	½ inch	20 - 30 Nm	2 A	Plug	--	3E-3364

Figure 11.2 Starter groups by part number

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

Part Number	Group Name
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
249-3681	Class S
266-7229	Class B
267-9535	Class C
269-2757	Class H
276-8900	Class H

Part Number	Group Name
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
415-1804	Class T
422-7553	Class O
422-7554	Class O
422-7555	Class O

Part Number	Group Name
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

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