CATERPILLAR®

Electric Power Application and Installation Guide

Starting System

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WHERE THE WORLD TURNS FOR POWER

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Starting System

An engine starting system must be able to crank the engine at sufficient speed for fuel combustion to begin normal firing and keep the engine running.

There are three common types of engine starting systems normally used for Caterpillar engines:
1) Electric
2) Air
3) Hydraulic

The choice of systems depends upon availability of the source of energy, availability of space for storage of energy, and ease of recharging the energy banks required for starting the engine.

Types of Starting Systems

Electric Starting Systems

Use chemical energy stored in batteries, automatically recharged by an engine-driven alternator or by an external source.

Air or Pneumatic Starting Systems

Use compressed air in pressure tanks, automatically recharged by an electric motor-driven air compressor.

Hydraulic Starting Systems

Use hydraulic oil stored in steel pressure vessels under high pressure automatically recharged by a small engine-driven hydraulic pump with integral pressure relief valve.

The technology of the systems are well developed. Any of the systems are easily controlled and applied either manually or automatically.

Electric and air starters can be used on both diesel and gas engines. Hydraulic starters can only be used with diesel engines.

Startability of a diesel engine is affected primarily by ambient temperature, engine jacket water temperature, and lubricating oil viscosity. Any parasitic loads (usually associated with the driven equipment) can greatly influence the startability, as well.

Function of Starting System

Terminology

Breakaway Torque

Engine breakaway torque refers to the torque required to begin rotating the crankshaft. The starter must be able to exceed the torque of the engine and auxiliary in order to begin rotating the engine. With an electric starter the voltage and amperage is important, so that the electric starter can reach its full potential which is listed in Table 1.

	Volts at Starter	Amps to Starter	Speed Starter/ Eng Cranking (rpm)	Potential Torque of Starter N·m (lb·ft)	Potential Torque on Flywheel N·m (lb·ft)
G3304, G3306 (156 flywheel teeth)	Starter Part No. — 1W5516 (12 pinion teeth)				
Breakaway*	17	1400	0/0	129 (95)	1674.4 (1235)
G3406 (113 flywheel teeth)	Starter Part No. — 2S7227 and 6V0927 (11 pinion teeth)				
Breakaway*	12.5	1400	0/0	135.6 (100)	1392.4 (1027)
G3408, G3412 (136 flywheel teeth)	Starter Part No. — 4N1062 (11 pinion teeth)				
Breakaway*	12.5	1400	0/0	135.6 (100)	1675.8 (1236)
G3508, 12, 16 (183 flywheel teeth)	Starter Part No. — 7C0527, 6V4246 (11 pinion teeth)				
Breakaway*	13	1400	0/0	124.7 (92)	2074.4 (1530)
	Starter Part No. — 6V0927 (11 pinion teeth)				
	12.5	1400	0/0	135.6/2250.7 (100/1660)	135.6/2250.7 (100/1660)

*Breakaway torque is theoretically 0 starter and engine rpm. However, the starter amperage limit is approximately 1400 amps. Thus the breakaway torque shown is reduced somewhat from actual to accommodate the amperage limit.

Table 1. Electric starter breakaway performance, gas.

Starter breakaway torque refers to the maximum torque a starter can generate at or near zero rpm. It is important to ensure that the starter breakaway torque is larger than the sum of the engine and auxiliary load breakaway torque. Since breakaway torque can vary widely, it is best to include a breakaway torque margin when handling auxiliary loads. The following equation should be used as a guideline to assure proper breakaway torque margin. The values used for $T_{eng\ brk}$ and $T_{aux\ brk}$ should be values representing worst case conditions under which an engine is expected to start.

$$T_{start\ brk} > (1.4)\left[T_{eng\ brk} + T_{aux\ brk}\right]$$

where,

$T_{start\ brk}$ = starter breakaway torque output

$T_{eng\ brk}$ = engine breakaway torque req

$T_{aux\ brk}$ = auxiliary breakaway torque req

The relationship of the starter torque to the torque applied to the engine (and auxiliary equipment if direct coupled) is:

$$\text{Starter Torque} = \text{Torque to Engine \& Driven Equipment} \times \text{Number of Pinion Teeth/Flywheel Teeth}$$

This formula will work for determining either the breakaway torque needs or the cranking torque needs of the starter.

Example 1.
Starter Sizing for Breakaway Torque

An air supply source of 620.5 kPa (90 psi) is available to start a 3512 gas engine. The lowest ambient temperature will be 10°C (50°F) and 30 wt oil will be used. The engine will drive a water pump through a clutch so the breakaway torque is negligible. The customer prefers an air starter.

A) What is the breakaway torque required for this application?

B) Does a single vane starter with 620.5 kPa (90 psi) inlet air pressure have sufficient energy to rotate the 3512 engine?

Solution A:

Consulting the Engine Breakaway and Cranking Torque Chart (see Table 2). The breakaway torque for the 3512 gas engine is 1247 N•m (920 lb•ft). The auxiliary equipment has negligible breakaway torque. The starter should be able to produce 1.4 times 1247 N•m (920 lb•ft) = 1746 N•m (1288 lb•ft) for torque.

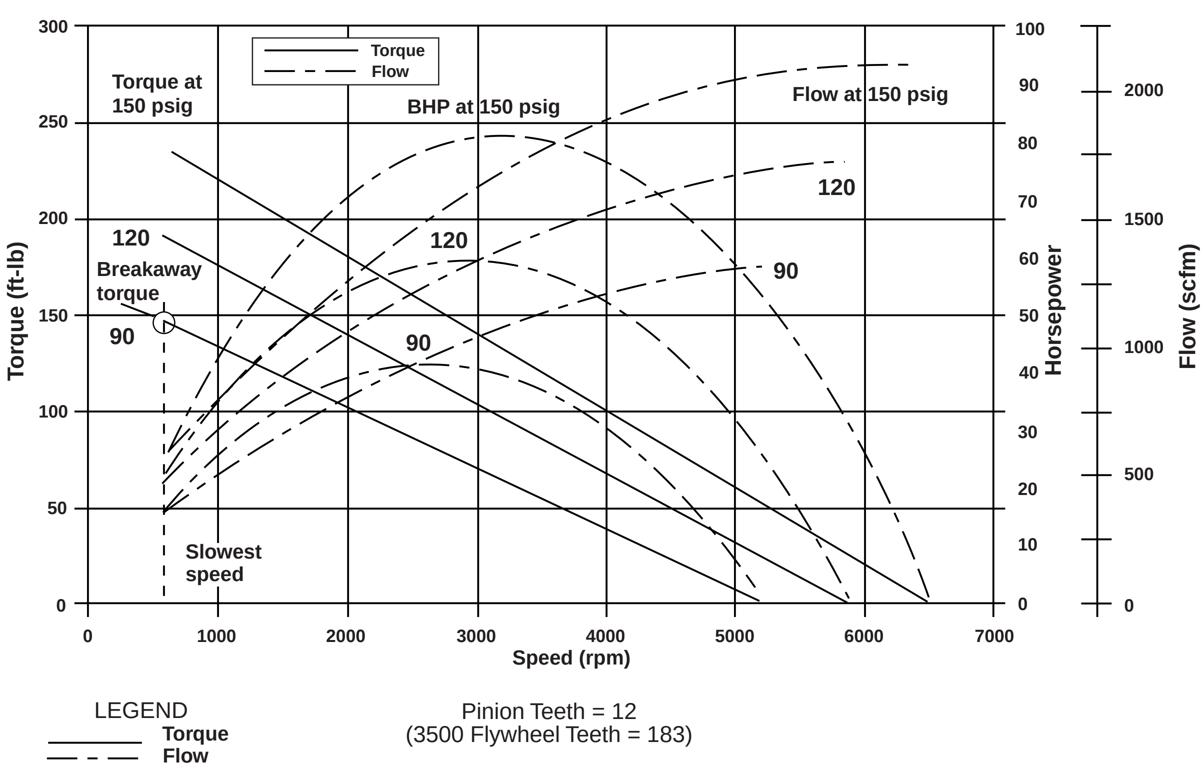


Figure 1. G3500 air starter (vane type) performance curve.

Solution B:
The starter torque = 1746 N•m (1288 lb•ft) × 12 (pinion teeth)/183 (number of flywheel teeth)

The starter torque = 115 N•m
The starter torque = 85 lb•ft

Next consult the Air Starter Torque Chart Figure 1 (can be obtained for the individual air starter from the air starter manufacturer), for the starter's capability at 620.5 kPa (90 psig). Use the torque of the slowest listed speed of the starter as the breakaway torque. The G3500 air starter (vane type) is 196.6 N•m (145 lb•ft). Thus one air starter for the 3512 engine will provide sufficient breakaway torque (145 lb•ft > 85 lb•ft).

Cranking Torque

Table 2 shows the torque requirements to crank an unloaded gas engine.

	Breakaway Torque		Cranking Torque (@ 100 or 150 rpm) SAE 30 Wt Oil 0°C (32°F)		Cranking Torque (@ 100 or 150 rpm) SAE 30 Wt Oil 10°C (50°F)	
Engine Model	**N•m**	**(ft-lbs)**	**N•m**	**(ft-lbs)**	**N•m**	**(ft-lbs)**
G3304	149	110	217	160	149	110
G3306	244	180	278	205	203	150
G3406	366	270	508	375	305	225
G3408	420	310	597	440	352	260
G3412	644	475	813	600	521	385
G3508	1016	750	1085	800	854	630
G3512	1247	920	1573	1160	1037	765
G3516	1545	1140	1898	1400	1288	950

Note: Oil Temperature and Viscosity are major contributors to the actual amount of torque needed to crank the engine at the specific speed. Breakaway torque is independent of oil viscosity or temperature.

Table 2. Engine breakaway and cranking torques, gas.

Note: The temperature and oil viscosity are the largest factors that affect the cranking torque needed to start an engine. Higher oil temperatures and less viscous oil require less torque to turn the engine.

Table 3 gives the cranking performance of the electric starters used on the G3500-G3300 engines. Consult these charts to determine starter speed, volts and amps to the starter and the starters torque capability at 100 rpm and 1500 rpm engine rpm (150 rpm should be used for magneto engines and 100 rpm for Caterpillar Electronic Ignition System equipped engines). The capability of the electric starter can be compared to the total of any particular engine model's and auxiliary equipment's cranking torque needs.

Crank Terminate

Starter Overspeed
Engine overspeed can result from a governor malfunction or fuel rack sticking. With no overspeed protection, a diesel engine can rapidly accelerate to the point of destruction.

Variables that Affect Length of Engine Start and the Cranking Torque

Size the starting system for an engine to meet the most demanding conditions under which a specific engine is expected to start. To account for the variability, consider the following guidelines:

1) **Engine Size:** As the number of cylinders increases, the torque requirements to crank the engine increases. The crank torque curves for each engine must be consulted when sizing a starting system.
2) **Engine Application:** Various applications have different auxiliary loads during the start up. The auxiliary load torque curve will affect the time to accelerate the engine to the minimum recommended cranking rpm.
3) **Fuel Composition:** Fuel composition varies widely from site to site. Fuels with low energy content will lengthen the cranking time as these fuels burn slower and cylinder firing during start-up is more erratic than when using natural gas.
4) **Cold Ambient Conditions:** Cold temperature increases the viscosity of the engine oil. The torque demand of the cranking engine increases as oil temperature decreases. Start length will increase due to cold temperatures. Note: The breakaway torque is not influenced by oil temperature.

Minimum Requirements for Sizing Support Equipment

When sizing a facility's support equipment for a starting system (i.e. air tank volume, air tank location, pipe diameter, pipe length, compressor size, battery quantity and capacity), the equipment must be capable of meeting the following minimum requirements for one start attempt:

1) The starting system must accelerate the engine and its auxiliary load to the Minimum Cranking RPM in five seconds.

2) The starter(s) must be able to sustain the Minimum Cranking RPM for a minimum of 25 seconds.

Note: Electric starter engagements longer than 30 seconds or repeat 30 second start attempts will overheat starters. Start attempts longer than 30 seconds may indicate engine problems.

Some applications may require multiple, back to-back start capability. In this case, multiply the above **one-start minimum requirements** by the total number of required start attempts. Thus, if a site must be capable of three back-to-back start attempts, the support equipment should be capable of three, five second acceleration intervals and three, twenty-five second intervals of sustained engine speed equal to or greater than the Minimum Starting RPM.

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

Air Temperature
The ambient temperature is extremely important for the starter system. The colder it is the higher torque is necessary for starting the engine. Take into consideration the temperature when reading a torque graph or table.

Electric Starting
Electric starting is the most convenient to use. Storage of energy is compact, however, charging the system is slow and difficult in emergencies. Electric starting becomes less effective as the temperature drops due to loss of battery discharge capacity and an increase in an engine's resistance to cranking under those conditions. It is the least expensive system and is most adaptable to remote control and automation (see Figure 2).

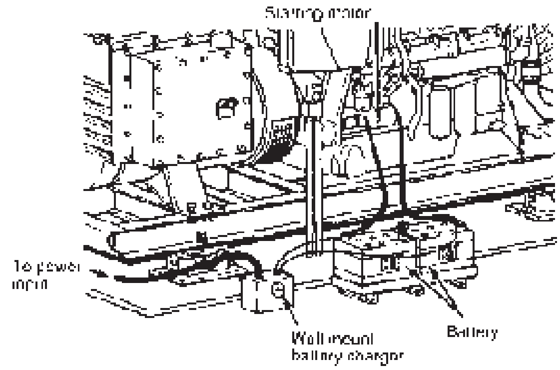


Figure 2. Battery location.

Damage can result if water enters and is retained in the starting motor solenoid. To prevent this, engines stored outside should be provided with a flywheel housing cover. If possible, the starting motor should be mounted with the solenoid in an up position which would provide drainage and prevent water from collecting in the solenoid.

Engines which are subject to heavy driven load during cold start-up should be provided with a heavy-duty starting motor.

Battery Types
Batteries provide sufficient power to crank engines long and fast enough to start (see Battery recommendations for Diesel, Table 4 and for Gas, Table 5).

Lead-acid types are common, have high output capabilities, and lowest first cost.

Nickel-cadmium batteries are costly, but have long shelf life and require minimum maintenance. Nickel-cadmium types are designed for long life and may incorporate thick plates which decrease high discharge capability. Consult the battery supplier for specific recommendations.

	Volts at Starter	Amps to Starter	Potential Torque of Starter N•m (lb•ft)	Potential Torque on Flywheel N•m (lb•ft)
G3304, G3306 (156 flywheel teeth)	Starter Part No. — 1W5516 (12 pinion teeth)			
Cranking* @ 100 engine rpm @ 150 engine rpm	19 22	800 500	70.5 (52) 30 (22)	916.5 (676) 387.8 (286)
G3406 (113 flywheel teeth)	Starter Part No. — 2S7227 and 6V0927 (11 pinion teeth)			
Cranking* @ 100 engine rpm @ 150 engine rpm	17 19	900 600	73 (54) 49 (36)	745.7 (550) 501.7 (370)
G3408, G3412 (136 flywheel teeth)	Starter Part No. — 4N1062 (11 pinion teeth)			
Cranking* @ 100 engine rpm @ 150 engine rpm	17 19	860 580	70.5 (52) 40.7 (30)	867.7 (640) 488 (360)
G3508, 12, 16 (183 flywheel teeth)	Starter Part No. — 7C0527, 6V4246 (11 pinion teeth) [Values for 1 starter]			
Cranking* @ 100 engine rpm	19	600	40.7 (30)	678 (500)
	Starter Part No. — 6V0927 (11 pinion teeth) [Values for 1 starter]			
	18.5	600	49 (36)	813.5 (600)

*Cranking torque is at 100 engine rpm. Cranking torque is very dependent on oil viscosity and temperature. When solving a cranking issue, increasing the temperature of the engine and oil plus lowering the viscosity of the oil will dramatically improve cranking performance.

Table 3. Electric starter cranking performance, gas.

Two considerations in selecting proper battery capacity are:

- The lowest temperature at which the engine might be cranked.
- The parasitic load imposed on the engine. A good rule of thumb is to select a battery package which will provide at least four 30 second cranking periods (total of 2 minutes cranking). An engine should not be cranked continuously for more than 30 seconds or starter motors may overheat.

Ambient temperatures drastically affect battery performance and charging efficiencies. Maintain 32°C (90°F) maximum temperature to assure rated output. The impact of colder temperatures is shown in Table 6.

Minimum Battery Cold Cranking Amperes at –18°C (0°F)				
Model	Voltage	–0.5°C (31°F) and Up*	–18°C (0°F) to –1°C (30°F)**	–31.6°C (–25°F) to –18.3°C (–1°F)
3208	12 24	1140 570	1460 730	1600 800
3304	12 24/30/32	1140 570	1500 750	1740 870
3306	12 24 30/32	1140 570 570	1500 750 750	2000 1000 870
3406	12 24 30/32	1740 800 800	1800 870 870	2000 1000 870
3408/3412	24 30/32	870 870	1000 870	1260 1260
D348	24 30/32	870 870	1000 870	1260 1260
D349	24/30/32	1260	1260	1260
D353	24 30/32	1000 1260	1260 1260	1260 1260
D379/398	24/30/32	1260	1260	1260
D399	24/30/32	1260	1260	—

*Below 15.5°C (60°F) use glow plugs if available.
**Below 0°C (32°F) use ether aid for direct injection engines.

Table 4. Caterpillar diesel engine battery recommendations.

Minimum Battery Cold Cranking Amperes				
Model	Voltage	15.5°C (60°F) and Up	–1°C (30°F) to 15.5°C (60°F)	–29°C (–20°F) to –1°C (30°F)
G3304	12 24-32	725	1450 925	1225
G3306	12 24-32	725	1450 925	1225
G3406	24-32		925	1225
G3408	24-32	925	1225	1300
G3412	24-32	925	1225	1300
G3508	24-32	925	1225	1300
G3517*	30-32	725	910	1300
G3516*	30-32	725	910	1300

*Two motors.

Note: Use aids below –18°C (0°F).

Table 5. Caterpillar gas engine battery recommendations.

Battery Sizing and Temperature

Low ambient temperatures drastically affect battery performance and charging efficiencies, as well as oil viscosity (see Table 7). High temperatures should also be avoided.

- Maintain 32°C (90°F) maximum temperature to assure rated output.
- High temperatures also decrease battery life.
- Ideally, temperatures surrounding the battery should not exceed 25°C (77°F). Battery life is roughly halved by a 10°C (17°F) rise in temperature; doubled if ambients are reduced 10°C.

°C	°F	27°C (80°F) Ampere Hours Output Rating
27	80	100%
0	32	65%
–18	0	40%

Table 6. Temperature vs. output.

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

Table 7. Battery performance.

Battery Cable Sizing (Maximum Allowable Resistance)

The start circuit between battery and starting motor, and control circuit between battery, switch, and motor solenoid must be within maximum resistance limits (see Table 8).

Magnetic Switch and Series-Parallel Circuit	Solenoid Switch Circuit	Starting Motor Circuit
12 Volt System 0.048 Ohm	0.0067 Ohm	0.0012 Ohm
24 Volt System 0.10 Ohm	0.030 Ohm	0.002 Ohm
32 Volt System 0.124 Ohm	0.070 Ohm	0.002 Ohm

Table 8. Maximum allowable resistance.

Not all this resistance is allowed for cables. Connections and contactors, except the motor solenoid contactor, are included in the total allowable resistance. Additional fixed resistance allowances are:

Contactors
Relays, Solenoid, Switches
0.0002 Ohm each

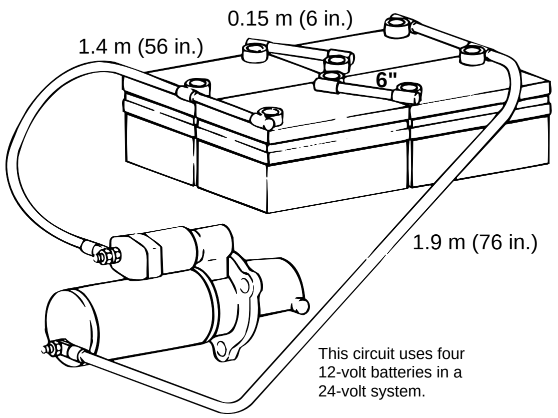
Connections
(series connector)
0.00001 Ohm each

The fixed resistance of connections and contactors is determined by the cable routing (see Table 9). Fixed resistance (Rf) subtracted from total resistance (Rt) equals allowable cable resistance (Rc): Rt - Rf = Rc.

Cable Size		12 Volt		24-32 Volt	
AWG	mm^2	Feet	Meters	Feet	Meters
0	50	4.0	1.22	15.0	4.57
00	70	5.0	1.52	18.0	5.49
000	95	6.0	1.83	21.0	6.40
0000	120	7.5	2.29	27.0	8.24

Table 9. Maximum recommended total battery cable length

Example:



System	24-volt
Starting motor type	Heavy duty
Maximum allowable resistance	.00200
Minus fixed resistance —	
6 connections @ .00001	.00006 ohm
Resistance remaining for cable	.00194
Battery cable length	3.6 m (144 in.)

Figure 3. Example.

With cable length and fixed resistance determined as shown in Figure 3, the appropriate cable size can be found using Figure 4. Only full-stranded copper wire should be used. Arc welding cable is much more flexible and easier to install than full stranded copper wire cable, but welding cable is not as durable and will be damaged from corrosion in a much shorter time.

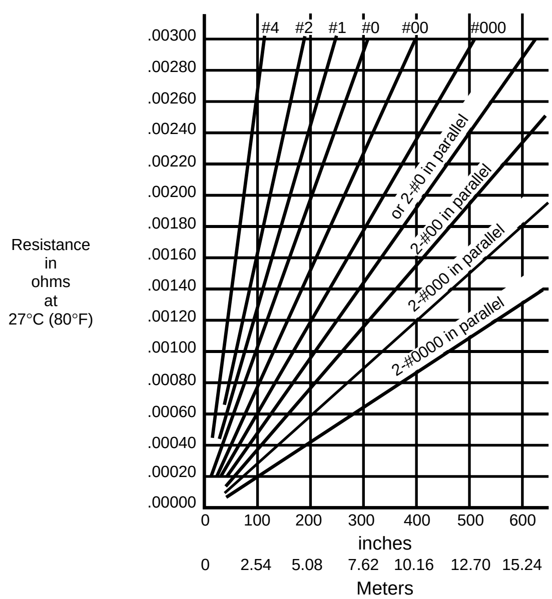


Figure 4. Cable sizing.

To meet cable length and resistance requirements, cable size must be No. 1. To determine fixed resistance in a parallel circuit, only series connections in one leg of the parallel circuit are counted.

Charging

Battery Chargers

Various chargers are available to replenish a battery.

Trickle chargers are designed for continuous service on unloaded batteries and automatically shut down to milliampere current when batteries are fully charged. Overcharging shortens battery life and is recognized by excessive water losses.

Conventional lead-acid batteries require less than 59.2 ml (2 oz) of make-up water during 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 which permit continuous loads at rated output.

Both trickle chargers and float equalize chargers require a source of A/C power while the engine is not running. 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.

Alternators

Alternators or engine driven generators can be used as charging systems, but have the disadvantage of charging batteries only while the engine runs. Where generator sets are subject to many starts, insufficient battery capacity could threaten dependability.

Grounding

The battery must be ground before running. One battery terminal must be connected to either the engine or the frame work in order to protect against electrical shock.

Design Consideration

The cranking batteries should always be securely mounted where it is easy to visually inspect and do maintenance (see Figure 2). They must be located away from flame or spark sources and isolated from vibration. Batteries should be mount level on nonconducting material and protected from splash and dirt. By positioning batteries near the starting motor, short slack cables can be used and voltage drops minimized. All battery connections must be kept tight and coated with grease to prevent corrosion.

Disconnect the battery charger when removing or connecting battery leads. Solid-state equipment, i.e., electronic governor, speed switches, can be harmed if subjected to charger's full output.

Air Starting

Air starting, either manual or automatic, is highly reliable. It is generally applied where facilities have existing plant air, or where a combustible gas may be present in the atmosphere.

Air starting usually offers higher cranking speeds than electric starting. This will usually result in faster starts with less cranking time; however, remote controls and automation are more complex. On the other hand, the air system can be quickly recharged. Air storage tanks are prone to condensation problems and must be protected against corrosion and freezing.

The air starting system includes: air starting motor, air storage tank, starting valve, pressure regulator, and oiler (see Figure 5). A starting motor discharge air silencer/vapor arrestor is an optional accessory to the air starting system.

A check valve between plant air and receiver assures that failure of plant air will not deplete the backup supply. The air compressors are driven by gasoline engines and electric motors wired to the emergency power source.

For factory supplied electric motor driven by continuous prelube systems, power to the prelube pump is removed by a signal from the control panel when a start is initiated (see Figure 6).

Venting of the starter system must be inspected before start-up to insure that no backpressure in the vent line builds up. To prevent backpressure, a separate vent line should be provided. Another option would be to install a check valve in the starter vent line. (Check valves are not recommended in applications where freezing of the check valve can occur.)

Tandem or compound engines use two motors and solenoid valves. Valves are equal distance from their respective motors for coordinated motor engagement. When a single solenoid controls air to both motors, piping between valve and each motor must be equal length.

Air motor supply pipes are short, direct, and at least equal in size to the motor intake opening. Black iron pipe is preferable and should be supported to avoid stresses on the compressor. Flexible connections between motor and piping are required.

Deposits of an oil-water mixture accumulating in receiver and piping are removed by traps installed at intervals in the lines. The lines should slope toward these traps.

Air cranking systems may freeze at low ambients. Water vapor in compressed air freezes during expansion in temperatures below 0°C (32°F). A dryer at the compressor outlet or a small quantity of alcohol in the starter air tank prevents freezing. At temperatures below –18°C (0°F) consult the generator set supplier.

Torque available from air motors accelerate the engine to twice the cranking speed in about half the time required by electric starters. Remote controls and automation, however, are more complex. Because the exhaust from the air starter is very loud, an air silencer may be appropriate.

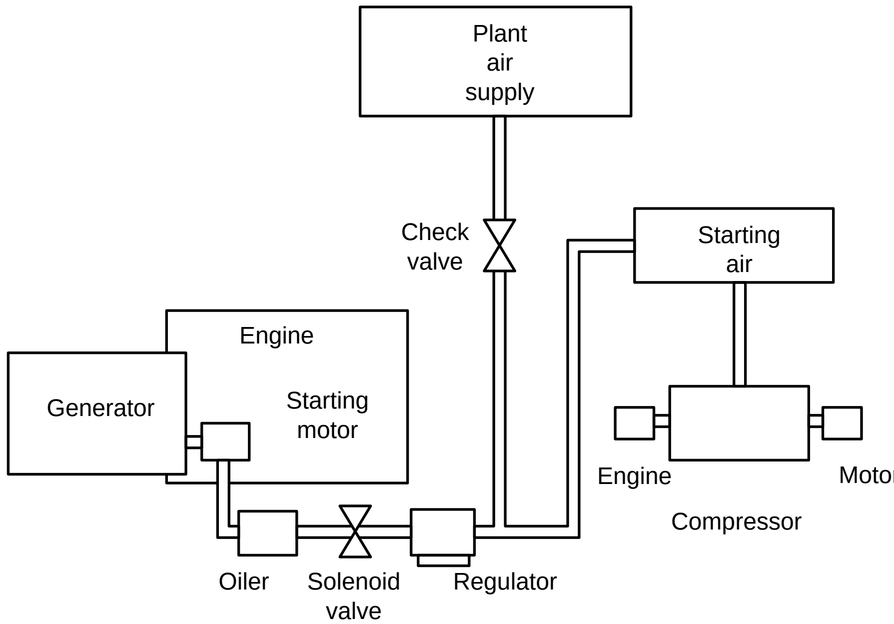


Figure 5. Air starting schematic.

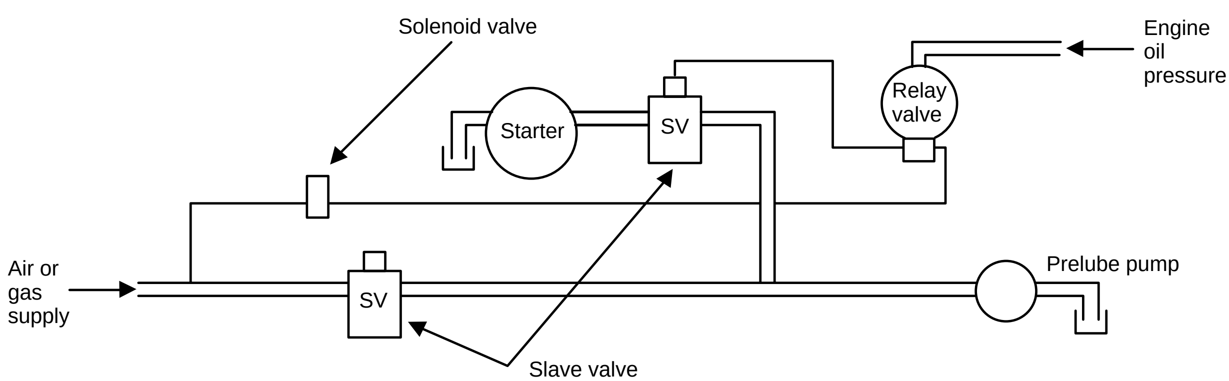


Figure 6. Air start prelube.

Free Air Consumption

Free air consumption depends to some extent on the same variables as air starting systems. In addition the pressure regulator setting must be taken into consideration.

The correct pressure regulator setting is 620 to 690 kPa (90 to 100 psi), with the higher pressure used to improve starting under adverse conditions. 0.14 to 0.42 m^3 (5 to 15 cu ft) per second is typical for engines from 37 to 1194 kW (50 to 1600 hp).

System Design Considerations

Air Pressure

Air is usually compressed between 758 and 1723 kPa (110 to 250 psi) and is stored in storage tanks. Stored air is regulated to 758 kPa (110 psi) and piped to the air motor. A check valve between the compressor and the air receiver is good practice, to protect against a failure of plant air which might deplete the air receivers supply. The air compressors are driven by external power sources.

Cranking Time

The cranking time per start depends upon the engine model, engine condition, ambient air temperature, oil viscosity, fuel type, and design cranking speed. Five to seven seconds for the first start is typical for an engine at 26.7°C (80°F). Restart of a hot engine usually takes less than two seconds.

Air Consumption of the Air Start Motor m³/sec (ft³/sec) -Vs-				Minimum Air Tank Pressure
	Air Pressure to Motor -Pt-			
Engine Model	793 kPaa (115 psia) 690 kPag (100 psig)	965 kPaa (140 psia) 862 kPag (125 psig)	1137 kPaa (165 psia) 1034 kPag (150 psig)	-Pmin- kPaa (psia)
3304B	.16 (5.8)	.20 (6.8)	.21 (7.7)	345 (50)
3306B	.17 (5.9)	.20 (6.8)	.22 (7.8)	352 (51)
3406B	.17 (6.2)	.21 (7.3)	.23 (8.3)	379 (55)
3406B	.18 (6.4)	.21 (7.3)	.24 (8.6)	372 (54)
3412	.25 (9.0)	.29 (10.3)	.33 (11.8)	310 (45)
D379	.26 (9.3)	.30 (10.8)	.36 (12.6)	310 (45)
D398	.28 (9.8)	.32 (11.4)	.38 (13.3)	345 (50)
D399	.30 (10.8)	.34 (12.1)	.40 (14.1)	448 (65)
3508	.26 (9.3)	.30 (10.8)	.36 (12.6)	310 (45)
3512	.28 (9.8)	.32 (11.4)	.38 (13.3)	345 (50)
3516	.30 (10.5)	.34 (12.1)	.40 (14.1)	448 (65)

Note: For engines equipped with pneumatic prelube: add 0.03 m^3/sec (1 ft^3/sec) air consumption.

Table 10. Diesel engine, air starting requirements at 10°C (50°F).

Air Consumption of the Air Start Motor m³/sec (ft³/sec) -Vs-				Minimum Air Tank Pressure
	Air Pressure to Motor -Pt-			
Engine Model	793 kPaa (115 psia) 690 kPag (100 psig)	965 kPaa (140 psia) 862 kPag (125 psig)	1137 kPaa (165 psia) 1034 kPag (150 psig)	-Pmin- kPaa (psia)
G3304	.16 (5.8)	.19 (6.8)	.22 (7.7)	242 (35)
G3306	.17 (5.9)	.20 (6.9)	.22 (7.8)	248 (36)
G3406	.18 (6.2)	.21 (7.3)	.23 (8.3)	276 (40)
G3408	.18 (6.4)	.21 (7.5)	.24 (8.6)	269 (39)
G3412	.25 (9.0)	.30 (10.3)	.33 (11.8)	207 (30)
G3508	.26 (9.3)	.31 (10.8)	.36 (12.6)	310 (45)
G3512	.28 (9.8)	.32 (11.4)	.38 (13.3)	344 (50)
G3516	.30 (10.5)	.34 (12.1)	.40 (14.1)	448 (65)
G353	.19 (6.6)	.22 (7.8)	.25 (8.9)	276 (40)
G379	.26 (9.3)	.31 (10.8)	.36 (12.6)	207 (30)
G398	.28 (9.8)	.32 (11.4)	.38 (13.3)	242 (35)
G399	.30 (10.5)	.34 (12.1)	.40 (14.1)	345 (50)

Note 1: Add to the G399 and G3516 0.03 m^3/sec (1 ft^3/sec) of air consumption for the air operated oil prelubrication pump. This pump will normally operate 2 to 10 seconds before the engine begins to crank.
Note 2: For start control systems with a purge cycle, include the time of the purge sequence to estimate starting time to obtain total estimated starting time.
*Minimum air storage tank pressure required to sustain cranking at 100 rpm.

Table 11. Gas engine, air starting requirements at 10°C (50°F).

Air Tank Sizing

Many applications require the sizing air storage tanks to provide a specified number of starts without recharging. The tanks must meet ASME specifications and be equipped with a safety valve and gauge. The tank size can be calculated from the following:

$$V_t = \frac{V_s \times T \times P_a}{P_t - P_{min}}$$

Where:

V_t = Air Storage Tank Capacity, m^3 (ft^3) (Figure 7)

V_s = Air consumption of the starter motor, m^3/sec (ft^3/sec) (see Table 10).

T = Total Cranking time required (seconds) if six consecutive starts are required, use seven (7) seconds for first start (while engine is cold), and two (2) seconds each for the remaining five starts, a total cranking time of seventeen (17) seconds.

P_a = Atmospheric Pressure (normally atmospheric pressure is 100 kPaa (14.5 psia).

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

P_{min} = Minimum Air Storage Tank Pressure required to sustain cranking at 100 rpm.

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)
– 6 consecutive starts. First start = 7 sec. the other 5 starts = 2 sec.
– average barometric pressure at this location = 100 kPa (14.5 psi)
– preconditioned engine installation.

(cfm × 0.02832 = m^3/min)

Solution:

V_s = 0.40 m^3/sec (14.1 ft^3/sec), found by using Table 10.

T = 7 + (5 × 2) = 17 sec

P_a = 100 kPa (14.5 psi)

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

P_{min} = 620.5 kPag (90 psig)

therefore,

$$V_t = \frac{0.4 \times 17 \times 100}{1034 - 620.5} = 1.64\ m^3$$

$$V_t = \frac{14.1 \times 17 \times 14.5}{150 - 90} = 57.93\ ft^3$$

Air Consumption of the Starter Motor

The starter motor air consumption depends on these same variables and also on pressure regulator setting. Normal pressure regulator setting is 690 kPa (100 psi) for both gas and diesel. Higher pressure can be used to improve starting under adverse conditions up to a maximum of 1034 kPa (150 psi) to the starting motor (gas and diesel). The values shown on the air starting requirements chart assume a bare engine (no parasitic load) at 10°C (50°F) (see Table 10 and 11).

Starting Aids

Starting aids are recommended when temperatures fall below certain levels, as shown in the Operation and Maintenance Guides. Glow plugs and/or ether starting aids are sufficient for most conditions, with oil and coolant heating necessary in extremely low ambients (refer to Operations and Maintenance Guides for further data on cold weather procedures).

Jacket Water Heaters

Jacket water heaters are electrical heaters which maintain the jacket water at a temperature high enough to allow for easy starting of the engine. Heaters with 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). Provisions should be made to maintain the jacket water temperature at a minimum of 43°C (110°F) for all G3516B applications. 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.

Flame Start

In a flame start, glow plugs project into the air inlet manifold and ignite a small amount of diesel fuel during manual starting. The flame is maintained until smooth idling conditions are achieved.

Battery Heaters

Battery heaters are usually recommended in cold ambient temperatures. The heaters should be set to maintain battery temperature in the range of 32 to 52°C (90 to 125°F) for maximum effectiveness.

Ether

Ether facilitates starting because it is a highly volatile fluid which has a low ignition temperature. Many types of ether starting aids are commercially available. The high pressure metallic capsule-type is recommended. When placed in an injection device and pierced, the 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.

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

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 of ether will be released, each time the button is pushed. Caterpillar ether systems are designed to release 2.25 cc of ether each time the system is activated. Excessive injection of ether can damage an engine.

Ether is a volatile and highly combustible agent. Small quantities of ether fumes added to the engines intake air during cranking reduce the compression temperature required for engine starting. Caution is required when using ether to prevent spread of fumes to atmosphere. A proper ether system will meter the rate of ether consumption. Only 1 cm^3 (0.033 oz) or less of ether should be released per 100 rated hp for each 10 seconds of cranking. Very low ambient temperatures may require increasing the ether consumption rate. *Under no circumstances should ether be released into an engine while running.*

Ether starting aids are restricted to manual starting systems and are rarely used for generator sets. Introduced into the intake air, it ignites the mixture at low cylinder temperatures. High pressure capsules are the safest and most dependable injection method. Ether injection should not be used on Cat 3600 Engines.

Oil Heaters

Heating elements in direct contact with noncirculating lubricating oil are usually not recommended due to the danger of oil coking. If specified, heater skin temperatures should not exceed 150°C (300°F) and have maximum heat densities of 0.02 W/mm^2 (13 W/in^2).

Additional Starters

Hydraulic starting provides the highest cranking speeds and fastest starts. It is relatively compact. Recharging time is fast, and the system can be recharged by a hand pump provided for this purpose. The high pressure of the system requires special pipes and fittings and extremely tight connections. Oil lost through leakage can be replaced, but recharging the pressurized gas, if lost, requires special equipment.

Air Impingement System

The air impingement system is a method of boosting the engine to get it started.

It must be noted that this system is not available for Caterpillar engines. This is due to unacceptable transient response and the fact that the turbo housing must be specially fabricated to accommodate the hose attachment.

Air impingement works by having a compressed air hose which is ported into the turbocharger turbine wheel. Once the solenoid valve is open, a blast of compressed air spins the turbine wheel. This creates more air on the compressor which then feeds more air to the cylinders which results in more combustion.

Notes

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