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New Technology Research & Development Program
Grant Contract 582-5-70807-0002

Task 3 Deliverable Report

The preparation of this report is based on work funded in part
by the State of Texas through a Grant from the
Texas Commission on Environmental Quality.

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New Technology Research & Development Program
Grant Contract #582-5-70807-0002
between the
County of El Paso
and the
Texas Commission on Environmental Quality

Task 3 Deliverable: Preliminary Testing and Validation of LNG and CNG Engine and Fueling System

The preparation of this report is based on work funded in part by the State of Texas through a grant from the Texas Commission on Environmental Quality

El Paso County New Technology Research and Development Grant

Task 3 Deliverable: Preliminary Testing and Validation of LNG and CNG Engine and Fueling System

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This report is submitted by El Paso County to the Texas Emission Reduction Program in fulfillment of the requirements of New Technology Research and Development Grant Contract #582-5-70807-0002 between the County of El Paso and the Texas Commission on Environmental Quality.

I. Introduction and Overview

El Paso County and its' primary subcontractor Ruby Mountain Inc. (RMI) have completed fabrication of the 33-passenger, low-floor, ADA-compliant project vehicle as well as the installation of the Cummins B Gas Plus natural gas engine. The compressed and liquefied (L/CNG) fueling system design and specifications were also completed and submitted with previous reporting.

Additionally, integration of the patented Economizer Valve into the fueling system has also been completed to allow the vehicle to operate on both liquefied and compressed forms of natural gas originating at different pressures. The Economizer Valve was developed by the Idaho National Laboratory. Preliminary testing and validation of the engine, transmission and natural gas fuel system has also been completed.

Based on the NTRD scope of work, the following task has been completed:

Task 3 Deliverable: Preliminary Testing and Validation of LNG and CNG Engine and fueling System

2.3. Task Statement: The PERFORMING PARTY will perform preliminary testing for validation of complete transit bus system.

2.3.1. The PERFORMING PARTY will perform preliminary testing for validation of complete transit bus system.

2.3.1.1. The PERFORMING PARTY will initiate system interface prove out.

2.3.1.2. The PERFORMING PARTY will conduct initial development testing.

2.3.1.3. The PERFORMING PARTY will perform run start/stop testing to verify system function.

2.3.1.4. The PERFORMING PARTY will coordinate w/body builder to install second unit body.

2.3.1.5. The PERFORMING PARTY will re-run start/stop testing to verify system function.

2.3.1.6. The PERFORMING PARTY will conduct initial fuel economy testing.

2.3.1.7. The PERFORMING PARTY will conduct brake test procedures.

2.3.1.8. The PERFORMING PARTY will conduct engine throttle evaluations.

2.3.3. Deliverables: The PERFORMING PARTY shall submit a final report to the TCEQ upon completion of this task. This will include but is not limited test data on fuel economy and any emission data collected.

This report and the accompanying attachments constitutes fulfillment of the aforementioned Task 3 deliverable.

II. Preliminary Testing for Validation of the Natural Gas Engine and Fuel System

The 33-passenger, low-floor, ADA-compliant project vehicle was fabricated by ARBOC Limited and installed onto the International 3200 Series Chassis as per the specifications previously developed and submitted to TCEQ. Bell Power Systems of Essex, CT installed the Cummins natural gas engine and CNG/LNG tanks into the vehicle as well as installing most of the plumbing for the both the LNG and CNG fuel systems. As such, Bell Power performed the preliminary testing and validation following integration of the engine and fueling systems. ARBOC assisted with the testing effort.

Specifically, Bell Power Systems and ARBOC performed preliminary testing for validation of the complete transit bus system related to the procedures below.

Initiate system interface prove out

ARBOC technicians performed a test drive of the project vehicle on a 40 mile-route. During the test, the only issue identified was the transmission interlock or the "park start" switch. Put simply, the transmission on the project vehicle starts in any gear. As diagnosed, the problem appears to be a wiring issue and is being corrected by ARBOC technicians.

Conduct initial development testing

The project vehicle was operated at acceleration as well as at start/stop, slow acceleration and fast acceleration. Other than a slight sluggishness in terms of initial acceleration, the project vehicle performed as expected. The likely potential remedy with the initial acceleration sluggishness issue includes bumping up the vehicle's engine turbo, and as such, conversations are underway with Cummins Westport (the engine manufacturer) to bump up the turbo. Final installation of the Hydraulic Launch Assist device will provide additional low-end torque until the vehicle accelerates to about 20 mph.

Perform run start/stop testing to verify system function

All systems tested functional: start/stop testing was successful.

Coordinate w/body builder to install second unit body

All testing was performed with the second unit body installed onto the International 3200 Series chassis. The second unit body was installed prior to the engine replacement performed by Bell Power Systems.

Re-run start/stop testing to verify system function

During the redundancy test, all systems again tested functional: start/stop testing was successful.

Conduct initial fuel economy testing

Preliminary fuel economy testing is being performed on the project vehicle by ARBOC. Data will be submitted with the Task 6 report.

Conduct brake test procedures

The project vehicle brakes are original equipment as installed onto the International 3200 Series chassis, and as such, were unaffected by the engine re-power or body modifications made to the project vehicle. As a result, brakes performed as expected.

Conduct engine throttle evaluations

The engine throttle evaluation testing on the project vehicle was successful, but identified the sluggish acceleration issue discussed previously.

The following Cummins engine test procedures were also performed following installation of the natural gas engine:

Test/Procedure Conducted	Outcome Summary*
Intake Restriction Test	Acceptable
Intake Manifold Pressure Differential Test	Acceptable
Exhaust Restriction Test	Acceptable
Cooling System Fill Test	Acceptable
Cooling System De-aeration Test	Acceptable
Volume Not Filled at Initial Fill Test	Acceptable
Cooling System Drawdown Test	Acceptable
Cooling System Coolant Recovery Test	Acceptable
Water Pump Inlet Restriction Test	Acceptable
Cooling System Limiting Ambient Temperature Test	Acceptable
Intake Temperature Rise Over Ambient Test	Acceptable
Intake Manifold Temperature Differential Test	Acceptable

Fuel Supply & Return Line Restriction System Test	N/A for CNG
Engine Mounting Test	Acceptable
Electrical System Cranking Test	Acceptable
Cranking Motor Capacity Test Procedure	N/A for CNG
Electrical Run, Stop, and Crank Controls System Test	Acceptable
Electrical Charging System Test	Acceptable
Alternator Wiring Voltage Drop Test Procedure	Acceptable
Alternator Capacity Test Procedure	Acceptable

*For specific testing outcome data, please see test procedure documentation sheets attached to this report as Attachment A.

III. Attachments

Attached to this report is the following:

ATTACHMENT A: Documentation of Cummins Engine Test Procedures

Task 3 Deliverable: Preliminary Testing and Validation of LNG and CNG Engine and Fueling System

Attachment A:
Documentation of Cummins Engine Test Procedures

Author: Peggy Storkman **Revision Date: March 27, 2002**

Intake Restriction Test

Purpose of Test: To insure that the intake restriction in the machine does not exceed Cummins requirement for the intake system with a clean air filter.

Required Equipment

- Manometer, pressure gauge or data logger capable of reading up to 30 in H2O (762 mm H20)
- Clean air filter element
- Intake manifold pressure sensor – mechanical engines only
- Engine speed sensor

Testing Notes

- This test must be run with the most restrictive set of options that can be used on the machine. This includes the use of intake air shutoff. The shutoff should NOT be activated during the test.
- For this test it will be necessary to run the engine at a fully loaded condition. Some applications are not designed for continuous operation at rated speed and load. In this case, Cummins recommends data-logging the pressures while the machine is operated in its extreme, "worst case" duty cycle.
- Use Advisor or the Engine Data Sheet to find the Intake Manifold Pressure at the rated power and speed and at a secondary operating condition (optional). This will be used to determine what power you are pulling during the test (mechanical engines only).

Intake manifold pressure at rated power & speed: (user reference only)	36.6	in Hg / mm Hg
Intake manifold pressure secondary operating point: (user reference only)	38.6	in Hg / mm Hg

- Use the engine data sheet to find the maximum intake air restriction with a clean filter. Record the value.

Maximum intake air restriction – clean filter (user reference only – restriction limits are established with the recommended intake piping size specified on the datasheet):	10	in / mm H2O

Test Procedure

1. Install a clean fuel filter element if necessary
2. Connect the manometer, pressure gauge or data logger to the air inlet pipe in a straight section as close to the turbocharger inlet as practical. The tapping in the intake pipe must be smooth and free of burrs to give an accurate pressure reading.
3. Run the engine with load so that it operates steady state at the rated power and speed. For mechanical engines, use the intake manifold pressure reading in

conjunction with the engine speed to confirm you are running at the maximum power operating condition. For electronic engines, this information can be retrieved via the engine datalink.

4. Record the intake restriction at rated speed and power.

Intake restriction at rated speed & power:	2	in / mm H2O
Does this value exceed the maximum allowable intake restriction?:	NO	Yes/No

5. Optional. Repeat the test at a second operating condition. Record the intake restriction.

Intake restriction at operating point:	—	in / mm H2O
Does this value exceed the maximum allowable intake restriction?:	—	Yes/No

6. Has all testing been run with the most restrictive set of options available on the machine?:	Yes	Yes/No

Special Considerations

1. Special care must be taken when attempting to load a machine to maximum power by means other than the way the machine was intended to operate (such as stalling the hydraulic pumps on a hydraulic or hydrostatic machine). Excessive heat can be generated during the test that will overload the machine's hydraulic, engine or other machine cooling systems. Sometimes special arrangements are required to deal with the increased heat loads.

Appendix

Author: Peggy Storkman **Revision Date: March 27, 2002**

Intake Manifold Pressure Differential (IMPD) Test

Purpose of Test: To insure that the pressure drop across the entire charge air cooling system from the turbocharger compressor outlet to the engine intake manifold does not exceed the IMPD limit specified on the engine datasheet.

Required Equipment

- Manometer, pressure gauge or data logger (make sure your equipment is rated for the temperatures and pressures that occur at the measurement locations)
- Intake manifold pressure sensor – mechanical engines only
- Engine speed sensor

Testing Notes

- This test is only required for Charge Air Cooled (CAC) engines.
- This test must be run with the most restrictive set of options that can be used on the machine.
- For this test it will be necessary to run the engine at a fully loaded condition. Some applications are not designed for continuous operation at rated speed and load. In this case, Cummins recommends data-logging the temperatures and pressures while the machine is operated in its extreme, "worst case" duty cycle.
- Use Advisor or the Engine Data Sheet to find the Intake Manifold Pressure at the rated power and speed and at a secondary operating condition (optional). This will be used to determine what power you are pulling during the test (mechanical engines only).

Intake manifold pressure at rated power & speed: (user reference only)	36.6	in Hg / mm Hg
Intake manifold pressure secondary operating point: (user reference only)	38.6	in Hg / mm Hg

- Use the engine datasheet to find the Maximum pressure drop from turbocharger compressor outlet to intake manifold (IMPD). Record the value.

Maximum IMPD from datasheet: (user reference only)	4	in Hg / mm Hg

Test Procedure

1. Install a pressure tap in the turbo compressor outlet elbow. Do not install the temperature and pressure measurements into a common tee.

2. Install a pressure tap in the intake manifold or inlet elbow attached to the manifold. Do not install the temperature and pressure measurements into a common tee.

3. Install a pressure gauge at each location.

4. For applications with variable speed engine cooling fans, make sure the fan is in its standard operating mode.

5. Connect all instrumentation to a data-logging device if available.

6. Run the engine with load so that it operates steady state at rated speed and load. For mechanical engines, use the intake manifold pressure reading in conjunction with the engine speed to confirm you are running at the rated power condition. For electronic engines, this information can be retrieved via the engine datalink.

7. Record the following stabilized pressure values:

Static pressure of turbocharger outlet charge air at rated power & speed:	38.6	in Hg / mm Hg
Static pressure of intake manifold charge air at rated power and speed:	36.6	in Hg / mm Hg
IMPD = the difference between these two values:	1.0	in Hg / mm Hg
Does the measured IMPD exceed the maximum allowable IMPD from the engine datasheet? If yes, please refer to AEB 24.06 for details:	NO	Yes/No

8. Optional. Repeat the test at a second operating condition. Record the stabilized pressure values.

Static pressure of turbocharger outlet charge air at operating:	—	in Hg / mm Hg
Static pressure of intake manifold charge air at operating:	—	in Hg / mm Hg
IMPD = the difference between these two values:	—	in Hg / mm Hg
Does the measured IMPD exceed the maximum allowable IMPD from the engine datasheet? If yes, please refer to AEB 24.06 for details:	—	Yes/No

Special Considerations

1. Special care must be taken when attempting to load a machine to maximum power by means other than the way the machine was intended to operate (such as stalling the hydraulic pumps on a hydraulic or hydrostatic machine). Excessive heat can be generated during the test that will overload the machine's hydraulic, engine or other machine cooling systems. Sometimes special arrangements are required to deal with the increased heat loads.

Author: Peggy Storkman Revision Date: April 3, 2002

Exhaust Restriction Test

Purpose of Test: To insure that the exhaust restriction in the machine does not exceed Cummins requirement for the exhaust system.

Required Equipment

- Manometer, pressure gauge or data logger capable of reading up to 60 in H2O or 2 psi (1500 mm H20)
- Intake manifold pressure sensor – mechanical engines only
- Engine speed sensor

Testing Notes

- This test must be run with the most restrictive set of options that can be used on the machine. This includes the use of exhaust brakes. The exhaust brake should NOT be activated during the test.
- For this test it will be necessary to run the engine at a fully loaded condition. Some applications are not designed for continuous operation at rated speed and load. In this case, Cummins recommends data-logging the pressures while the machine is operated in its extreme, "worst case" duty cycle.
- Use Advisor or the Engine Data Sheet to find the Intake Manifold Pressure at the rated power and speed and at a secondary operating condition (optional). This will be used to determine what power you are pulling during the test (mechanical engines only).

Intake manifold pressure at rated power & speed: (user reference only)	36.6	in Hg / mm Hg
Intake manifold pressure secondary operating point: (user reference only)	38.6	in Hg / mm Hg

- Use the engine data sheet to find the maximum exhaust back pressure. Record the value.

Maximum exhaust back pressure (user reference only – restriction limits are established with the recommended exhaust piping size specified on the datasheet):	68 H2O	in Hg / mm Hg

Test Procedure

1. Connect the manometer, pressure gauge or data logger to a straight section of exhaust pipe as close to the turbocharger outlet as possible, but at least one pipe diameter downstream of the turbocharger outlet flange. If the machine has an exhaust pyrometer this can often be removed and this port can be used for the measurement. The port in the exhaust pipe must be smooth and free of burrs to give an accurate pressure reading.
2. Run the engine with load so that it operates steady state at rated power and speed. For mechanical engines, use the intake manifold pressure reading in conjunction

with the engine speed to confirm you are running at the maximum power operating condition. For electronic engines, this information can be retrieved via the engine datalink.

3. Record the exhaust restriction at rated speed and power.

Exhaust restriction at rated speed & power:	30.7 H_2O	in / mm Hg
Does this value exceed the maximum allowable exhaust back pressure?:	NO	Yes/No

4. Optional. Repeat the test at a second operating condition. Record the exhaust restriction.

Exhaust restriction at operating point:	—	in / mm Hg
Does this value exceed the maximum allowable exhaust back pressure?:	—	Yes/No

5. Has all testing been run with the most restrictive set of options available on the machine?:	—	Yes/No

Special Considerations

1. Special care must be taken when attempting to load a machine to maximum power by means other than the way the machine was intended to operate (such as stalling the hydraulic pumps on a hydraulic or hydrostatic machine). Excessive heat can be generated during the test that will overload the machine's hydraulic, engine or other machine cooling systems. Sometimes special arrangements are required to deal with the increased heat loads.

Appendix

Author: Rick W Anderson **Revision Date: Apr 10, 2002**

Cooling System Fill Test

Purpose of Test: To see if the engine and cooling system can be filled successfully at a fill rate of 5 gallons/minute such that there is no additional need to "top off" the system after fill, pause during the fill, or any other special fill procedures.

Required Equipment

- adjustable water source & water hose
- separate on/off valve
- container (bucket) pre-marked to show 5 gallon level
- measuring container (divisions in US fluid ounces, 32-64 oz approximate capacity)
- stopwatch or timer
- flowmeter or flowtotalizer (recommended)

Testing Notes

- Check that the unit has standard functioning engine thermostat(s) installed.
- Check that the cab heater(s) are connected and that any shut-off valves are in the open position. If the cab heater is located above the engine, the cab heater circuit may trap a considerable amount of air during fill, and may cause the water pump to stall. If this occurs, the heater circuit shutoff(s) may need to be closed during the fill, and special fill instructions permanently posted on the machine near the fill location.
- Close off or disconnect the corrosion resistor (water filter with water conditioner) from the system to prevent discoloration of the water (whenever possible).
- If a Cooling System Deaeration and/or Drawdown test will be run, a deaeration & drawdown (D & D) kit should be installed prior to the Fill Test. A D & D kit sketch is included in the Cooling System Deaeration Test and Cooling System Drawdown Test procedures documents.

Test Procedure

1. Make sure the machine engine and cooling system has been filled with water, fully dearated, and topped off full again. Leave the fill cap off the radiator.
    - Check the method used by the cooling system to establish expansion space. This will usually be a fill neck extension, but may also be a single sight glass or a pair of sight glasses. The radiator should be filled until the coolant overflows (on systems with a fill neck extension), or until the water reaches the (lower) sight glass or the 'Full Cold' level (on radiators with a sight glass other system).

- If the system includes a coolant recovery (expansion) bottle, the bottle and hose should be left empty.

2. Drain the coolant from the engine and radiator into a container and measure the total volume using a separate graduated measuring container. Record the total system volume.

   - Be careful, the coolant is probably very hot.
   - Be sure to drain the water from the lowest point on the engine/radiator cooling system in order to get an accurate measurement.

   Total Cooling System drain volume: [7.3] gals

3. **(Coolant Recovery Systems only)** Disconnect the coolant recovery (expansion bottle) hose from the radiator. Plug the end that attached to the radiator. Fill the expansion bottle and hose with water up to the "Full Cold" mark on the bottle. Drain water from the bottle and hose into a container, and measure and record the volume.

   Expansion bottle/hose coolant volume below the "Full Cold" mark: [123] oz (US fluid ounces).

4. Check (calibrate) the flow rate of the water source (fill hose) by timing the fill of a five gallon container. Adjust flow and recheck as necessary, until a rate of 5.0 to 5.2 GPM is obtained. Record the total time (in minutes) to fill the 5 gallon container.

   Time to fill a 5 gallon container: [60] secs

   - The water source flow rate must be calibrated at or near the height of the fill location (realistically speaking). A water source calibrated to flow at 5 GPM while standing on the ground, will probably not produce 5 GPM up on top of a large haul truck.
   - It is also important that the water pressure is relatively stable. Using a small water well with a pump that regularly comes on and goes off (as water is used) is not a good water source to be used for the fill test.

5. Fill the system and record the time taken.

   - Note: The fill process must be a continuous flow of water. You may not pause during the fill to allow the level in the top tank to drop, or the top tank should not overflow part way through the fill.
   - The fill test <u>does not</u> allow the system to be "topped off" after the initial fill.

Total time to fill the machine cooling system: 1.15 mins

Did the cooling system fill successfully at a fill rate of 5 gallons/minute such that there was no additional need to "top off" the system after fill, pause during the fill, or any other special fill procedures?	Yes	yes/no
• Did the cooling system fill at the recorded rate until full, without overflowing during the fill?	Yes	yes/no
• Does this machine have a cab heater core connected to the cooling system?	Yes	yes/no
• Was the heater core installed and were all valves open during the cooling system fill process?	Yes	yes/no
• Did the heater core circuit fill acceptably during the cooling system fill process?	Yes	yes/no

Author: Rick W Anderson **Revision Date: Apr.10, 2002**

Cooling System Deaeration Test

Purpose of Test: To test the deaeration capability of the cooling system to ensure it has the ability to complete purge all air from the coolant in 25 minutes or less.

Required Equipment

- deaeration & drawdown kit (D& D kit) (see Figure 1)
- trouble light or strong flashlight
- stopwatch or timer
- digital temperature gauge *
- 2 temperature probes *
- 2 rubber hoses with hose clamps
- 2 NPTF hose fittings to attach hoses to block
- measuring container (divisions in US fluid ounces, 32-64 oz approximate capacity)
- a means of controlling the airflow through the radiator (such as covering the radiator with cardboard)
- items marked with a (*) may not be needed on electronic engines with the use of Cummins Calterm, Field Calterm, or Insite.

Testing Notes

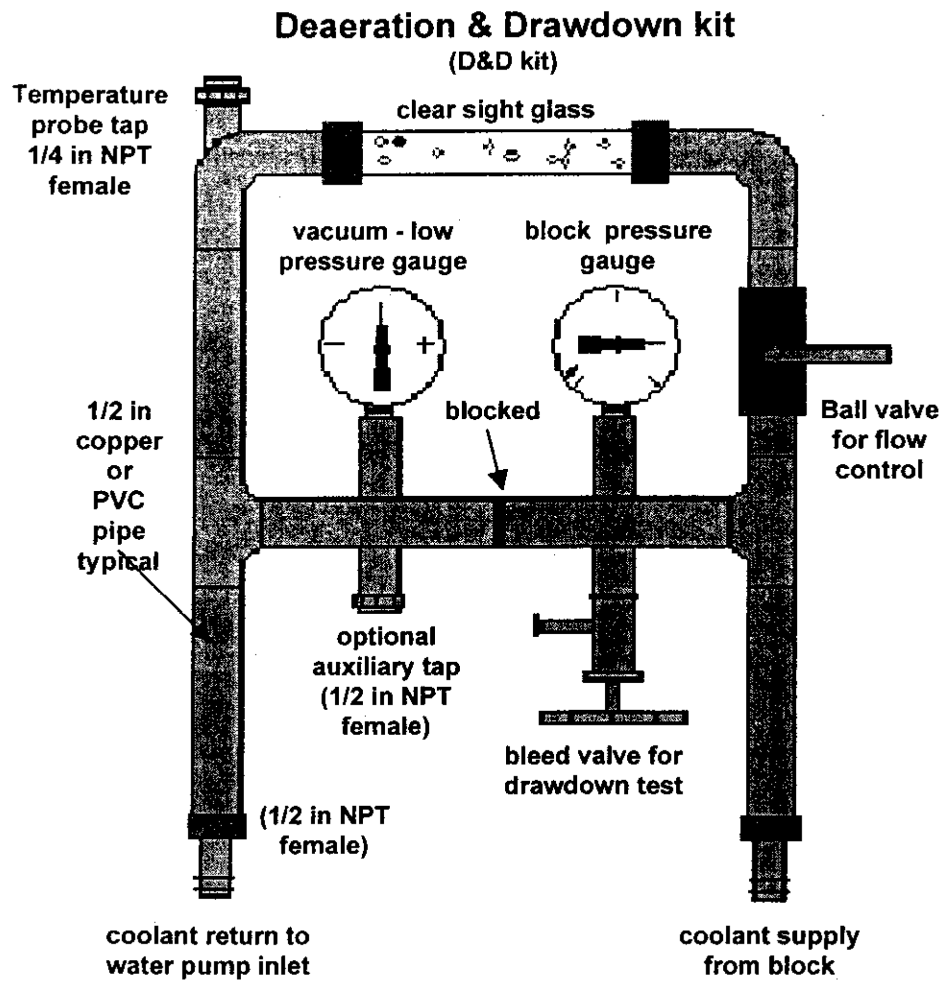
- The Cooling System Deaeration Test should be run immediately following the Cooling System Fill Test. The cooling system should be full (from the normal fill process), and the coolant level must not be "topped off" after the fill (due to the coolant level dropping in the top tank).
- The engine must have a standard functioning engine thermostat(s) installed.
- Close off or disconnect the corrosion resistor (water filter with water conditioner) from the system to prevent discoloration of the water (whenever possible).
- During this test the coolant will need to be heated up to a temperature where the thermostat(s) are fully open, but not too hot where vapor bubbles begin to appear in the coolant(typically between 187-192 deg F). This can be achieved by loading the engine and monitoring coolant temperature, and/or install a means of controlling the airflow through the radiator (such as covering the radiator with cardboard or removing the fan) and running the engine unloaded.

Test Procedure

1 Check that the radiator cap is off. Remove if necessary.

2 Install a D & D kit (as shown in Figure 1). The supply line for the D & D kit must be plumbed on the pressure side of the water pump, and the return plumbed to the water pump inlet or radiator bottom hose (as close to the water pump inlet as is reasonable).

- It is critical that the D & D kit and hoses be located below the return location during the fill test so that the D & D kit completely fills with water and does not trap air.



(**Figure 1.**)

3 Check the supply and return side flow valves on the D & D kit to ensure both are fully open.

4 (optional) Install clear plastic tubing or sight glass in the engine fill line (makeup line), if it is anticipated that the cooling system may have problems with coolant reverse flow up the fill line. Care must be taken to ensure the clear plastic tubing is capable of handling coolant temperatures up to 250 deg F.

5 Install a coolant temperature measuring device (temperature probe) in the engine prior to the engine thermostat. (For the purpose of monitoring engine coolant temperature, especially prior to the thermostat opening)

6 (optional) Install a coolant temperature measuring device in the cooling system after the thermostat but prior to the radiator. The D&D includes a tap for this purpose (see Figure 1). This probe may be used in place of the temperature probe prior to the thermostat, but does not provide reliable information prior to the thermostat opening point.

7 Check that the cab heater is connected (if present), and that any shut-off valves are in the open position. If the cab heater is located above the engine, the cab heater circuit may trap a considerable amount of air during fill, and may cause the water pump to stall. If this occurs the heater circuit shutoff(s) may need to be closed during the fill, and special fill instructions posted on the machine near the fill location.

8 Start the stop watch and start the engine. After 10 seconds of idling, increase the speed to approximately peak torque speed. Check that "block" pressure is being registered, and that it is fairly constant.

- If block pressure has not been established, monitor block pressure.
  - If there is no indication of pressure after 60 seconds running, shut down and check for the cause. If during any subsequent running, the block pressure should fall to zero PSI (or very close to it, except during low idling) shut down immediately and check for the cause. Loss of block pressure is usually caused by trapped air in the system moving to the water pump inlet.
  - If block pressure is established prior to 60 seconds:

    Record time when block pressure was established, engine speed, coolant temperature prior to the thermostat, coolant temperature after the thermostat, block coolant pressure, bubble size and comments as appropriate.

    (see form at end of test procedure)
- If block pressure has been established:

  Record time when block pressure was established, engine speed, coolant temperature prior to the thermostat, coolant temperature after the thermostat, block coolant pressure, bubble size and comments as appropriate.

  (see form at end of test procedure)

9 Once water flow (block pressure) is established, run the engine up to governed (rated) speed. Manipulate the flow of air to the radiator to achieve and maintain a water outlet temperature of 187-192 deg F. Falling below 187 deg F will allow the thermostat to begin to close and limit coolant flow, and climbing above 192 deg F can cause air (vapor trace bubbles) to enter the unpressurized coolant from water pump cavitation and/or boiling of the coolant.

10 If a fill line sight glass is used, it should be checked for reverse flow. If reverse flow is apparent, record this fact. (Reverse flow constitutes a failed test.)

11 Every three to five minutes:

Record the time, engine speed, coolant temperature prior to the thermostat, coolant temperature after the thermostat, block coolant pressure, bubble size and comments as appropriate.

(see form at end of test procedure)

- Unless the test is being conducted in bright sunlight, a trouble light or strong flashlight should be used for observing the air bubbles in the sight glass.
- When viewing air bubbles (using the sight glass in the D & D kit) the coolant flow valve on the coolant return side of the D & D kit should be fully open. The coolant flow valve on the coolant supply side of the D & D kit should be closed to a point where the coolant flow through the D & D kit is very slow. This helps make any bubbles in the coolant much easier to see.
  - Air bubbles that are 1/8 inch diameter or larger should be described as large or very large.
  - concentrations of bubbles greater than pinpoint should be described as fine.
  - pin point size bubbles only, in a continuous stream (which may very well be vapor trace bubbles rather than air bubbles), should be described as very fine.
  - water that is perfectly clear or that only contains random trace bubbles, should be described as clear.
- When measuring block pressure, the flow valve on the coolant supply side of the D & D kit must be closed completely (the flow valve on the return side may be open or closed, it does not matter).
- When measuring coolant temperature (using the thermal couple tap in the D & D kit) both flow valves on the D & D kit should be fully open.

12 The test is completed, and successful deaeration has been obtained, when the sight glass becomes satisfactorily 'clear" before the end of the allowed time (25 minutes.

- If a continuous stream of pin point bubbles is still in evidence at the end of the allowed time period, but there is reason to believe that progress toward complete deaeration is being made, continue to run for an additional 10 minutes to see if "clear" can be obtained.
- If at the end of 25 minutes the sight glass is not showing the cooling system to be "clear" and the system does not appear to be making significant progress (as described above), or at the end of 35 minutes the cooling system is not "clear", the cooling system has failed the deaeration test and the test is complete.

Cooling System Deaeration Test						
Time (mins)	(secs)	Engine Speed (rpm)	Coolant Temp prior to stat (deg F)	Coolant Temp after stat (deg F)	Block Coolant Pressure (psi)	Comments (bubble size, time when stat opens, reverse flow, etc.)
	30	1000	130	94	2	fine
3	30	1480	143	99	3	fine
6	00	2400	166	122	4	fine
12	00	2500	189	185	4	very fine
15	20	2500	190	187	4	very fine - stats open
18	00	2500	191	189	5	clear
21	00	2500	190	190	5	clear

Other Comments/Observations:

Summary	Time (Mins)	(secs)	Coolant temp prior to stat (deg F)
Elapsed time to establish coolant block pressure after initial fill.		30	130
Elapsed time to when thermostat first opens.	15	20	190
Elapsed time to when coolant is completely clear of bubbles.	18	00	191

Did the cooling system deaeration system successfully purge all air from the coolant in 25 minutes or less?	Yes	yes/no
13 Did the engine lose coolant pressure at any time after it was established?	NO	yes/no
14 If so, how many times?	—	
15 If so, what was the longest interval without coolant pressure?	—	secs
16. Was this test run without a radiator cap on the top tank?	Yes	yes/no
17. Was a fully functioning thermostat(s) in use in the machine during the test?	Yes	yes/no
18. Once the engine coolant reached the temperature range of 187 to 192 degrees F, was it maintained within this range for the remainder of the test?	Yes	yes/no
19. Were the heater core valves open during the deaeration test?	Yes	yes/no

Author: Rick W Anderson Revision Date: Apr.10, 2002

Volume Not Filled at Initial Fill Test (VNFIF)

Purpose of Test: To determine the volume of coolant required to bring the radiator top tank volume back to full after the coolant deaeration process (volume not filled at initial fill (VNFIF)).

Required Equipment

- trouble light or strong flashlight
- measuring container (divisions in US fluid ounces, 32-64 oz approximate capacity)

Testing Notes

- The Cooling System Volume Not Filled at Initial Fill (VNFIF) Test must be run after the completion of the Cooling System Deaeration test, but before the Cooling System Drawdown test.

- After deaerating the cooling system the VNFIF must be run before the coolant changes temperature significantly. The VNFIF should be immediately after shutting down the engine, after the deaeration test.

Test Procedure

1. The cooling system should have been filled according to the procedures defined in the Cooling System Fill Test, and deaerated according to the Cooling System Deaeration Test. After deaeration the coolant level will most likely have dropped in the top tank a bit due to trapped air being purged from the system.

2. Add coolant from a container with a known volume to the radiator top tank until the coolant rises to the bottom of the fill neck (on systems with a fill neck extension) or until the water reaches the (lower) sight glass or the "Full Cold" level (on other systems). Record the volume of water that was required to bring the cooling system back to full. This is the volume of air that was displaced during the deaeration process.

   Volume of coolant added to the radiator top tank to bring the system back to full (top off volume) after the deaeration test: [64] oz (US fluid ounces).

   Is the VNFIF volume less than the tested Drawdown volume? [Yes] Yes/No

Author: Rick Anderson Revision Date: Apr 10, 2002

Cooling System Drawdown Test

Purpose of Test: The purpose of the drawdown test is to determine how much coolant (volume) can be lost from the cooling system before the cooling system begins to entrain air into the coolant. This volume must be greater than 6% of the total cooling system volume, and greater than the Volume Not Filled at Initial Fill (VNFIF).

Required Equipment

- deaeration & drawdown kit (D& D kit) (see Figure 1)
- trouble light or strong flashlight
- stopwatch or timer
- digital temperature gauge *
- temperature probe *
- 2 rubber hoses with hose clamps
- 2 NPTF hose fittings to attach hoses to block
- measuring container (divisions in US fluid ounces, 32-64 oz approximate capacity)
- a means of controlling the airflow through the radiator (such as covering the radiator with cardboard)
- items marked with a (*) may not be needed on electronic engines with the use of Cummins Calterm, Field Calterm, or Insite.

Testing Notes

- The Cooling System Drawdown Test should be run after the completion of the Cooling System Volume Not Filled at Initial Fill (VNFIF) test.

- It must be confirmed that the cooling system is fully deaerated, and full to the bottom of the fill neck or filled until water reaches the lower "Full Cold" sight glass on Non-Coolant Recovery Cooling Systems, or to radiator cap sealing surface on Coolant Recovery Cooling Systems.

- If an expansion volume test has just been conducted, it will be necessary to remove some water from the system to return the system to the normal "Full" level. It is frequently expedient to do this with the engine running at high speed, drawing off the water through the hose and valve that will be used for the drawdown test itself. This will permit a rough calibration of the valve position needed to give a flow of 1.0 to 2.0 gpm.
- The engine must have a standard functioning engine thermostat(s) installed.
- Close off or disconnect the corrosion resistor (water filter with water conditioner) from the system to prevent discoloration of the water (whenever possible).

- In this test it is important that the coolant drain line flow (the flow of coolant being drained from the engine via a D & D kit) during the test should be between 1.0 and 2.0 gpm. If the user is not familiar enough with what this kind of flow looks like form the D & D kit, a trial run should be run prior to the test using a marked bucket and stopwatch and repeated until the users judgement is calibrated. Too rapid a flow will give an artificially low level of drawdown as air will be pulled down the fill line before all coolant has gone down. If the flow rate is too slow, the coolant temperature can rise excessively leading to difficulties in differentiating between vapor trace bubbles and true air bubbles.

- During this test the coolant will need to be heated up to a temperature where the thermostat(s) are fully open, but not too hot where vapor bubbles begin to appear in the coolant(typically between 187-192 deg F). This can be achieved by loading the engine and monitoring coolant temperature, and/or install a means of controlling the airflow through the radiator (such as covering the radiator with cardboard or removing the fan) and running the engine unloaded.

Test Procedure

1. Remove the radiator cap. All cooling system tests (except the cooling capability and coolant recovery tests) are to be run with the cap off.

2. Check that the unit has standard functioning engine thermostat(s) installed.

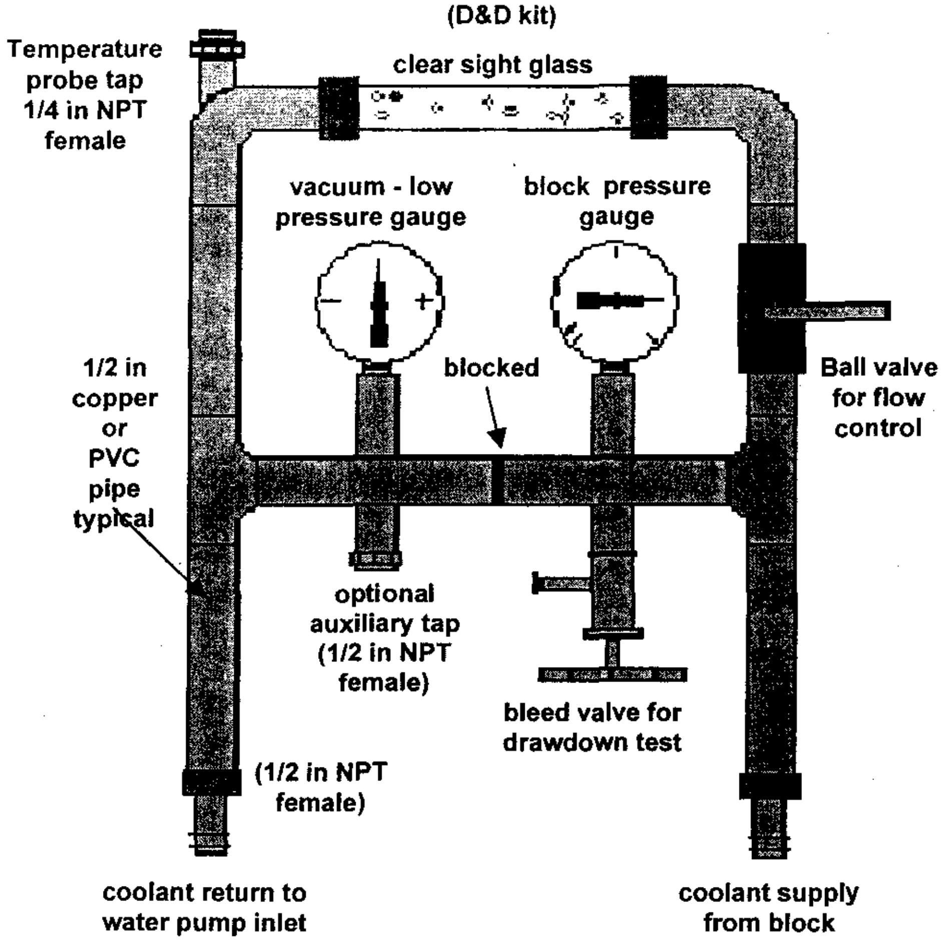
3. Close off or disconnect the corrosion resistor from the system to prevent discoloration of the water, wherever possible.

4. Install a coolant temperature measuring device (temperature sensor) in the engine prior to the engine thermostat. (For the purpose of monitoring engine coolant temperature, especially prior to the thermostat opening)

5. Install a means of controllably draining water from the system into a measuring container. A D & D kit (as shown in figure 1 below) works well for this function. The supply line for the D & D kit must be plumbed on the pressure side of the water pump, and the return plumbed to the water pump inlet or radiator bottom hose (as close to the water pump inlet as is reasonable). It is critical that the D & D kit and hoses be located below the return location during the fill test so that the D & D kit completely fills with water and does not trap air.

Deaeration & Drawdown kit

(D&D kit)



(Figure 1)

6. If a D & D kit is used, check the supply and return side flow valves on the D & D kit to ensure both are fully open.

7. If a cab heater (that utilizes engine coolant) is connected to the system, check that any shut-off valves are in the open position

8. Start the engine and take the engine up to governed speed. Load the engine and/or manipulate the airflow to achieve and maintain a coolant temperature of 187 to 192 deg F (enough to keep the thermostat fully open).

9. Begin to draw off cooling system water at a flow rate of no less than 1.0 gpm and no more than 2.0 gpm into a container. Continue to draw off water until bubbles ("fine" or large, ignore any 'very fine" trace bubbles) appear in the D & D kit sight glass.

- As previously stated the coolant drain line flow during the test should be between 1.0 and 2.0 gpm. If the user is not familiar enough with what this kind of flow looks like form the D & D kit, a trial run should be run prior to the test using a marked bucket and stopwatch and repeated until the users judgement is calibrated.

10. At the first sign of 'fine" bubbles, close off the drain line. Measure and record the volume water drawn off.

    - On engines with an electronic coolant level sensor, confirm that the coolant level fault or warning was activated before the coolant began to areate.

    Volume of coolant drawn before coolant began to aerate: [320] oz (US fluid ounces).

    Is this value > the Cummins limit of 6% of the Total Cooling System coolant volume? [Yes] yes/no

    Is this value > Volume Not Filled at Initial Filled (VNFIF) (from the test by the same name)? [Yes] yes/no

12. **(Coolant Recovery Cooling Systems only)** For Coolant Recovery Cooling Systems the volume below the "Full Cold" mark on the coolant recovery bottle must be added to the volume measured in #11 above. This will be done automatically in Cummins Advisor, and should not be included in volume #11.

    - Coolant Recovery bottle and hose coolant volume below the "Full Cold" mark (from Fill Test): [64] oz (US fluid ounces).

    - Total potential drawdown volume including coolant volume below the "Full Cold" mark on the coolant recovery bottle: [128] oz (US fluid unces).

    Is this value > the Cummins limit of 6% of the Total Cooling System coolant volume? [Yes] yes/no

    Is this value > Volume Not Filled at Initial Filled (VNFIF) (from the test by the same name)? [Yes] yes/no

13. Was a fully functioning thermostat(s) in use in the machine during the test? [Yes] yes/no

14. Was this test run without a radiator cap on the top tank? [Yes] yes/no

15. Once the engine coolant reached the temperature range of 187 to 192 degrees F, was it maintained within this range for the remainder of the test? [Yes] yes/no

B. (For Coolant Recovery Cooling Systems)

1. The coolant recovery bottle should be filled from a container with a known volume from the 'Full Cold' to the "Full Hot' levels.

2. Record the volume of water added.

C. (For systems with one sight glass in the top tank)

1. The deaerated cooling system should be full to the centerline of the sight glass in the top tank.

2. Water should be added to the radiator top tank from a container with a known volume until the coolant level is even with the fill neck pressure cap sealing surface.

3. Record the volume of water added.

D. (For systems with two sight glasses in the top tank)

1. The deaerated cooling system (radiator top tank) should be full to the centerline of the lower sight glass.

2. Water should be added to the top tank until the level is even with the centerline of the upper sight glass (this is the starting volume for this test).

3. Water should be added from a container with a known volume until the level is even with the fill neck pressure cap sealing surface.

4. Record the volume of water added.

Total cooling system coolant expansion space volume: [120] oz (US fluid ounces).

Is the expansion space volume greater than 6% of the total Cooling System volume? [Yes] yes/no

Author: Rick W Anderson **Revision Date: Apr 10, 2002**

Cooling System Coolant Recovery System Test

Purpose of Test: To insure that the coolant recovery system cycles properly and that the coolant recovery bottle was sized correctly

Required Equipment

- digital temperature gauge
- 1 temperature probe
- measuring container (divisions in US fluid ounces, 32-64 oz approximate capacity)
- a means of controlling the airflow through the radiator (such as covering the radiator with cardboard)

Testing Notes

- Coolant Recovery non-positive dearating type cooling systems are allowed by Cummins only on engines below 6.0 liters.
- The cooling system should be filled via the procedure defined in the Cooling System Fill Test, and fully deaerated (with the cap off) as defined in the Cooling System Deaeration Test.
- The top tank should not be "topped off" after deaeration.

Test Procedure

1. Install a coolant temperature measuring device (temperature probe) in the engine prior to the engine thermostat. (For the purpose of monitoring engine coolant temperature)

2. Install the means of controlling the flow of air through the radiator (such as covering the radiator with cardboard or removing the fan). (It will be necessary to hold a water outlet temperature of 187-192 deg F at various engine speeds)

3. The coolant recovery bottle should be filled to the "Full Cold" mark on the bottle, but no higher.

4. Check the radiator cap to ensure it is a "double seal" style cap, and put the cap back on the radiator top tank (tighten).

5. Restart the engine, and run the engine up to governed (rated) speed. Manipulate the flow of air to the radiator so as to achieve and maintain a water outlet temperature of 187-192 deg F for 10 minutes. (This should cause the water to expand, and push all of the air out of the radiator top tank)

6. Shut off the engine, and allow the cooling system to cool down to ambient temperature.
   - Removing any material previously installed to block the radiator airflow and spraying the radiator with cool water will speed the coolant cool down process.
7. Remove the radiator cap. (**IMPORTANT!** Make sure the radiator/coolant has cooled before removing the radiator cap.) Observe the level of the coolant in the coolant recovery bottle or hose (you may have to remove the hose clamp at the radiator cap).
   - Was there any coolant left in the coolant recovery bottle and/or hose after temperature cycling the cooling system? [Yes] yes/no
8. Observe the level of the coolant in the radiator top tank.
   - Was all of air forced out of the radiator top tank after cycling the coolant recovery system? (Is the top tank full to the top of the radiator cap sealing surface?) [Yes] yes/no
9. Measure the volume between the Cold and Hot marks on the Coolant Expansion bottle (coolant expansion space).
   - Coolant Expansion Space (volume between the cold and hot marks on the expansion bottle) [128] oz US fluid onces

Was the functioning of the coolant recovery system tested, and did it cycle correctly? [Yes] yes/no

Author: Rick Anderson **Revision Date: 5/06/02**

Water Pump Inlet Restriction Test

Purpose of Test: To measure the static pressure at the water pump inlet and the pressure drop across the radiator to confirm that both are within Cummins Installation Requirements limits.

Required Equipment

- digital temperature gauge
- temperature probe
- pressure/vacuum gauge (-20 to +20 in Hg range)
- two -20 to +20 in Hg pressure/vacuum sensors
- a means of controlling the airflow through the radiator (such as covering the radiator with cardboard)

Testing Notes

- A temperature probe should be installed in the engine cylinder head immediately prior to the thermostat or in the water outlet connection.
- The Cooling System Water Pump Inlet Restriction Test should be run after the cooling system has been fully deaerated and the system has been "topped off" to a complete full condition.
- The engine must have a standard functioning engine thermostat(s) installed.
- During this test the coolant will need to be heated up to a temperature where the thermostat(s) are fully open, but not hot enough to cause vapor bubbles to begin to appear in the coolant (typically between 187-192 deg F). This can be achieved by loading the engine and monitoring coolant temperature, and/or installing a means of controlling the airflow through the radiator (such as covering the radiator with cardboard or removing the fan) and running the engine unloaded.
- A -20/+20 in Hg pressure sensor should be installed in the water pump inlet.
- A -20/+20 in Hg pressure sensor should be installed in the water outlet connection or radiator top hose as close as is reasonable after the water outlet connection. It should not be installed in an elbow hose, reducing hose connection, or in any location when the natural coolant flow is disturbed.

Test Procedure

1. Check that the radiator cap is on. Remove if necessary.

2. At 0 RPM, measure the water pump inlet pressure/vacuum and water pump outlet pressure.

@ 0 RPM

- Water pump Inlet pressure @ 0 RPM [0] in Hg.
- Water pump Outlet pressure @ 0 RPM [0] in Hg.

3. Start the engine. After 10 seconds of idling, run the engine up to governed (rated) speed. Manipulate the flow of air to the radiator to achieve and maintain a water outlet temperature of 187-192 deg F. Falling below 187 deg F will allow the thermostat to begin to close and limit coolant flow, and climbing above 192 deg F can cause air (vapor trace bubbles) to enter the unpressurized coolant from water pump cavitation and/or boiling of the coolant.

4. Once the coolant temperature has reached a temperature of 187-192 deg F (thermostat full open temperature), reduce the engine speed to Low Idle.

5. At Low Idle, measure the water pump inlet pressure/vacuum and water pump outlet pressure.

@ Low Idle

- Water pump Inlet pressure/restriction @ Low Idle [-1] in Hg. (enter in of Hg vacuum as negative pressure)
- Water pump Outlet pressure @ Low Idle [+3] in Hg.

6. Run the engine back up to governed (rated) speed. Confirm that the coolant temperature remains between 187-192 deg F. Manipulate the flow of air to the radiator to achieve a water outlet temperature of 187-192 deg F if necessary.

7. At Rated Speed measure the water pump inlet pressure/vacuum and water pump outlet pressure.

@ Rated Speed

- Water pump Inlet pressure/restriction @ Rated Speed [-1.6] in Hg. (enter in of Hg vacuum as negative pressure)
- Water pump Outlet pressure @ Rated Speed [9.7] in Hg.

Did the water pump inlet restriction meet Cummins Requirements for this type of cooling system at both Idle and Rated Speed? [ ] yes/no

Did the pressure drop across the engine cooling system (water pump outlet – water pump inlet pressure) meet Cummins Requirements at both Idle and Rated Speed? [ ] yes/no

8. Was a fully functioning thermostat(s) in use in the machine during the test? Yes yes/no

9. Was this test run without a radiator cap on the top tank? Yes yes/no

10. Once the engine coolant reached the temperature range of 187 to 192 degrees F, was it maintained within this range for the remainder of the test? Yes yes/no

Author: Peggy Storkman Revision Date: March 26 , 2002

Cooling System Limiting Ambient Temperature (LAT) Test

Purpose of Test: To insure the machine's cooling system maintains a water out temperature below the maximum value defined on the engine datasheet.

Required Equipment

- 5 Thermocouples
- Blocked open thermostat – blocked open to appropriate dimension defined by Cummins
- Intake manifold pressure sensor (mechanical engines only)
- Engine speed sensor

Testing Notes

- Testing must occur with all engine compartment hoods, covers, grilles, louvres, etc. in place and secure.
- For this test it will be necessary to run the engine at a fully loaded condition. Some applications are not designed for continuous operation at rated speed and load. In this case, Cummins recommends data-logging the temperatures and pressures while the machine is operated in its extreme, "worst case" duty cycle. Test duration must be long enough to ensure the full effects of temperature rises in other systems (e.g. hydraulic oil cooling) are present.
- Use Advisor or the Engine Data Sheet to find the Intake Manifold Pressure at rated (or the maximum power condition for the machine). This will be used to determine what power you are pulling during the test (mechanical engines only).

Intake manifold pressure at the operating condition: (user reference only) [36.6] in Hg/ mm Hg

- All thermocouples must be installed with the sensing tip in the fluid being measured, not touching any metallic surface.
- Record the engine coolant that will be used during this test (water, 50/50 ethylene glycol & water, etc.).

Engine coolant used during the test: [50/50]

Is this the coolant that will be used in the machine during normal operation?: [Yes] Yes/No

- Use Advisor or the Engine Data Sheet to determine the maximum coolant operating temperature at engine outlet (maximum allowable top tank temperature).

Maximum allowable top tank temperature: (user reference only) [212] deg F / C

Test Procedure

1. (Optional) Install a thermocouple in the intake air piping upstream of the turbocharger inlet. This thermocouple is not required but can be useful in diagnosing cooling system issues. The thermocouple should be no closer than 1" away from the restriction tap.
2. (Optional) Attach a thermocouple to the front engine lifting bracket or similar location to measure engine compartment temperature. This thermocouple is not required but can be useful in diagnosing cooling system issues.
3. Locate another thermocouple outside the vehicle to measure ambient air temperature. This thermocouple should be located out of the sun and away from any heat source. The ambient temperature must be at least 70 deg F for a valid LAT test. Record the ambient temperature.

Ambient air temperature: [83] deg F / C

4. Install a thermocouple to measure engine outlet coolant temperature (Top Tank Temperature). Install the thermocouple between the engine water outlet and the radiator inlet in the coolant piping as close to the engine as possible.
5. (Optional) Install a thermocouple to measure engine inlet coolant temperature (Bottom Tank Temperature). Install the thermocouple between the radiator outlet and the engine water inlet connection as close to the engine as possible. This thermocouple is not required by can be useful in diagnosing cooling system issues.
6. Install the intake manifold pressure sensor and engine speed sensor (mechanical engines only).
7. Install a blocked open engine thermostat. This will prevent thermostat modulation from impacting the results.
8. For applications with variable speed engine cooling fans, make sure the fan is in its standard operating mode.
9. Connect all instrumentation to a data-logging device if available.
10. Run the engine at load such that it operates at the steady state rated or maximum operating condition. For mechanical engines, use the intake manifold pressure reading in conjunction with the engine speed to confirm the load you are pulling. For electronic engines, this information can be retrieved via the engine datalink.
11. Engine speed and load should be maintained at a steady state condition or as close as is reasonably possible until all temperatures stabilize.
12. Record the stabilized Top tank temperature

Stabilized top tank temperature: [179] deg F / C

13. Calculate the limiting ambient temperature (LAT) using the following formula:
    LAT = (Max. allow. top tank temp – Measured top tank temp) + ambient temp

Limiting ambient temperature (LAT): [116] deg F / C

14. (Optional) Repeat the test at a second operating condition if necessary.

Top tank temperature:	—	deg F / C
Limiting ambient temperature (LAT):	—	deg F / C

15.	Is your top tank temperature greater than the maximum allowable top tank temperature?	NO	Yes/No

16. Remove the blocked open thermostat and replace with an operational thermostat.

17.	Was the cooling test run at rated speed and power?	Yes	Yes/No
18.	Was the machine cooling test run with a thermostat blocked open to the dimension defined by Cummins?	Yes	Yes/No

Special Considerations

1. Special care must be taken when attempting to load a machine to maximum power by means other than the way the machine was intended to operate (such as stalling the hydraulic pumps on a hydraulic or hydrostatic machine). Excessive heat can be generated during the test that will overload the machine's hydraulic, engine or other machine cooling systems. Sometimes special arrangements are required to deal with the increased heat loads.

Appendix

Author: Peggy Storkman **Revision Date: March 26, 2002**

Intake Temperature Rise Over Ambient Test

Purpose of Test: Excessive heating of intake air can adversely affect engine and machine performance (altitude capability, LAT, durability, etc.). This test is used to confirm that the amount of intake air heating does not exceed Cummins limits.

Required Equipment

- 3 Thermocouples
- Clean air filter
- Intake manifold pressure sensor – mechanical engines only
- Engine speed sensor

Testing Notes

- Testing must occur with all engine compartment hoods, covers, grilles, louvers, etc. in place and secure.
- For this test it will be necessary to run the engine at a loaded condition. Check the Engine Data Sheet to determine the operating condition that delivers the maximum intake airflow. This is typically rated speed and power.
- Some applications are not designed for continuous operation at rated speed and load. In this case, Cummins recommends data-logging the temperatures and pressures while the machine is operated in its extreme, "worst case" duty cycle. Test duration must be long enough to ensure the full effects of temperature rises in other systems (e.g. hydraulic oil cooling) are present.
- Use Advisor or the Engine Data Sheet to find the Intake Manifold Pressure at that operating condition. This will be used to determine what power you are pulling during the test (mechanical engines only).

Intake manifold pressure at the operating condition: (user reference only) [36.6] in Hg / mm Hg

- Use the Engine Data Sheet to find the Maximum allowable air temperature rise over ambient.

Max. allowable air temperature rise over ambient: (user reference only) [20] Delta deg F /C

Test Procedure

1. Install a thermocouple in the intake air piping upstream of the turbocharger inlet. The thermocouple should be no closer than 1" away from the restriction tap.
2. Attach a thermocouple to the front engine lifting bracket or similar location to measure engine compartment temperature.

3. Locate another thermocouple outside the vehicle to measure ambient air temperature. This thermocouple should be located out of the sun and away from any heat source. Record the ambient temperature.

Ambient air temperature:	83	deg F / C
Are all temperature probes located away from undesired heat sources?	Yes	Yes/no

4. Install a clean air filter if necessary.

5. Run the engine with load so that it operates steady state at the operating condition defined above. For mechanical engines, use the intake manifold pressure reading in conjunction with the engine speed to confirm you are running at the maximum airflow operating condition. For electronic engines, this information can be retrieved from the engine datalink.

6. Record the intake air temperature (measured at the turbocharger inlet) at the maximum airflow operating condition after the engine compartment temperature stabilizes.

Intake air temperature:	101	deg F / C

7. The amount of intake air heating (intake temperature rise over ambient) is calculated by subtracting the ambient air temperature from the intake air temperature.

Air temperature rise over ambient:	18	Delta deg F /C
Is this value greater than the Maximum allowable value on the datasheet?:	NO	Yes/No

Special Considerations

1. Special care must be taken when attempting to load a machine to maximum power by means other than the way the machine was intended to operate (such as stalling the hydraulic pumps on a hydraulic or hydrostatic machine). Excessive heat can be generated during the test that will overload the machine's hydraulic, engine or other machine cooling systems. Sometimes special arrangements are required to deal with the increased heat loads.

Author: Peggy Storkman Revision Date: March 26, 2002

Intake Manifold Temperature Differential (IMTD) Test

Purpose of Test: To determine if the IMTD is within the limit set forth by EPA for emissions certification and to make sure that the intake manifold temperature does not exceed the alarm/derate set point during high ambient operation.

Required Equipment

- 3 Thermocouples
- Intake manifold pressure sensor – mechanical engines only
- Engine speed sensor

Testing Notes

- This test is only required for Charge Air Cooled (CAC) engines.
- Testing must occur with all engine compartment hoods, covers, grilles, louvers, etc. in place and secure.
- For this test it will be necessary to run the engine at a fully loaded condition. Some applications are not designed for continuous operation at rated speed and load. In this case, Cummins recommends data-logging the temperatures and pressures while the machine is operated in its extreme, "worst case" duty cycle. Test duration must be long enough to ensure the full effects of temperature rises in other systems (e.g. hydraulic oil cooling) are present.
- Use Advisor or the Engine Data Sheet to find the Intake Manifold Pressure at the worst case operating condition. This will be used to determine what power you are pulling during the test (mechanical engines only).

Intake manifold pressure at the operating condition: (user reference only)	36.6	in Hg / mm Hg

- Use Advisor or the Engine Data Sheet to find the Intake Manifold Temperature Alarm/Derate set point and the Maximum Intake Manifold Temperature Differential.

Intake manifold temperature Alarm/Derate set point: (user reference only)		deg F / C
Maximum intake manifold temperature differential -IMTD: (user reference only)	20	Delta deg F /C

- The minimum ambient temperature at which an accurate CAC performance test can be run in 70 deg F. Cummins will not accept test results run at an ambient below 70 deg F.
- All thermocouples must be installed with the sensing tip in the fluid being measured, not touching any metallic surface.
- It is required that you meet the IMTD defined on the engine datasheet for ALL speed and load conditions. (Ref. AEB 24.06).

Test Procedure

1. Install a thermocouple in the engine intake manifold or elbow attached to the manifold to read the temperature of the air as it enters the manifold. Intake manifold temperature on electronic engines can be monitored and/or logged via the engine datalink.
2. Locate another thermocouple outside the vehicle to measure ambient air temperature. This thermocouple should be located out of the sun and away from any heat source. Record the ambient temperature.

Ambient air temperature:	83	deg F / C
Are all temperature probes located away from undesired heat sources?	Yes	Yes/no

3. Install a pressure tap in the intake manifold or inlet elbow attached to the manifold. Use a different location, but near to, the location of the intake manifold temperature thermocouple (mechanical engines only). Do not install the temperature and pressure measurements into a common tee.
4. For applications with variable speed engine cooling fans, make sure the fan is in its standard operating mode.
5. Connect all instrumentation to a data-logging device if available.
6. Run the engine with load so that it operates steady state at the operating condition defined above. For mechanical engines, use the intake manifold pressure reading in conjunction with the engine speed to confirm you are running at the maximum power operating condition. For electronic engines, this information can be retrieved via the engine datalink.
7. After 5-10 minutes of operation, the intake manifold temperature will typically stabilize at a maximum value. Record this value.

Intake manifold temperature at rated speed & power:	102	deg F / C

8. Optional. Repeat the test at a second operating condition. Record the intake air temperature.

Intake manifold temperature at operating point:	—	deg F / C

9. The amount of CAC intake air heating (intake temperature rise over ambient) is calculated by subtracting the ambient air temperature from the intake manifold temperature.
IMTD=CAC Intake Manifold Temp – Ambient Air Temp (a smaller value is better).

Record your measured IMTD:	19	Delta deg F /C

10. Is your measured IMTD greater than the Maximum allowable IMTD specified on the engine datasheet?:

Is your measured IMTD greater than the Maximum allowable IMTD specified on the engine datasheet?:	NO	Yes/No

If yes, please refer to AEB 24.06 for details.

Special Considerations

1. Special care must be taken when attempting to load a machine to maximum power by means other than the way the machine was intended to operate (such as stalling the hydraulic pumps on a hydraulic or hydrostatic machine). Excessive heat can be generated during the test that will overload the machine's hydraulic, engine or other machine cooling systems. Sometimes special arrangements are required to deal with the increased heat loads.

Author: Peggy Storkman **Revision Date: March 27, 2002**

Fuel Supply & Return Line Restriction System Test

Purpose of Test: Excessive restriction in the fuel supply or return lines can affect engine performance and cause damage to the fuel pump. This test is used to confirm that the restrictions in the machine do not exceed Cummins limits for a clean fuel filter.

Required Equipment

- Pressure/vacuum gauge scaled to read at least +/-20 in Hg (500 mm Hg)
- Fittings to the fuel supply and return lines (ST-434-1 for #8 line, ST-434-2 for #10 line). Some engine have dedicated compucheck fittings for measuring restriction.
- Thermocouple
- Engine speed sensor
- Clean fuel filter

Testing Notes

- Fuel supply and return restriction will be measured with the engine at rated speed with no load on the engine.
- All thermocouples must be installed with the sensing tip in the fluid being measured, not touching any metallic surface.
- Any fittings that are added to the fuel line should have the same inner diameter as the fuel line to reduce measurement error.
- The worst case for fuel supply line restriction is with the fuel tank near empty. Restriction measurements will be adjusted to account for this worst case situation.

Test Procedure

1. Install a clean fuel filter.

2. Insert a thermocouple in the fuel tank. Run the engine at high idle, no load until the temperature stabilizes. Record the temperature.

   Fuel tank temperature at high idle, no load: [ ] deg F / C

3. Attach a pressure/vacuum gauge through suitable fittings to the fuel supply line as close to the engine as possible or to the fuel supply restriction fitting on the engine if applicable.

4. Install any optional fuel system hardware such as remote fuel filter/water separators, shutoff valves or fuel heating devices. If the equipment has any optional fuel tank locations, the fuel tank location which requires the longest supply / return lines should be tested.

5. Mount the pressure/vacuum gauge above or at the same elevation as the point on the engine or fuel line where the hose to the gauge is attached. Hosing should be routed to avoid trapping fluid in the hose.

6. With no load on the engine, slowly ramp up engine speed until you reach rated speed. Hold this speed until the restriction value stabilizes. Record the fuel supply restriction.

   Fuel supply line restriction @ rated speed, no load (uncorrected): [ ] in Hg / mm Hg

7. If the fuel level in the tank was not near empty, the measured fuel supply restriction should be corrected with the following formula:

   SAE: Measured fuel supply restriction (in Hg) + Fuel level in tank above the near empty level (in) * 0.646 = Corrected fuel supply restriction (in Hg)

   OR

   METRIC: Measured fuel supply restriction (mm Hg) + Fuel level in tank above the near empty level (m) * 62.4 = Corrected fuel supply restriction (mm Hg)

   If the fuel level in the tank was more than near empty, the corrected restriction will be higher than measured. Record the corrected value.

   Fuel supply line restriction @ rated speed, no load (corrected for worst case – fuel at near empty): [ ] in Hg / mm Hg

8. Optional. If the machine does not normally operate at rated speed, repeat the test at a secondary engine speed. Record the fuel supply restriction.

   Fuel supply line restriction @ operating speed, no load (corrected for worst case – fuel at near empty): [ ] in Hg

9. Attach a pressure/vacuum gauge through suitable fittings to the fuel return line as close to the engine as possible or to the fuel return restriction fitting on the engine if applicable.

10. Mount the pressure/vacuum gauge above or at the same elevation as the point on the engine or fuel line where the hose to the gauge is attached. Hosing should be routed to avoid trapping fluid in the hose.

11. Repeat steps 5 & 7, measuring and recording the return line restrictions.
   Fuel return line restriction @ rated speed, no load: [ ] in Hg

   Optional: Fuel return line restriction @ operating speed, no load: [ ] in Hg

12. Does the fuel system meet the fuel cooling guidelines as defined on the engine curve and datasheet?		Yes/No
13. Has all testing been run with the most restrictive set of options available on the machine?		Yes/No

Author: Rick Anderson **Revision Date: 5/06/02**

Engine Mounting Test

Purpose of Test: To observe the vibration characteristics of the engine system, compare the performance of the system to calculated results, and evaluate if the vibration characteristics of the system are acceptable.

Required Equipment

- Engine speed sensor

Testing Notes

- None

Test Procedure

Make observations @ Engine Cranking Speed

1. Modify the fuel system or ECM to put the engine in a "no start" condition.

   - Engine cranking observations should be made with the engine in a no start condition. The following are methods to get the engine into a no start condition:
     - Inline Pump – Disconnect fuel shutoff valve linkage and tie back pump shutoff lever.
     - Rotary Pump, mechanical and electronic with externally connected solenoid – Remove activation wire from solenoid pin or blade connection.
     - Rotary Pump, electronic without externally connected solenoid – Manually set fueling to zero with field tool, remove fuse for shutoff solenoid, or disconnect power to ECM.

2. Move into a position where the engine, front engine vibration isolators, and rear engine vibration isolators are very visible. Be sure this location is safe, stable, and well away from all moving parts (such as the engine fan).

3. Crank the engine for 5 to 10 seconds and observe the vibration characteristics of the engine isolators and engine system.

   - Record any vibration problems or issues seen during cranking (i.e. vibration system in amplification during cranking, isolator deflection obviously much greater than calculated value, machine components vibrating excessively (in resonance), operator feels unacceptable vibration, engine movement unacceptable, etc.).

Make observations @ Low Idle Speed

4. Return the engine to a "start" condition.

5. Start the engine, and run it at engine low idle. Observe the vibration characteristics of the engine isolators and engine system.

    - Record any vibration problems or issues seen at low idle (i.e. vibration system in amplification during cranking, isolator deflection obviously much greater than calculated value, machine components vibrating excessively (in resonance), operator feels unacceptable vibration, engine movement unacceptable, etc.).

Make observations during an Engine Speed Sweep

6. Very slowly increase the engine speed from engine low idle to engine high idle (speed sweep). Observe the vibration characteristics of the engine isolators and engine system at all speeds.

    - Pay special attention to the calculated roll axis natural frequency speed and calculated vertical axis natural frequency speed.
    - Record any vibration problems or issues seen, and document the speed at which it occurred (i.e. vibration system in amplification during cranking, isolator deflection obviously much greater than calculated value, machine components vibrating excessively (in resonance), operator feels unacceptable vibration, engine movement unacceptable, etc.).
    - It may be necessary to run the engine speed sweep several times in order to be sure you are observing all vibration issues.

7. During all tests above, was Front Isolator Deflection viewed as Acceptable? [Yes] yes/no

8. If no, explain and at what speeds. (Describe all issues.)

    ____

    ____

    ____

9. During all tests above, was Rear Isolator Deflection viewed as Acceptable? [Yes] yes/no

10. If no, explain and at what speeds. (Describe all issues.)

    ____

    ____

    ____

11. During all tests above, was Engine Roll Axis vibration viewed as Acceptable? [Yes] yes/no

12. If no, explain and at what speeds. (Describe all issues.)

____

____

____

13. During all tests above, was Engine Vertical Axis vibration viewed as Acceptable? [Yes] yes/no

14. If no, explain and at what speeds. (Describe all issues.)

____

____

____

Author: Mark W. Dozier Revision Date: April 26, 2002

Electrical Cranking System Test

Required Equipment

- Thermometer (Engine Oil Temperature)
- Current Probe – Clamp on recommended, range should include cranking motor current draw at maximum starter power output (see starter performance curve)
- Minimum of 1 multimeter, suggest use of 2 to 4.
- Tachometer (dash tachometer may work if low range resolution is good)
- Optional – Data logger, recommended for best data acquisition.
- AEB 111.15

Testing Notes

1) The Cranking Motor Capacity Test should only be run when the engine oil temperature is below 105F (40C).

2) All tests performed on the cranking system should be run with the machine in a no start condition. The following are methods to get the engine into a no start condition:
   - Inline Pump – Disconnect fuel shutoff valve linkage and tie back pump shutoff lever.
   - Rotary Pump, mechanical and electronic with externally connected solenoid – Remove activation wire from solenoid pin or blade connection.
   - Rotary Pump, electronic without externally connected solenoid – Manually set fueling to zero with field tool, remove fuse for shutoff solenoid, or disconnect power to ECM.

Pre-Test

1. Instrument a means to measure the cranking motor current and the engine speed during crank. Measure and record cranking motor current and engine speed during cranking. — 550 A, 215 RPM

2. Is the cranking motor current during crank less than the maximum allowable continuous current value for the starter? (Values can be found in the Cranking System Test Appendix in Table A2) — Yes Y/N

3. Is the engine cranking speed greater than 75 RPM? — Yes Y/N

4. If the answer for question 2 or 3 is "No", the starter may be malfunctioning or inadequate for the machine. The starter should be replaced by the same type of starter or, if necessary, a larger starter prior to running the cranking system tests.

Cranking Motor Wiring Resistance Test

Purpose of Test: The following procedure will help to determine whether or not the cranking motor cables (battery cables) are sized properly for the application.

Test Procedure

1. Instrument a means to measure starter motor current (I_{ST}) during cranking (see Figure 1). The use of a clamp on current probe is recommended.

2. Instrument a means to measure battery voltage during cranking (see Figure 1). If using a multimeter, extension leads may be necessary for safety reasons. Battery voltage should be measured at the battery terminals that are furthest from the starter.

3. Instrument a means to measure starter voltage during cranking (see Figure 1). Extension leads may be necessary if the engine compartment poses a safety hazard. Starter voltage should be measured from the starter B+ terminal to starter ground point. The ground point is the starter ground lug, if present, or the point where the battery negative cable connects to the starter. If there is no connection from the battery negative terminal to the starter for grounding, the measurement point for the ground side should be a starter mounting bolt.

4. Instrument a means to measure cranking motor positive cable voltage drop (see Figure 1). The measurement points for this should be the battery positive terminal and the starter B+ terminal. Extension leads may be necessary if the starter is far from the batteries.

5. Instrument a means to measure cranking motor ground circuit voltage drop (see Figure 1). The measurement points for this should be the cranking motor ground point (same point used for the cranking motor voltage measurement) and the battery negative terminal. Extension leads may be necessary if the starter is far from the batteries.

6. Prepare to measure engine speed, starter current, battery voltage, starter voltage, cranking motor positive cable voltage drop, and cranking motor ground circuit voltage drop during crank. Voltage measurements can be taken manually with multimeters or with a data logger.

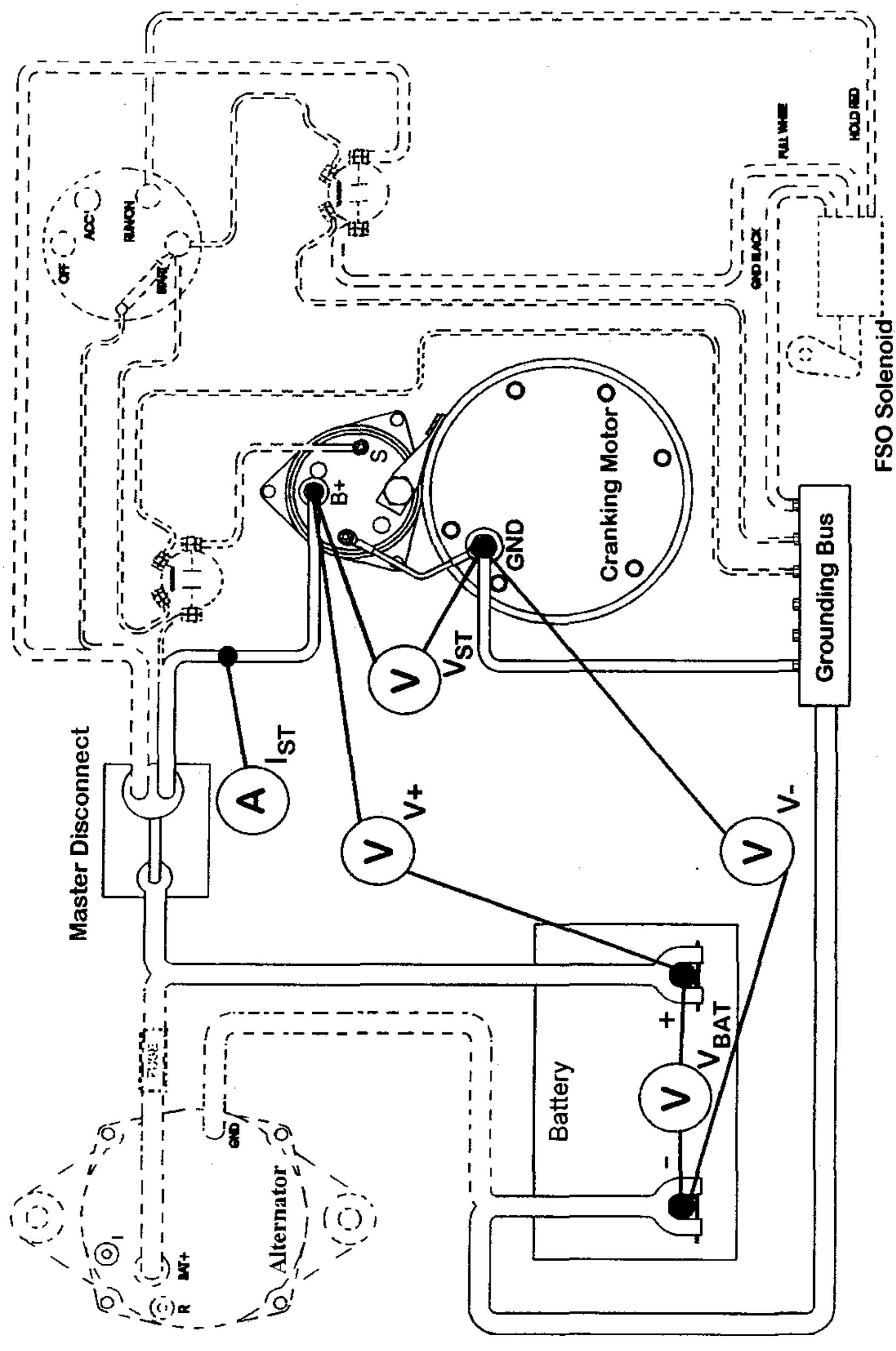


Figure 1: Cranking System 'Where to Measure'

7. Crank engine and wait until crank speed steadies out (either audibly or by tachometer). This usually happens within 5 seconds. Measure and record engine cranking speed. Simultaneously measure and record starter current (I_{ST}), battery voltage (V_{BAT}), starter voltage (V_{ST}), cranking motor positive cable voltage drop (V+), and cranking motor ground circuit voltage drop (V-). Simultaneous measurements are recommended because they are used together to determine cranking system resistance. If they cannot be measured simultaneously, the test can be run again to obtain the missed measurement(s). The cranking current should be no more than 5% different if the voltages are measured in subsequent tests. Record the results of the test here:

Engine Speed	715	RPM
I_{ST}	550	A
V_{BAT}	11.1	V
V_{ST}	10.9	V
V+	.6	V
V-	.2	V

8. Determine if measurements are valid:
   A. Calculate V_{BAT} - V_{ST}. (V_{BAT} - V_{ST} should be positive.) .2 V
   B. Calculate (V+) + (V-). ((V+) and (V-) should be positive.) .8 V
   C. Is (V+) + (V-) within 10% of V_{BAT} - V_{ST}? Yes Y/N
   If not, the test may need to be re-run after the integrity of the joints and connections has been verified.

9. Calculate system resistance with the following equation: R .0003636 ohms

$$\Omega(ohms) = \left(\frac{(V_{BAT} - V_{ST})}{I_{ST}}\right)$$

10. Is the calculated resistance less than or equal to the maximum allowable resistance for the starter used? Yes Y/N
Note: Refer to Table A1 in the Cranking System Test Appendix for maximum allowable resistances.

Cranking Motor Capacity Test Procedure

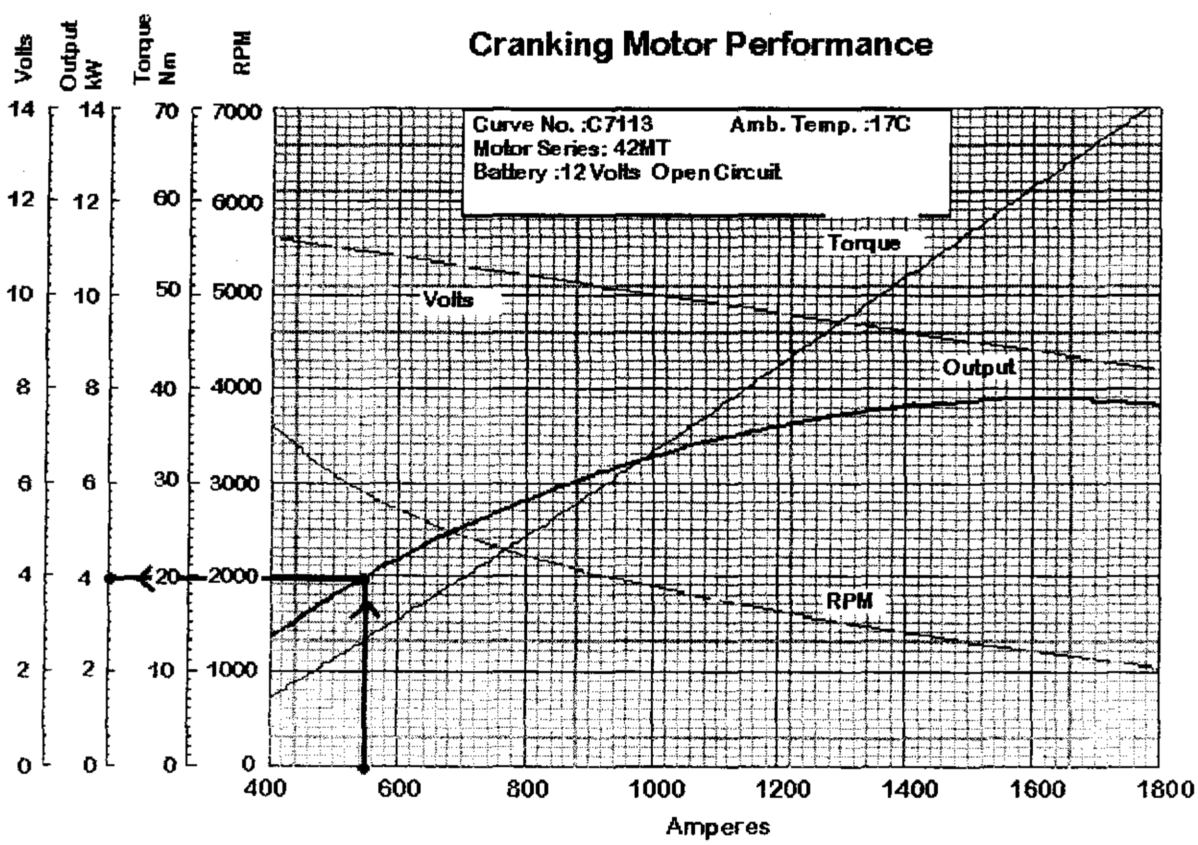
Purpose of Test: The following procedure can help determine whether or not a cranking motor is adequately sized for the application.

Test Procedure

1. Measure engine oil temperature and record (Engine oil temperature should be below 100F (40C) for this test, i.e. It is best not to warm up the engine prior to testing).

2. Use the starter current (I_{ST}) from the Cranking Motor Wiring Resistance Test and the starter performance curve to determine cranking power requirement during test. The starter performance curve can be found on the Advisor CD in the path Advisor Technical Library-> Industrial Technical Library-> Technical Information->Delco Starters and Alternators. An example is shown in Figure 2.

P_{TEST} [ ] kW

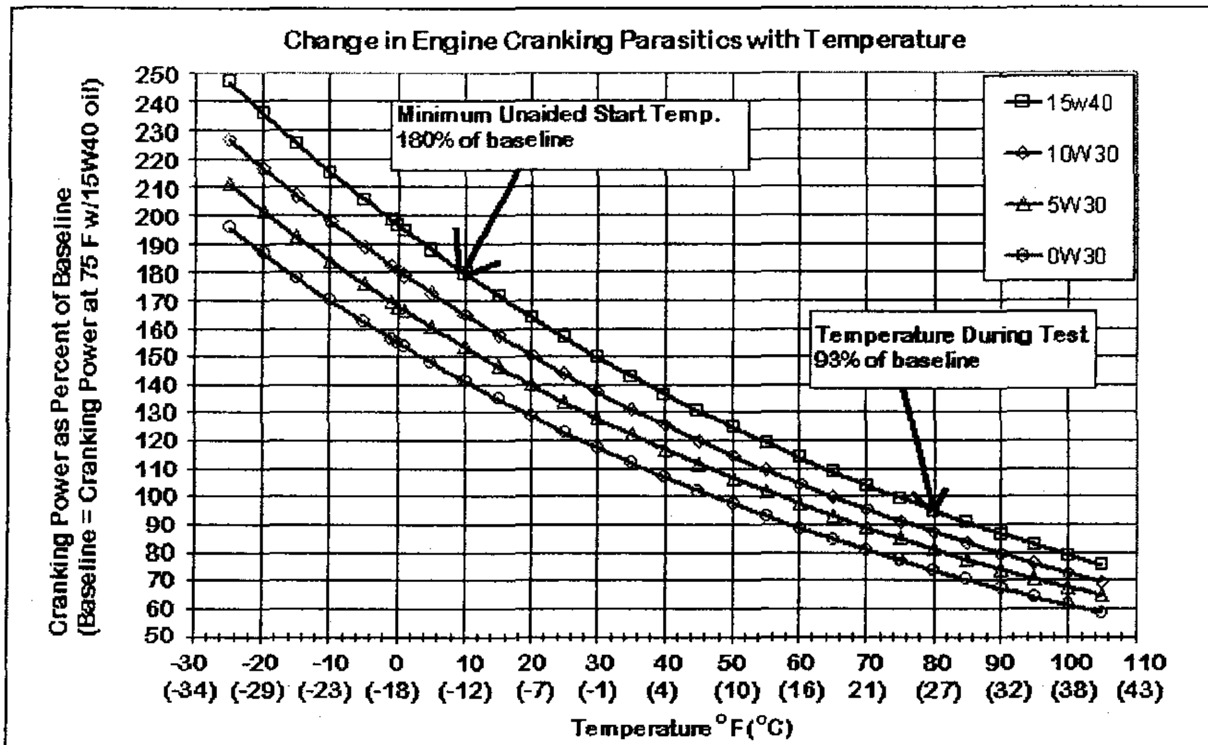


I_{ST} = 545 Amps ==> P_{TEST} = 3.9kW

Figure 2: Example Starter Performance Curve Showing Starter Current to Starter Power Conversion

3. Use Figure 3 to determine cranking power requirement at the minimum unaided start temperature for the engine.

P_{MIN} [ ] kW



<u>Example:</u>
Engine Oil Temperature during crank test: 80 F
Engine and Starter: QSC with 12V 42MT
Starter current during crank test: I_{ST} =545 Amp
Starter Power during crank test (from I_{ST} and starter performance curve): P_{TEST}= 3.9 kW
Starter Power at Min. Undaided start temp. (Using Chart Above): P_{MIN}= (3.9*(180%/93%)) = 7.54 kW
Maximum Crankin gMotor Power (from option note or starter performance curve): P_{MOTOR}= 7.76 kW
Evaluation: Because 7.76>7.54, the cranking motor is adequately sized if the assumptions hold.

Figure 3: Chart for Power Correction to Minimum Unaided Start Temperature with Example

4. Record cranking motor power, either from AEB111.15 or from peak on starter performance curve.

P_{MOTOR} [ ] kW

5. Determine the cranking system power margin. Is ($P_{MOTOR} - P_{MIN}$) ≥ 0? _____Y/N
If not, the starter may not have adequate capacity to crank the engine at the minimum unaided start temperature.

Note: Questions relating to, and the evaluation of, cranking motor capacity (power margin) are based on the assumption that power train parasitics experience a similar increase in power requirement as the engine with respect to temperature. Machines with hydraulic systems may exhibit a more rapid increase in power requirements with respect to decreasing ambient temperatures. This is due to the rapid increase in viscosity of hydraulic oils as temperature decreases. Lower viscosity engine oil, hydraulic oil, and/or a higher capacity cranking motor should be used to improve engine cranking for lower ambients. Figure 3 should be used as a guideline only. Machines that operate continuously in "arctic" conditions should be designed and tested to ensure adequate engine starting.

6. Is the engine cranking RPM (recorded in the Cranking System Wiring Resistance Test) greater than the minimum required cranking speed found on the engine data sheet? _____Y/N

Special Considerations

1. Dual/triple starter systems: Perform the Cranking Motor Wiring Resistance and the Cranking Motor Capacity tests for each starter. Record the worst case (highest resistance or lowest power margin) and input in Advisor. Each starter should meet the wiring resistance requirement and the combined starter system should meet the cranking motor capacity requirement!

2. Dual bank batteries: Perform the Cranking Motor Wiring Resistance Test for both sets of batteries. Both circuits should meet the maximum resistance requirements. Record the worst case and input in Advisor.

Appendix

Table A1: Cranking Circuit Maximum Allowable Resistance

Delco HD Apps. Guide 1/98			SAE Standard J541		
Starter	Volt	Max Resistance	Starter System	Volt	Max. Voltage Drop/Resistance
28MT	12V	0.0012 ohm	Medium/Light Duty	12V	0.2V/100A → (0.002 ohm)
	24V	0.002 ohm		24V	0.4V/100A → (0.004 ohm)
37MT 41MT 42MT 50MT	12V	0.00075 ohm	Heavy Duty	12V	0.1V/100A → (0.001 ohm)
	24V	0.002 ohm		24V	0.17V/100A → (0.0017 ohm)

Table A2: Cranking Motor Maximum Allowable Continuous Current

Starter Model	Starter Voltage	Max. Continuous Current to Starter
28MT	12 Volt	750
	24 Volt	450
37MT & 41MT	12 Volt	1400
	24 Volt	750
42MT	12 Volt	1650
	24 Volt	850
50MT	24 Volt	1000

Author: Mark W. Dozier **Revision Date: April 26, 2002**

Electrical Run, Stop, and Crank Controls System Test

Required Equipment

- Current Probe – Clamp on recommended, range should be 0-100A DC or higher.
- Minimum of 1 multimeter, suggest use of 2 to 4.
- Optional – Data logger, recommended for best data acquisition.
- AEB 111.15

Testing Notes

1. Run, Stop, and Crank Controls tests should be run before or after the cranking system tests. Both sets of tests require the engine to be in a no start condition.

2. All tests performed on the cranking system should be run with the engine in a no start condition. The following are methods to get the engine into a no start condition:
   - Inline Pump – Disconnect fuel shutoff valve linkage and tie back pump shutoff lever.
   - Rotary Pump, mechanical and electronic with externally connected solenoid – Remove activation wire from solenoid pin or blade connection.
   - Rotary Pump, electronic without externally connected solenoid – Manually set fueling to zero with field tool, remove fuse for shutoff solenoid, or disconnect power to ECM.

Starter Solenoid Control Circuit Voltage Drop Test Procedure

Purpose of Test: The following test can help to determine whether or not the starter solenoid is getting the minimum voltage to operate properly.

Test Procedure

1. Instrument a means to measure battery voltage (see Figure 1).

2. Instrument a means to measure starter solenoid voltage (see Figure 1).

3. Instrument a means to measure starter solenoid positive wire voltage drop. The connection points of this measurement should be the battery positive terminal and the starter solenoid "S" terminal (see Figure 1).

4. Instrument a means to measure starter solenoid ground circuit voltage drop. The connection points of this measurement should be the starter ground connection and the battery negative terminal (see Figure 1).

5. Prepare to measure and record battery voltage, starter solenoid voltage, starter solenoid positive wire voltage drop, and starter solenoid ground circuit voltage drop here. These measurements can be taken manually with multi-meters or with a data logger.

6. Crank the engine and wait until crank speed steadies out (either audibly or by tachometer). This usually happens within 5 seconds. It is best practice to get all measurements simultaneously. Record the battery voltage (V_{BAT}), starter solenoid voltage (V_{SOL}), starter solenoid positive wire voltage drop (V_{S+}), and starter solenoid ground circuit voltage drop (V_{S-}).

V_{BAT}	11.1	V
V_{SOL}	10.9	V
V_{S+}	.6	V
V_{S-}	.2	V

7. Determine if measurements are valid:
   A. Calculate V_{BAT} - V_{SOL}. (V_{BAT} - V_{SOL} should be positive.) .2 V
   B. Calculate (V_{S+}) + (V_{S-}). ((V_{S+}) and (V_{S-}) should be positive.) .8 V
   C. Is (V_{S+}) + (V_{S-}) within 10% of V_{BAT} - V_{SOL}? Yes Y/N
   If not, the test may need to be re-run after the integrity of the joints and connections has been verified.

8. Calculate the starter solenoid system total voltage drop (voltage drop should not exceed 1.0/2.0V for 12/24V systems):

   $V_{DROP\ TOTAL} = V_{BAT} - V_{SOL}$ $V_{DROP\ TOTAL}$ .2 V

9. Is the total system voltage drop $\leq$ 1.0/2.0V for a 12/24V system? Yes Y/N
   If not, the system has failed the test.

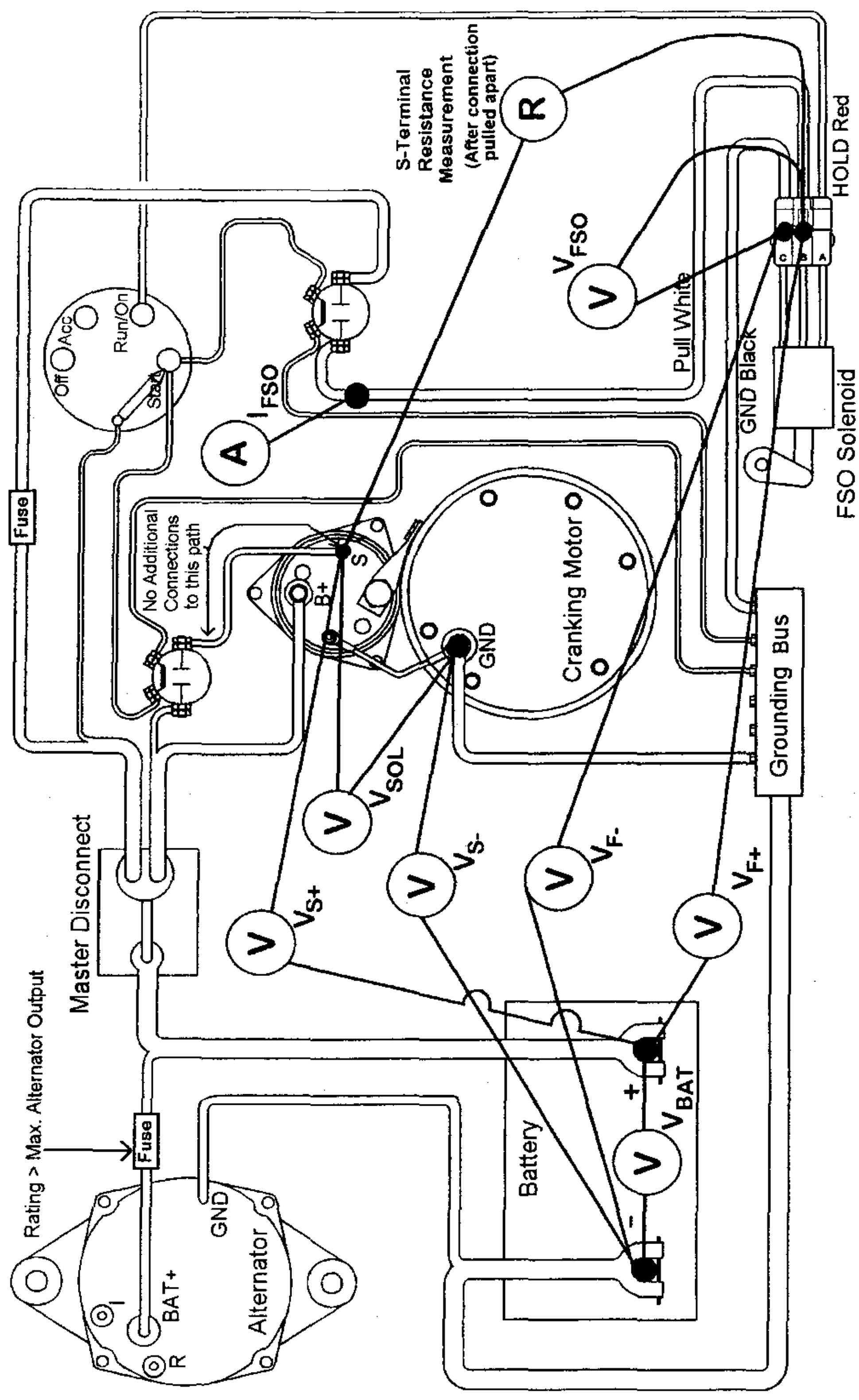


Figure 1: Run, Stop, and Crank Controls "Where to Measure"

External Direct Link Fuel Shutoff Solenoid Control Circuit (used with Bosch inline fuel pumps) Test Procedure

Purpose of Test: The following procedure will determine if the electrical system is able to provide the minimum required voltage to the FSO solenoid.

Test Procedure

1. Instrument a means to measure fuel shutoff solenoid pull in current. The use of a clamp on current probe is recommended (see Figure 1).

2. Instrument a means to measure fuel shutoff solenoid pull in coil voltage. The voltage should be measured at the fuel shutoff solenoid side of the connector. A breakout harness is a nondestructive method of obtaining this measurement (see Figure 2).

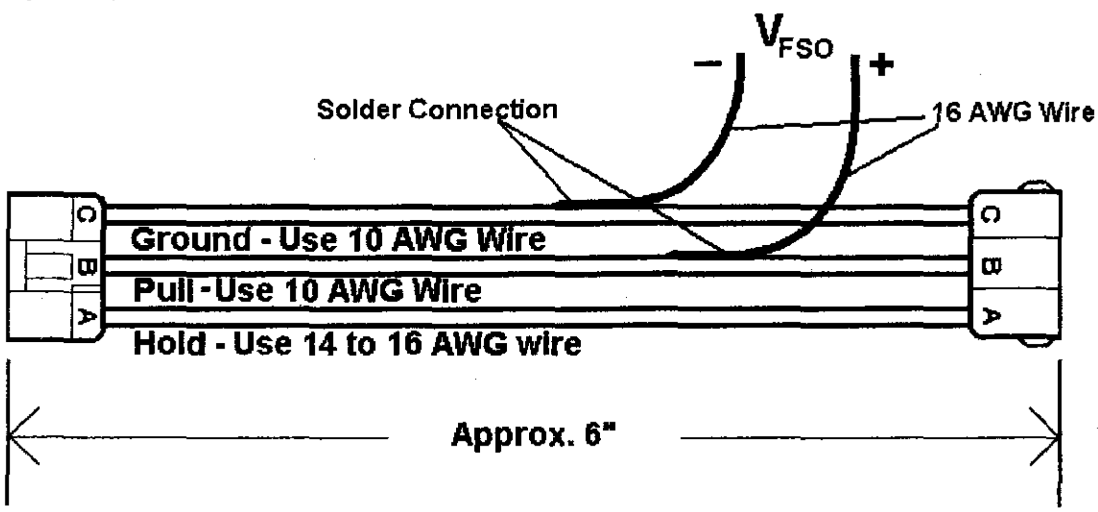


Figure 2: Fuel Shutoff Solenoid Breakout Harness

3. Instrument a means to measure battery voltage (see Figure 1).

4. Instrument a means to measure FSO solenoid pull coil wire voltage drop. The measurement points for this are the battery positive terminal and the FSO solenoid pull coil measurement point used for getting the pull coil voltage (see Figure 1).

5. Instrument a means to measure FSO solenoid ground circuit voltage drop. The measurement points for this are the FSO solenoid ground measurement point used for getting the pull coil voltage and the battery negative terminal (see Figure 1).

6. Prepare to measure and record fuel shutoff solenoid pull in coil voltage and current, battery voltage, FSO solenoid pull coil wire voltage drop, and FSO solenoid ground circuit voltage drop.

7. Crank the engine and wait until crank speed steadies out (either audibly or by tachometer). This usually happens within 5 seconds. Measure and record the fuel shutoff solenoid pull in coil current (I_{FSO}) and voltage (V_{FSO}), battery voltage (V_{BAT}), FSO solenoid pull coil wire voltage drop (V_{F+}), and FSO solenoid ground circuit voltage drop (V_{F-}).

I_{FSO}		A
V_{FSO}		V
V_{BAT}		V
V_{F+}		V
V_{F-}		V

8. Is the fuel shutoff solenoid pull in current greater than 30A/15A for a 12V/24V system? If not, the solenoid may not be working properly and the test may need to be re-run with a new solenoid.

9. Determine if measurements are valid:
   A. Calculate V_{BAT} - V_{FSO}. (V_{BAT} - V_{FSO} should be positive.) ______V
   B. Calculate (V_{F+}) + (V_{F-}). ((V_{F+}) and (V_{F-}) should be positive.) ______V
   C. Is (V_{F+}) + (V_{F-}) within 10% of V_{BAT} - V_{FSO}? ______Y/N
   If not, the test may need to be re-run after the integrity of the joints and connections has been verified.

10. Look up and record the minimum allowable solenoid voltage from Table A1 in the Run, Stop, and Crank Controls System Test Appendix. V_{TABLE} [ ] V

11. Is (V_{BAT} - V_{FSO})< (V_{MIN} - V_{TABLE}) where V_{MIN} is 10.5/21V for 12/24V system? If yes, then the solenoid wiring meets the requirements. ______Y/N
(V_{MIN} – V_{TABLE}) represents the allowed voltage losses in the wiring and connections.
(V_{BAT} – V_{FSO}) represents the measured voltage losses in the wiring and connections.

S-Terminal Wiring Test Procedure

Purpose of Test: This test will determine whether or not the system is S-Terminal wired.

Test Procedure

1. Pull apart the fuel shutoff solenoid electrical connector. Measure the resistance from the pull coil pin in the OEM side of the connector to the starter solenoid S-terminal (see Figure 1 for measurement points). Record the value.

   Resistance [ ] ohms

2. Is there continuity or resistance of less than 5 ohms between the two points? If "Yes", the machine is probably S-Terminal wired. _____Y/N

Note: If the measured resistance is much more than 5 ohms (i.e. 25 Mohms), input 100 ohms into Advisor to indicate discontinuity between the two points.

Special Considerations

Not applicable.

Appendix

Table A1: Fuel Shutoff Solenoid Minimum Voltage

	FV Option	Voltage	FV P/N	Minimum Solenoid Voltage (VTABLE)
4B	9182	12	3932529	9.7
	9188	24	3932530	19.1
	9215	12	3932545	8.3
	9197	12	3932545	8.3
	9198	24	3932546	16.6
	9233	12	3935649	8.3
	9234	24	3935650	15.7
6B	9223	12	3935429	8.7
	9224	24	3935430	17.1
	9225	12	3935431	8.7
	9226	24	3935432	17.1
	9181	12	3932529	9.7
	9187	24	3932530	19.1
6C	9125	12	3926411	9.6
	9178	12	3930233	8.3
	9179	24	3930234	16.6
	9132	12	3930233	8.3
	9133	24	3930234	16.6
	9171	12	3930235	8
	9172	24	3930236	16
	9229	12	3935456	8.3
	9230	24	3935457	15.7
	9233	12	3935649	8.3
	9234	24	3935650	15.7

Author: Mark W. Dozier Revision Date: April 26, 2002

Electrical Charging System Test

Required Equipment

- Tachometer (dash tachometer would work for this test)
- Current Probe – Clamp on recommended, range should include alternator rated output current.
- Minimum of one multimeter, suggest use of two to four
- Optional – Data Logger, recommended for best data acquisition.
- AEB 111.15

Testing Notes

The charging system tests should be run after the cranking system and the run, stop, and crank controls tests. The engine will need to be run for the charging system tests.

Pre-Test

1. Instrument a means to measure alternator voltage. Start the engine and bring to low idle. Measure and record the alternator voltage. 14.2 V

2. Is the voltage within the limits of 13.5-15.5V/27-31V for 12V/24V systems? Yes Y/N
   If not, then the alternator regulator or the batteries may not be functioning correctly and should be checked/replaced prior to performing the charging system tests.

Author: Mark W. Dozier **Revision Date: April 26, 2002**

Alternator Wiring Voltage Drop Test Procedure

Purpose of Test: The following procedure can help determine whether or not the alternator wiring is sized sufficiently to adequately charge the batteries.

Test Procedure

1. Instrument a means to measure battery voltage (see Figure 1). Measurements should be taken at battery terminals furthest from the alternator.

2. Instrument a means to measure alternator voltage (see Figure 1).

3. Instrument a means to measure positive cable voltage drop. The connection points for this measurement should be the battery positive terminal and the alternator B+ terminal (see Figure 1).

4. Instrument a means to measure alternator ground circuit voltage drop. The connection points for this measurement should be the alternator ground point and the battery negative terminal and the alternator (see Figure 1).

5. Instrument a means to measure alternator current (see Figure 1). A clamp on current probe is recommended. Be sure to clamp probe around all current flows from the alternator.

6. Record alternator rated output. This can be found in the option note, on the alternator, or on the alternator performance curve found in Advisor. Alternator rated output current is found at 6000 alternator RPM.

I_{ALT_RATED} [200] A

7. Prepare to measure and record the alternator current, battery voltage, alternator voltage, alternator positive cable voltage drop, and the alternator ground circuit voltage drop. It is best to measure these simultaneously. The voltages can be measured at different times as long as the current remains within 10% of the original tested value (critical when there are not enough multimeters to measure all voltages simultaneously).

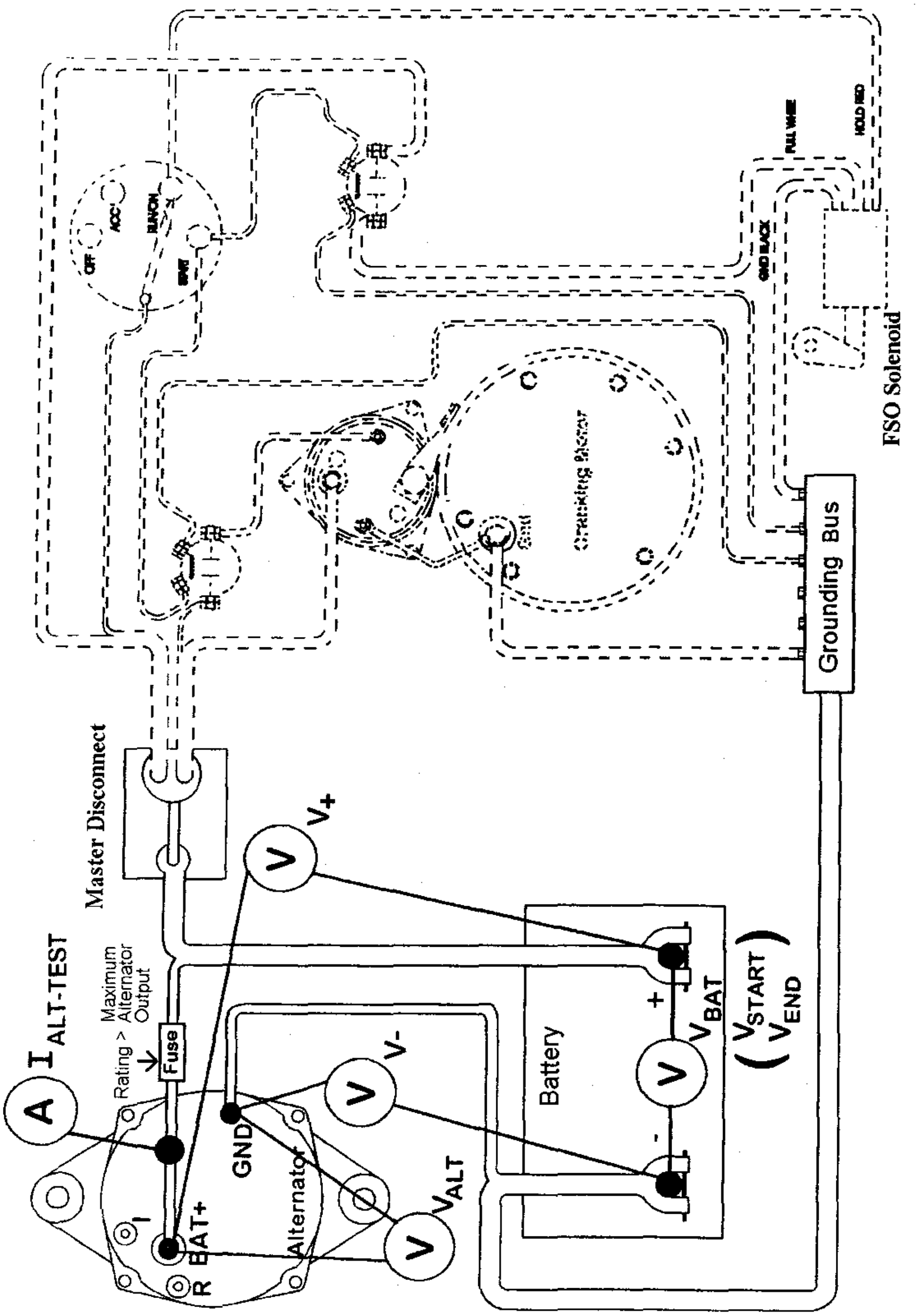


Figure 1: Charging System "Where to Measure"

8. Start the engine, bring it to low idle and turn on all possible electrical accessories. The goal of this test is to record voltages when the alternator is at its rated current output. Sometimes a cold alternator will have full output at idle after the cranking system tests. If full output of the alternator cannot be achieved, it may be necessary to increase engine speed or take voltage measurements at reduced alternator output. Record the alternator current ($I_{ALT-TEST}$), battery voltage (V_{BAT}),alternator voltage (V_{ALT}), alternator positive cable voltage drop (V_+), and the alternator ground circuit voltage drop (V_-) at the highest attainable alternator output.

$I_{ALT-TEST}$	200	A
V_{BAT}	14.1	V
V_{ALT}	14.2	V
V_+	.05	V
V_-	.04	V

9. Determine if measurements are valid:
   A. Calculate V_{ALT} - V_{BAT}. (V_{ALT} - V_{BAT} should be positive.) .4 V
   B. Calculate (V_+) + (V_-). ((V_+) and (V_-) should be positive.) .09 V
   C. Is (V_+) + (V_-) within 10% of V_{ALT} - V_{BAT}? Yes Y/N
   If not, the test may need to be re-run after the integrity of the joints and connections has been verified.

10. Calculate charging system voltage drop at rated alternator current output according to the following (the voltage drop should not exceed 0.5V/1.0V for 12/24V system):

$$V_{DROP} = \left(\frac{I_{ALT-RATED}}{I_{ALT-TEST}}\right) \times (V_{ALT} - V_{BAT})$$

V_{DROP} .1 V

11. Is V_{DROP} less than or equal to the maximum allowable drop of 0.5V/1.0V for 12V/24V systems? Yes Y/N

Alternator Capacity Test Procedure

Note: The system should pass the Alternator Wiring Voltage Drop Test prior to this test being performed.

Purpose of Test: The following procedure can help determine whether or not an alternator is appropriately sized for the application.

Test Procedure

1. Instrument a means to measure engine speed during the test (see Figure 1).
2. Instrument a means to measure battery voltage (see Figure 1).
3. Start the engine and bring it to low idle. Record low idle speed. Turn on TYPICAL electrical loads used at low idle. Immediately measure battery voltage and record.

Low idle speed	750	RPM
Start battery voltage, low idle, typical electrical loading	14.1	V

4. Let the engine run at low idle for at least 2 minutes and measure the battery voltage again. Record this value. A longer test will generally give better results, but the test time for each point should not exceed 5-10 minutes.

End battery voltage, low idle, typical electrical loading	14.2	V

5. Repeat steps 1 and 2 with TYPICAL electrical system loading for high idle and a user defined critical continuous operating point. Record the values here.

High idle speed	1100	RPM
Start battery voltage, high idle, typical electrical loading	14.1	V
End battery voltage, high idle, typical electrical loading	14.2	V
User defined speed	1000	RPM
Start battery voltage, user def. speed, typical electrical loading	14.2	V
End battery voltage, user def. speed, typical electrical loading	14.3	V

6. Repeat steps 1, 2, and 3 with EXTREME electrical system loading. At each engine speed, turn on all possible electrical loads for the tests. Record the values here.

Low idle speed	750	RPM
Start battery voltage, low idle, extreme electrical loading	14.1	V
End battery voltage, low idle, extreme electrical loading	14.1	V
High idle speed	1110	RPM
Start battery voltage, high idle, extreme electrical loading	14.1	V
End battery voltage, high, extreme electrical loading	14.1	V
User defined speed	1000	RPM
Start battery voltage, user def. speed, extreme electrical loading	14.1	V
End battery voltage, user def. speed, extreme electrical loading	14.0	V

7. Did the batteries maintain their charge during all of the tests? (The batteries should not discharge by more than 0.25 volts during any test.) If "NO", then the system may not have the capacity to charge the system at that condition. Yes Y/N

Special Considerations

Dual Alternator: Perform the Alternator Wiring Voltage Drop Test on each alternator. Record and input the worst case into Advisor. Both alternators should pass this test.

Appendix

Not applicable.