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# Standard Test Method for
# Evaluation of Engine Fuels For Injector Deposits in the L10 Diesel Engine

This standard is issued under the fixed designation D XXXX-XX; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parenthesis indicates the year of last reapproval. A superscript epsilon (e) indicates an editorial change since the last revision or reapproval.

## 1. Scope[1]

1.1. This test method describes a four-stroke cycle diesel engine test procedure for evaluating fuel depositing tendencies and the effect of fuel detergents by examining injector flow loss and injector deposits. It is commonly known as the L10 Injector Depositing Test, and is used by the Engine Manufacturers Association (EMA) as part of their Fuel Quality Position[2] and by the Truck Maintenance Council and National Council of Weights and Measures (NCWM) as part of their premium diesel fuel definitions.

1.2. *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.3. The values are stated in either SI units or in other units; however, SI units are to be regarded as the standard. Engine build-up specifications and injector set-up, where non-metric, may be used as standard.

1.4. The test method outlined in this standard can be used by any properly equipped laboratory, without outside assistance. However, the ASTM Test Monitoring Center (TMC)[3] provides reference fuel additive, the test oil, and an assessment of the test results obtained on those fuels by the laboratory. By this means, the laboratory will know whether their use of the test method gives results statistically similar to those obtained by other laboratories.

Accordingly, this test method is written for use by laboratories which utilize TMC services. Laboratories which choose not to use those services may simply ignore those portions of the test method which refer to the TMC. This method may be modified by means of Information Letters issued by the TMC. In addition, the TMC may issue supplementary memoranda related to the method.

1.5. This test method is arranged as follows:



## 2. Referenced Documents

2.1. ASTM Standards:

E 29 Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

E 178 Standard Practice for Dealing with Outlying Observations

E 344 Terminology Relating to Thermometry and Hydrometry

2.2 Other Standard:

CRC Rating Manual No. 18 Diesel Engine Rating Manual

## 3. Terminology

3.1. Definitions

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[1] This test method is under the jurisdiction of ASTM Committee D-2 on Petroleum Products and Lubricants an is the direct responsibility of Subcommittee D02.E on Burner, Diesel, Marine, and Industrial Gas Turbine Fuels.

[2] This document may be obtained from:
The Engine Manufacturers Association, 401 North Michigan Avenue, Chicago, IL 60611-4267, Phone: (312) 644-6610
Email: ema@sba.com

[3] ASTM Test Monitoring Center, 6555 Penn Avenue, Pittsburgh, PA 15206-4489; Phone: (412) 365-1000, Fax: (412) 365-1047

This test method is supplemented by Information Letters and Memoranda issued by the ASTM Test Monitoring Center. Users of this method can contact the ASTM Test Monitoring Center to obtain the most recent of these.

3.1.1. *calibrate, v* to determine the indication or output of a measuring device with respect to that of a standard (ASTM E 344).

3.1.2. *calibration test, n* an engine test conducted on a reference fuel under carefully prescribed conditions whose result is used to determine the suitability of the engine stand/laboratory to conduct such tests on non-reference fuels. In this Standard, calibration test and reference test are synonymous.

3.1.2.1. *Discussion* In this Standard it can also refer to tests conducted on parts to insure their suitability for use in reference or non-reference tests.

3.1.3. *candidate fuel, n* a fuel that is intended to have the performance characteristics necessary to satisfy a specification and is tested against that specification.

3.1.4. *carbon, n* a firm, normally black, highly insoluble deposit composed primarily of organic residue, and most readily definable by thickness of volume and by texture. It is usually non-lustrous, except when rubbed smooth between adjoining parts.

3.1.4.1. *Discussion* carbon may be from light yellow to black, including brown and gray in color.

3.1.5. *clogging, plugging, n* the restriction of a flow path due to the accumulation of material along the flow path boundaries.

3.1.6. *engine oil, n* a liquid that reduces friction or wear, or both, between the moving parts within an engine; removes heat, particularly from the underside of pistons; and serves as a combustion gas sealant for the piston rings.

3.1.6.1. *Discussion* it may contain additives to enhance certain properties. Inhibition of engine rusting, deposit formation, valve train wear, oil oxidation, and foaming are examples.

3.1.7. *heavy carbon, n* carbon that has obvious depth/thickness as compared to adjacent carbon deposits and is polished.

3.1.8. *lacquer, n* a thin, hard, oil-insoluble deposit, composed primarily of organic residue, and most readily definable by color intensity.

3.1.8.1. *Discussion* Lacquer is not easily removed by wiping and is resistant to saturated solvents such as petroleum naptha, but soluble in other solvents such as benzene, chloroform, ketones, and similar compounds classed as "lacquer solvents". It may be variously colored, usually in gray, brown, or amber hues. The definition and rating factors of lacquer must be determined by using the CRC Rust/Varnish/Lacquer Rating Scale.

3.1.9. *light carbon, n* carbon that has texture and slight depth/thickness as compared to lacquer.

3.1.10. *medium carbon, n* carbon that has obvious depth/thickness as compared to adjacent carbon deposits but is not polished.

3.1.11. *non-reference test, n* – any test conducted between referencing tests.

3.1.11.1. *Discussion* any test run on a referenced stand shall be considered a non-reference test.

3.1.12 *reference fuel, n*--a fuel of known performance characteristics, used as a basis for comparison.

3.1.12.1 *Discussion*--reference fuels are used to calibrate testing stands.

## 4. Summary of Method

4.1. Prior to each run the engine and injectors are prepared in strict accordance to furnished specifications. The coupled pair of Cummins L10 engines are cycled at 15 second intervals between closed throttle motoring and full throttle fueling for a total of 125 hours. This procedure has been found to cause injector deposits.

4.2. At the conclusion of the test, the injectors are evaluated on a test bench to determine flow losses compared to their pre-test flow, and the plungers are removed and rated for injector deposits.

## 5. Significance

5.1. The test method is designed to relate to injector deposits formed in the field where the duty cycle involves a significant amount of motoring (deceleration).

5.2. The test method is useful for the evaluation of diesel fuel quality and for deposit reduction imparted by fuel detergents. It is used by the EMA, NCWM, and the Truck Maintenance Council along with other tests, for defining premium fuel quality. It is used by Cummins, Inc. to define acceptable fuel quality.

5.3. The results are significant only when all details of the test procedure are followed. A significant body of information indicates that this test is useful for evaluating the depositing tendencies of diesel fuels. Although this method utilizes open cup injectors, results are believed applicable to engines using closed cup injectors where depositing occurs on the exterior of the injector, interfering with spray pattern symmetry. Nevertheless, this factor should be considered when extrapolating test results to other engine and injector types.

## 6. Apparatus

6.1. *Test Engine* A pair of Cummins 1988 L10 engines (CPL 939, 1619, 1623, or 1223) is required. The engines are rated at 300 HP @2100 r/min and may be purchased from an authorized Cummins distributor. The two engines are coupled in a tandem set-up where one engine drives the other, and in turn is driven, in 15 second cycles. Fixed time PT injectors are used as described under 6.10.1. The engine arrangement is shown in A1.1.

6.2. *Air Inlet System* Use an intake air system capable of controlling intake air temperature and pressure at the values specified in Table 4.

6.3. *Cooling System* Use the cooling system described in A1.2 and A1.3 Provisions must be made to supply the engine with inlet water at the values specified in Table 4.

6.3.1. *Cooling System Air Bleed* Shall be re-routed to drain into the expansion tank or other waste water supply as shown in A1.3 It should not be re-introduced into the engine coolant intake which would impact on the engine coolant temperature. A petcock shall be installed where shown in A1.3 and is opened while filling the cooling system. An alternative to using the manually operated petcock is to route a separate bleed line to the waste water system from both the cylinder head vent and the aftercooler vent. They are not to be joined.

6.3.2. *Thermostat Bypass Tube* Shall be blocked off and rendered inoperative as shown in A1.2 The constant bypass as shown in A1.2 is not to be confused with the bypass tube. The constant bypass remains unchanged.

6.3.3. *Thermostat* The valve portion of the thermostat shown in A1.2 shall be removed, leaving in place the "washer" portion of the thermostat.

6.3.4. *Engine Water Pump* Shall remain as standard.

6.3.5. *Coolant Heat Exchanger* Shall be able to supply coolant to the engine at the values specified in Table 4. Cooling water intake temperature shall be measured at the flange into the turbocharger aftercooler at the location shown in A1.3.

6.4. *Speed/Load Controls* Speed and not load is controlled with the tandem engine arrangement. The friction horsepower of the engine in tandem acts as a dynamometer.

6.5. *Throttle Control* Use an air-actuated, on/off control system and throttle actuator as shown in A1.4 and A1.5. Throttle actuation from full-on to full-off must be achieved in one second or less. Fuel rail pressure must return to a steady pressure within a maximum of 3 seconds after cycle changes. A Parker[4] Air Cylinder, Part Number .75 DPSRX 1.50, has been used successfully along with a 4-Way 2-Position solenoid ASCO[5] Part No. JFK8344A72 or JFK8344G72.

6.6. *Fuel System* The fuel system shall be modified as follows:

6.6.1. Render the air/fuel control inoperative by using the Cummins kit described in A1.6 for use when AF control is not required.

6.6.2. Modify the return line as shown in A1.7. This allows easy measurement of the throttle leakage as required by the test procedure. Replace the 5/16 in. tubing with 3/8 in. (or larger) tubing to reduce back pressure in the fuel pump.

6.6.3. Use only Cummins approved and calibrated injectors as referenced in 6.10.1.

6.6.4. Use only Cummins approved and qualified fuel pumps as described in 6.10.2.

6.7. *Lubricant System* Shall be modified to provide oil cooling and single filter as follows:

6.7.1. Utilize only one full-flow filter (LF3000 - Part Number 3318853) with the filter head option shown in A1.8 with the part numbers shown in A1.9. Remove the thermostat shown and block passage using a 1-in. freeze plug, directing all oil flow through the oil cooler.

6.7.2. Labs shall measure and report oil consumption. A sight glass as shown in A1.10 may be used for monitoring and adjusting oil level.

6.8. *Exhaust System* An exhaust system with back-pressure control capable of maintaining the prescribed test conditions in Table 4 shall be used.

6.9. *Thermocouples and Pressure Sensors*

6.9.1. Thermocouples are required for obtaining temperatures at the following locations. The immersion depth shall be such that the tip of the sensor is midstream of the fluid measured unless otherwise specified.

6.9.1.1. Inlet air. (Illustrated in A1.11)

6.9.1.2. Turbine outlet Temperature (Illustrated in A1.11)

6.9.1.3. Exhaust temperature for each cylinder. (Illustrated in A1.12)

6.9.1.4. Coolant inlet (Illustrated in A1.3); coolant outlet. (Illustrated in A1.13)

6.9.1.5. Oil temperature in sump. (Illustrated in A1.14)

6.9.1.6. Fuel temperature at inlet of fuel filter. (Illustrated in A1.15)

6.9.1.7. Aftercooler air-out temperature. (Illustrated in A1.16)

6.9.2. Pressure sensors are required for obtaining pressures at the following locations:

6.9.2.1. Intake and exhaust pressure measurements shall conform as closely as possible to the Cummins Engineering Standard 14,900-38 illustrated and located as shown in A.1.11.

6.10. *Parts* Information concerning procurement of test injectors and fuel pumps, and replacement parts other than parts bought from local suppliers, and approval of equivalent part substitutions allowed in this procedure is obtained from the test sponsor[6]. Other parts and their sources referred to throughout the procedure are found in the footnotes.

[4] Parker Hannifin, Regional Sales Office
1-800-272-7537

[5] Can be obtained from:
ASCO (Automated Switch Company)
Hanover Road
Florham Park, NJ 07932
Phone: (201) 966-2000, (212) 344-3765
Fax: (201) 966-2628

[6] Cummins, Inc, Attn: Warren Totten, Mailcode: 50183, 1900 McKinley Ave., Columbus, IN 47201. Telephone: 812-377-3429, Fax: 812-377-7808, email: warren.a.totten@ctc.cummins.com.

6.10.1. *Injectors* Stepped Plunger and Cup (SPC) injectors (Part Number 3069759) shall be used. Figure A1.17 shows a simplified diagram of this injector.

6.10.2. *Fuel Pump* New fuel pumps, (Part Number 3060718) shall be obtained from the local Cummins dealer. No substitutions are permitted.

6.10.3. *Turbocharger* H2 Series Turbocharger (Part Number 352537) can be rebuilt or purchased from the local Cummins dealer. Bulletin Number 3810351 "Shop Manual H2 Series Turbocharger" describes turbocharger rebuild procedures.

6.10.4. Pistons, rings, liners, valves, valve trains, filters, and other replacement parts can be purchased from the local Cummins dealer. Only new original equipment manufacturer parts are acceptable. Reconditioned parts are not to be used.

6.10.5. Parts required for a complete engine overhaul are specified in Table 1. Those footnoted are replaced after 40 non-reference tests. A complete overhaul is required after 80 non-reference tests have been conducted.

## 7. Reagents and Materials

7.1. *Fuel* Use Haltermann Products 0.4% sulfur Diesel Test Fuel[7] (also used for Caterpillar 1-K engine testing) as the base fuel for all calibration runs, both additized and non-additized. Specifications are shown in A2.0. Approximately 1135 L (300 gallons) are consumed during each test.

*7.2. Lubricant* Use TMC-5000 for all runs. TMC-5000 is a 15W-40 diesel engine oil. This lubricant is available from the TMC (see footnote 3) for those laboratories conducting this test.

7.3. *Fuel Additive* Use CRA-1 at 200 ppm by volume for all calibration tests made with additized fuel. This additive is available from the TMC.

7.4. *Engine Coolant* Use Cummins pre-mix (Cummins Compleat PG).

7.5. *Cleaning Materials* Use Cummins "Restore" in solution with water in the cooling system flush procedure referenced in 9.4.

## 8. Safety

8.1. Engine testing can expose personnel and facilities to a number of safety hazards. It is recommended that only personnel who are thoroughly trained and experienced in engine testing should undertake the design, installation and operation of engine test stands. Each laboratory conducting engine tests should have their test installation inspected and approved by their Safety Department. Provide personnel working on the engines with the proper tools, be alert to common sense safety practices and avoid contact with moving or hot engine parts. Guards should be installed around all external moving or hot parts. When engines are operating at high speeds, heavy duty guards are required and personnel should be cautioned against working alongside the engine and coupling shaft. Provide barrier protection for personnel. All fuel, oil lines and electrical wiring should be properly routed, guarded and kept in good order. Scraped knuckles, minor burns and cuts are common if proper safety precautions are not taken. Safety masks or glasses should always be worn by personnel working on the engines and no loose or flowing clothing should be worn near running engines.

8.2. Keep the external parts on the engine and the floor area around the engines clean and free of oil and fuel spills. In addition, keep working areas free of all tripping hazards. In case of injury, no matter how slight, first aid attention should be applied at once and the incident reported. Personnel should be alert for leaking fuel or exhaust gas. Leaking fuel represents a fire hazard and exhaust gas fumes are noxious. Containers of oil or fuel cannot be permitted to accumulate in the testing area.

8.3. Equip the test installation with a fuel shut-off valve designed to automatically cut off the fuel supply to the engine when the engine is not running. A remote station for cutting off fuel from the test stand is recommended. Suitable interlocks are recommended so that the engine is automatically shut down when any of the following events occur: engine overspeeds, exhaust system fails, room ventilation fails or the fire protection system is activated. Consider an excessive vibration pickup interlock if equipment is operated unattended. Provide fixed fire protection equipment and make dry chemical fire extinguishers available at the test stands.

8.4. Additional safety precautions may also be needed for specific laboratories.

**Precaution**—Many ASTM Tests use chemicals to flush engines between tests. Some of these chemicals require that personnel wear face masks, dust breathers and gloves as exothermic reactions are possible. Provide emergency showers and face rinse facilities when handling materials.

[7] This fuel is obtained from:
Haltermann Products, USA., 1201 South Sheldon Road, P.O. Box 429, Channel View, TX 77530-0429, Telephone: (713) 457-2768, Fax: (713) 457-1469

**TABLE 1 Parts Required for Complete Engine Overhaul**

| Part | Part Number |
|---|---|
| Head[A] | 3896292 (unguided)<br>3896288 (guided) |
| Pistons | 3055622 |
| Piston Ring Set | 3803961 |
| Cylinder Liners | 3080760 (Kit 3803703) |
| Main Bearings | 3801150 (includes thrust bearing) |
| Rod Bearings | 3016760 |
| Crank Thrust Bearing | 3822062 |
| Turbocharger[A] | 352537 (Kit 3803024 includes gaskets) |
| Cam Bearings | 3820566 |
| Cam Thrust Bearing | 3896335 |

The following parts are checked for wear and either replaced or rebuilt as specified in 6.10.4:

| Part | Part Number |
|---|---|
| Crossheads | 3070175 |
| Valve Push Tubes | 3892251 |
| Injector Push Tubes | 3892170 |
| Injector Links | 3028065 |
| Camshaft | 3820013 (CPL 939, CPL 1223)<br>3895801 (CPL 1619, CPL 1623) |
| Valve Cam Followers | 3328671 |
| Injector Cam Followers | 3161476 |
| Water Pump | 3803403 |
| Lube Pump | 3893935 |
| Lube Cooler | 3600880 |

[A] Refer to Section 9.3.1 for rebuild/replacement guidelines.

## 9. Preparation of Apparatus

9.1. *Supplementary Service Information*

9.1.1. *Cummins Service Manual* Engine service information not found in this test procedure may be obtained by referring to the *Cummins Service Manual for L10 Engine* - Bulletin No. 3810476[8]. Other useful information can be found in the Cummins Troubleshooting and Repair Manual for L10 Engines, Bulletin No. 3810246-00[8].

9.1.2. *Cummins PT Fuel System Theory and Operation* A description of all aspects of the fuel system used in this procedure is found in Bulletin 3387213-01R[8] of this name dated 12-85.

9.1.3. *Cummins PT Shop Manual*, Type D Top Stop Injector, Bulletin No. 3810344[8].

9.1.4. *Low Flow Cooling System* Bulletin No. 3387275[8].

9.1.5. *Pretest Maintenance Check List* A recommended list of items which are checked or replaced at the intervals specified is shown in Table 1. (6.10.4)

9.2. *Engine Break-In*

9.2.1. Perform an engine break-in as shown in Table 2 for all new and completely rebuilt engines.

**TABLE 2 Engine Break-In**

| Speed (RPM) | Torque (ft-lbs) | Time |
|---|---|---|
| 1200 | 200 | Until water out reaches 70°C |
| 1300 | 300 | 2 minutes |
| 1600 | 500 | 5 minutes |
| 1200 | Full | 4 minutes |
| 2100 | Full | 4 minutes |

| Speed (RPM) | Power (hp) | Time |
|---|---|---|
| 2100 | 300 hp | 24 hours (minimum) |

9.3. *General Engine Inspection*

9.3.1. Perform a complete engine inspection and overhaul of the top works after 40 non-reference tests (5000 hours). This overhaul includes a new head and new or rebuilt turbocharger. After 80 non-reference tests, perform a complete overhaul including all bearings, camshaft inspection (and replacement as necessary). Install a new or rebuilt turbocharger and new head. Parts required are listed in Table 1 under 6.10.4.

9.3.2. Maintain a complete record of all engine maintenance and measurements. Retain a description of inspection methods along with maintenance records for review by TMC when requested. This is especially important for all inspection and maintenance information concerning fuel system components.

9.4. *Engine Cooling System Cleaning*

9.4.1. Clean the cooling system after each 40 non-reference tests using the following procedure:

9.4.1.1. Drain system; add one gallon of Cummins "Restore" for each 10-15 gallons of system capacity and fill the system with plain water.

9.4.1.2. Run the engine at normal operating temperatures for 60-90 minutes.

9.4.1.3. Drain the system and refill with plain water.

9.4.1.4. Run the engine at normal temperatures for 5 minutes.

9.4.1.5. Drain the system and check cleanliness of the system. Flush again if necessary.

9.4.1.6. Add coolant to the system as specified in 7.4.

9.5. *Instrument Calibration Requirements*

9.5.1. Calibrate all thermocouples, pressure measuring system equipment, and speed sensor prior to each set of calibration runs. These instrumentation calibrations shall be made part of the laboratory record and available for review by the TMC upon request.

9.6. *Fuel System Measurement Requirements*

9.6.1. Prior to installation, fuel injectors must be measured and adjusted as directed in the shop manual listed in 9.1.3 to meet the following:

9.6.1.1. Cup to plunger leakage shall be tested in accordance with section 4-03-01 of Bulletin No. 3810344. If one bubble appears after 10 seconds, or if the time between bubbles is more than 5 seconds, the cup to plunger seat is acceptable.

9.6.1.2. Barrel to plunger leakage shall not exceed 2.5 units (at 60 psi) when tested in accordance with section 4-03-02 of Bulletin No. 3810344.

9.6.1.3. Check ball leakage shall not exceed 8.5 units (at 60 psi) when tested in accordance with section 4-03-03 of Bulletin No. 3810344.

9.6.1.4. *Top Stop Plunger Travel* Use top stop setting fixture, Part Number 3822696, to adjust top stop plunger travel in accordance with section 4-04 of Bulletin No. 3810344. Top Stop shall be set to 0.1978 in. to 0.1982 in.

9.6.1.5. *Flow Testing* Use injector test stand, Part Number 3375317, to check the injector flow in accordance with section 4-05 of Bulletin No. 3810344. Pre-test injector flow shall be 138.5 to 140.5 $mm^3$/stroke. Replacement of the orifice plug may be required to meet this requirement. Use 0.021 in. orifice plug, Part Number 3044996, or 0.022 in. orifice plug, Part Number 3044997.

9.7. *Injector Installation* For the following procedure, see sequences (a) through (l) illustrated in A1.18.

9.7.1. Lightly lubricate injector "O" rings with engine test oil and install injector into the injector bore with the fuel inlet hole toward the exhaust manifold.

[8] These bulletins can be obtained from any Cummins distributor or dealership or by contacting 1-800-DIESELS (1-800-343-7357).

9.7.2. Use a blunt instrument to seat the injector. Insure the instrument contacts the injector body and not the plunger.

9.7.3. A "snap" will be heard and felt as the injector is seated. If the injector does not seat, remove and inspect "O" rings for damage. Replace damaged "O" rings.

9.7.4. Install injector hold-down clamps with bolts and tighten alternately and evenly in the following steps:

| Step | In.-lb$_f$ |
|---|---|
| 1 | 45 |
| 2 | 90 |
| 3 | 130 |

9.7.5. Install injector plunger links into each injector and inspect for free movement. Raise link approximately 1/3 of its length and then let it fall into the injector.

9.7.6. Lube all valve stems with engine test oil and install valve bridges.

9.7.7. Lube the tops of all valve bridges and injector links with engine test oil.

9.7.8. Install push rods.

**Caution**—Injector push rods are longer than valve push rods.

9.7.9. Injectors and valve adjustments must be made when the engine coolant out temperature is less than or equal to 60ºC (140ºF). Inspect push rods when rotating crankshaft. Insure that the push rods are in the sockets of the camshaft followers and that rocker lever adjusting screws are not over tightened enough to cause engine damage. Rotate the engine by the flywheel.

**Caution**— Tandem engines must be rotated by the flywheel to prevent breakage of the accessory drive.

The adjustment can begin on any valve set mark. In this example the adjustment begins on the "A" valve set mark with cylinder number five valves closed and cylinder number three ready for adjustment. See the set of sequence pictures in A1.18 sequence (a)-(l) while proceeding with the following procedure.

9.7.9.1. Rotate the crankshaft clockwise to align the "A" mark on the accessory drive pulley with the pointer on the gear cover. A1.18 sequence (d) illustrates this step.

9.7.9.2. Check the valve rocker levers on cylinder number five to see if both valves are closed. Both valves are closed when both rocker levers are loose and can be moved from side to side. If both valves are not closed, rotate the accessory drive one complete revolution, and align the "A" mark with the pointer again.

9.7.9.3. Check the valve rocker levers on cylinder #5 to see that both valves are closed.

9.7.9.4. Refer to the injector adjustment sequence chart and adjust #3 injector and intake and exhaust valve on #5 cylinder. See A1.18 sequences (b) and (e).

9.7.9.5. Loosen the lock nut on the injector adjusting screw on cylinder #3. Tighten the adjusting screw until all of the clearance is removed from the injector train. Tighten the adjusting screw one additional turn to correctly seat the link. See A1.18 sequence (f).

9.7.9.6. Loosen the injector adjusting screw until the injector spring retainer touches the top stop screw. See A1.18 sequence (g).

9.7.9.7. Tighten adjusting screw until injector plunger just bottoms in the injector cup to insure injector travel. Back off and set with no pre-load and zero lash. See A1.18 sequence (h).

**Caution**—An overtightened setting on the injector adjusting screw will produce increased stress on the injector train and the camshaft injector lobe which can result in engine damage.

9.7.9.8. Hold the adjusting screw in this position. The adjusting screw must not turn when the lock nut is tightened. See A1.18 sequence (i).

Torque Value:
without torque wrench adapter 60 N m (45 ft-lb)
with torque wrench adapter (ST-669) 45 N m (35 ft-lb)

9.7.9.9. After adjusting the valves on cylinder #5, rotate the engine (by using the flywheel ) and align the next valve set mark on the accessory drive pulley with the pointer on the gear cover. See A1.18 sequence (k). Adjust the appropriate injector and valves following the Injector and Valve Adjustment Sequence Chart per A1.18 sequence (l).

9.7.9.10. After all injectors and valves have been adjusted, remeasure all valve clearances to compensate for any camshaft or rocker lever deflection that may have occurred. Record data on Head Setting sheet found in Annex A4.1.

9.7.9.11. Recheck all injector travel measurements with injector travel kit #3823610. This process should be done while following the injector adjustment sequence chart.

9.7.9.12. Assemble the dial indicator and related hardware to measure injector travel (from the injector travel measurement kit #3823610).

9.7.9.13. Bolt the dial indicator fixture to the rocker lever housing with the tip of the indicator resting on the top of the plunger.

9.7.9.14. Zero the dial indicator and confirm that the zero is correct.

9.7.9.15. Using the rocker lever adapter in kit #3823610 and a 1/2 in. breaker bar with 3/4 in. socket, move the rocker lever/injector plunger down and record data on Head Settings sheet found in A4.1. Injector plunger travel shall be 0.198 in. ±0.002.

9.7.9.16. Measure 7 gallons TMC-5000[3] and pour oil over valve train to fill crankcase Fill oil filter with additional oil and install.

9.7.9.17. Install valve cover.

9.8. *Oil Filters*

9.8.1. Use standard spin-on full flow LF3000 oil filters (Part Number 3318853; one per engine) and discard after each test.

9.9. *Engine Lubrication*

9.9.1. Fill the sump as in 9.7.9.16 with 7 gallons TMC-5000[3]. Use additional oil to charge filter as in 9.7.9.16.

9.9.2. Insure proper oil level during the test. Record all oil additions. Take an oil sample from the engine gallery at the end of each test and store for future reference. The sample may be discarded after one year.

9.9.3. Allow engine to cool; check oil level with dipstick; add oil as necessary to bring to the full mark, and record data.

9.10. *Test Fuel*

9.10.1. *Base Fuel* Use Haltermann Products 0.4% sulfur base fuel (used for Caterpillar 1K engine testing) as the base fuel for all calibration tests. (See footnote 7) Specifications for this fuel are included in Appendix A2.0. Approximately 1135 liters (300 gallons) are required to complete a test.

9.10.2. *Additized Reference Fuel*—Use Haltermann Products base fuel in 9.10.1 with 0.200 mL CRA-1[3] fuel additive per 1 liter base fuel for additized reference tests. Premix the additive in approximately 7 liters (2 gal) base fuel. Add this mixture to the base fuel and mix with the test quantity at least two complete turnovers. Take a fuel sample at the end of test and store for future reference. The sample may be discarded after one year.

9.10.3. *Non-Reference Tests* Use fuel as specified by the test sponsor.

9.11. *Pre-Test Fuel Flush*

9.11.1. Prior to the start of each test, flush the fuel system, including the engine and supply, to remove any residual fuel additive left in the system from the prior test. Flush the fuel supply pump and day tank as well. To flush engine, adjust injector screws carefully downward to bottom the injector plunger in the cup. This prevents fuel from entering the cylinder during the flush. Connect a fuel hose to the inlet side of the fuel pump. Override the fuel pump solenoid. Pump the fuel through the fuel pump, through the fuel drilling in the cylinder head, and out the engine fuel return line to the day tank. Drain the fuel from the day tank and clean or flush the tank with test fuel. Replace fuel filters (FF105) at this time as well as the fuel pump filters (Cummins Part Number 146483).

**Caution**—barring the engine at this time will damage the injectors.

9.12. *Throttle Leakage* Prior to test, set fuel pump throttle leakage at 100 ± 5 cc/min at the completion of the Warm-Up Throttle Schedule (Table 3). Refer to Figure A1.19 for a diagram illustrating throttle leakage. Record throttle leakage at the end of test or within last 24 hours of testing. It should be within 80-120 cc/min.

9.12.1. The engine should be driven at 2300 r/min and fuel temperature should be maintained while measuring throttle leakage.

9.12.2. Open the petcock at the fuel outlet from the head. Close the manual valve in this same line.

**Caution**—The order in which these valves are closed is very important. Failure to close/open them in the correct order may cause a blown rail pressure transducer and/or cause fuel backup in the head.

9.12.3. Place a container under the petcock and catch all fuel coming from the petcock for one minute.

9.12.4. Open the manual valve in the fuel return line, then close the petcock.

**Caution**—the order here is very important to prevent damage to the rail transducers and the engine.

9.12.5. Use a graduated cylinder to measure the amount of fuel collected in a one-minute period; record. Throttle leakage should be 95-105 ml. If not within this range, make the following adjustments:

9.12.5.1. Maintain engine speed and fuel temperature.

9.12.5.2. Drive the engine with throttle closed at 2300 RPM.

9.12.5.3. If throttle leakage is excessive, loosen the locknut and back the rear throttle stop screw out (towards the rear of the engine).

9.12.5.4. If throttle leakage is insufficient, adjust the throttle stop screw in (towards the front of the engine).

9.12.5.5. Tighten the locknut on the throttle stop screw after completing the adjustments.

## 10. Procedure

10.1. Overview

10.1.1. Two Cummins L10 engines are connected in series, front to rear with the first engine's driveshaft connected to the second engine's flywheel adapter (A1.1). Achieve throttle position by actuators controlled by a programmable cycle. Simultaneously cycle the throttle levers within one second between closed throttle motoring and full throttle fueling every 15 seconds for a total of 125 hours. While one engine is powering at approximately 55-65 HP, the other is closed throttle motoring.

10.1.2. Control engine speed at 2300 r/min by modifying the high idle governor on the fuel pumps. Initial adjustments are made on the Cummins fuel pump calibration stand, with minor adjustments made on the engines, as required, to maintain 2300 RPM. There should be only a slight increase in RPM (approximately 50 RPM for one second) when the engines cycle from motoring to power. Fuel rail pressure shall return to a steady pressure within 3 seconds maximum after cycle change.

**Note 1**: With this tandem engine set-up, no load control is possible - each engine provides load for the other through inherent friction HP.

10.1.2.1. Record engine speed and fuel rail pressure on both engines to verify that the cycle is performing properly.

10.2. *Engine Warm-up and Shut-down*

10.2.1. Start both engines with an auxiliary starting system. Idle the engines to ensure oil pressure and water presence. Begin manual cycling of the engines. One engine throttle is actuated for a set period of time, and then

**TABLE 3 WARM-UP THROTTLE SCHEDULE**

| Switch Throttles Every: | Until Oil Sump Temperatures Reach: |
|---|---|
| Idle until | 30°C (86°F) |
| 2 sec. Until | 50°C (120°F) |
| 5 sec. Until | 65°C (150°F) |
| 10 sec. Until | 77°C (170°F) |
| 15 sec. Until | 104°C (220°F) |
| Perform Throttle Leakage Adjustment (at beginning of test only) | |
| Start test clock when temperatures are in specification | Temperatures must be within specification within one hour. |

**TABLE 4 Test Operating Conditions**

| Parameter | Specified Operating Range |
|---|---|
| Engine Speed, r/min | 2300 ±15 |
| Temperature, coolant out, °C (°F) | 88 ± 3 (190 ± 5) |
| Temperature, coolant in, °C (oF) | 54 ± 3 (130 ± 5) |
| Temperature, fuel, °C (oF) | 40 ± 2 (104 ± 4) |
| Temperature, inlet air, °C (°F) | 30 ± 3 (86 ± 5) |
| Temperature, oil sump, °C (°F) | Record |
| Temperature, aftercooler | |
| Driving, °C (°F) | Record |
| Driven, °C (°F) | Record |
| Engine load, BHP (tandem engines) | 55-65 (not measured) |
| Inlet air restriction, kPa (in. $H_2O$), maximum | 2.0 (8.0) |
| Exhaust back pressure, kPa (in. $H_2O$) | 0.3-1.7 (1.3-6.7) |

| Parameter | Typical Operating Range |
|---|---|
| Pressure, oil gallery, kPa (psi), minimum | 206 (30) |
| Pressure, block water, kPa (psi), minimum | 206 (30) |
| Pressure, fuel rail | |
| Driving, kPa (psi) | 172-240 (25-35) |
| Driven, kPa (psi) | 0-27 (0-4) |
| Pressure, intake manifold | |
| Driving, kPa (in Hg) | 30-40 (9-12) |
| Driven, kPa (in Hg) | 15-25 (4-7) |
| Crankcase pressure, kPa (in. $H_2O$) | 0-1.2 (0-5) |
| Oil consumption, g (lbs.) | Record |

**Note 2:** Controlled parameters should be targeted for the middle of the specification range. Candidate and Reference tests must be controlled to the same point.

closed. This is repeated with the other engine. Switch the throttles according to the schedule in Table 3.

10.2.2. For shut-down, bring engine to idle for a minimum of one minute and then shut down.

10.3. *Operating Conditions*

10.3.1. During this test, target all controlled parameters to the middle of the specification range. Run the engine continuously for 125 hours at the conditions shown in Table 4.

**11. Inspections**

11.1. *Valve Train and Injector Travel* At the conclusion of the test measure and record injector travel and intake and exhaust valve lash. Excessive variations from the start of test measurements may signal an engine or injector problem. (Refer to the Cummins Service Manual).

11.2. *Injector Removal - End of Test (EOT)*

11.2.1. Remove valve cover and related hardware

11.2.2. Complete EOT injector travel and valve clearance measurements and log on the Head Settings Form A4.1 or equivalent. Measurements shall be made when coolant out temperature is less than or equal to 60ºC (140ºF).

11.2.3. Loosen locknuts on exhaust and injector rocker arms and back off all valve and injector screw adjusters.

11.2.4. Remove all exhaust and injector push rods; maintain the order in which they are removed. The engine may need to be rotated in order to remove some push rods.

11.2.5. Flip rocker arms up allowing access to valve bridges and injector links.

11.2.6. Remove crossheads and injector links; maintain the order in which they are removed.

11.2.7. Remove injector hold-downs: maintain the order in which they are removed.

11.2.8. Use injector removal tool CJ125A and remove all injectors.

11.2.9. Before reflowing injectors, drain oil from upper cavity of injectors.

11.3. Determine post-test injector flow as described in 9.6.1.5. Post-test injector flow shall be compared to pre-test flow for determination of injector flow loss.

11.4. *Feed Port Depositing* If an injector has a flow loss of 10% or greater, feed port depositing has occurred. Feed port deposits in more than one cylinder result in a failed test. If one injector has a plugged feed port, that injector is not used in rating average calculations for flow loss, but is used in deposit rating calculations.

11.5. *Injector Deposit Ratings* Carefully remove plungers from injector bodies so as not to disturb deposits. If the plunger does not easily fall out of the injector, lightly tap the body on a wooden surface. A plunger removal tool 3375397 is available for difficult-to-remove plungers.

**Note 3**: Only raters who have successfully completed the L10 injector deposit rating workshops are qualified to rate this test.

11.5.1. Perform ratings using a cool-white circular 22 watt fluorescent tube and a 5 inch diameter 3-diopter magnifier lens. Use the same rating booth style described in CRC Manual 18[9].

11.5.2. The area of the L10 injector plunger that is rated is directly above where the plunger tapers down to the tip. Only the flat area is rated (A.3.1).

11.5.3. Clean the injector by gently dabbing the area to be rated with a soft cloth or tissue, being careful not to rub off deposits.

11.5.4. With a pencil, draw two thin lines along the axis of the injector plunger 180$^{o}$ from each other to divide the plunger into an A and B side. Rate the area marked upper and lower in A.3.1.

11.5.5. Start with side A upper section and consider this 100% of one area. Referring to the definitions listed in Section 3.1, determine the percentage of this area that is covered with carbon, if any, and record this percentage. (use the rating worksheet in A3.2 or equivalent)

11.5.6. Rate the remaining area (not covered by carbon) utilizing the CRC Rust/Varnish/Lacquer Rating Scale[10].

11.5.7. Repeat the carbon and lacquer rating for the remaining three areas (Lower A, and Upper and Lower B).

11.5.8. *Sample Calculations*:

Accomplish all carbon and lacquer/varnish rating computations using the following formulae:

Carbon Rating = Area of Carbon Deposit (%) X Deposit Factor

Lacquer Rating = Area of Lacquer Deposit (%) X (10.0 - merit rating)/100

*Example 1:* 15% Heavy Carbon
15 X 1.0 = 15.00 demerits

*Example 2:* 15% Light Carbon
15 X 0.25 = 3.75 demerits

*Example 3:* 15% of #8.5 lacquer
15 X (10 - 8.5)/100 = 0.22 demerits

*Example 4:* 15% of #6 lacquer
15 X (10-6)/100 = 0.60 demerits

Because each of the four areas rated add up to 100%, it is necessary to divide the total of the four areas by 4 to get the final rating for the plunger. Use the rating worksheet in A3.2 or equivalent. Use ASTM E-29 rounding off method for all values.

11.5.9. An individual injector deposit rating may be eliminated from the results if it is statistically shown to be an outlier as per ASTM E178 *Standard Practice for*

[9] Available from:
Coordinating Research Council, Inc., 3650 Mansell Rd., Suite 140, Alpharetta, Georgia 30022, Telephone: (678) 795-0506, Fax: (678) 795-0509.

*Dealing with Outlying Observations*. Specifically, refer to E178-94, 4.1, 4.2, and Table 1 at the 5% level of significance.

11.5.10. Photograph both sides of the plungers, 180º apart; i.e. Side A and Side B (as detailed in 11.5.4) should be photographed. Side A of all six plungers may be photographed in one shot, and Side B of all six plungers may be photographed in one shot.

11.6. *Test Validity* To be considered operationally valid, a test must meet the following conditions:

11.6.1. Conform to the test procedure and any approved revisions by the L10 Injector Depositing Test Surveillance Task Force. The test stand must conform to all of the latest revisions listed in the Procedure and those outlined in Information Letters from the TMC.

11.6.2. The average of the hourly readings of all controlled parameters must be in specification.

11.6.3. All hourly outliers of controlled parameters are to be reported.

11.6.4. All down time is to be reported. In no case is total downtime to exceed 72 hours.

11.6.5. Injector changes must meet injector change-out protocol as follows:

11.6.5.1. *Up to 25 Hours* The first twenty five test hours will be used to break in all injectors and verify that they are functioning properly.

a. Injectors may be replaced due to high flow losses or mechanical injector problems up to twenty-five test hours.

b. High flow loss injectors or mechanical problems are detected by experiencing a drop in exhaust port temperatures along with an increase in rail pressure.

c. Ratings or flow losses are not required on injectors removed during the first twenty-five test hours. Do not use the injector flow loss nor plunger rating of removed injectors in the end of test averages.

d. Flow loss measurements and CRC ratings of plungers for injectors replacing those removed during the first 25 hours are used to calculate the end of test flow loss and plunger rating averages.

11.6.5.2. *After 25 Hours*

a. A maximum of one injector may be replaced after 25 hours if the engine cannot be controlled within the test specification due to high flow loss or mechanical problems. If more than one injector must be replaced after 25 hours, the test is a failure.

b. The flow loss and CRC rating from the removed injector, as well as the replacement injector that was installed, are not used to calculate the flow loss and rating averages.

c. If the cause for the injector removal is due to a mechanical problem (injector plunger not seating in injector cup properly, injector breakage), one additional injector is allowed to have a flow loss in excess of 10%. Per the test criteria, the flow loss and CRC rating data from that additional replacement injector data is not used in the end of test averages, thus leaving four injectors for the average calculations.

d. If no mechanical problems are noted with the removed injector, no additional injector is allowed to have a flow loss in excess of 10%. If one additional injector has a flow loss in excess of 10% the test is a failure.

11.6.5.3. *Mechanical injector problem at end of test*

a. If a mechanical problem (injector plunger not seating in injector cup properly, injector breakage) is noted on one injector, that injector is not used in calculating the flow loss and rating averages. To calculate end-of-test flow and rating averages, one additional injector is allowed to have a flow loss in excess of 10%. Per the test criteria, that additional injector data is not used in the end of test averages, thus leaving four injectors for the average calculations.

b. If more than one injector has a mechanical problem at the end of test, the test is a failure.

## 12. Calibration of Test Method

12.1. Calibrate (reference) the engine prior to running non-reference fuel tests according to the following requirements:

12.1.1. *New Stand Acceptance* (applies to each engine)

12.1.1.1. Two acceptable reference fuel test sets are required for a total of 4 acceptable reference tests. A set is one base reference fuel test and one test with reference fuel plus reference additive.

12.1.2. *Existing Stand Reference Frequency*

12.1.2.1. Reference a previously accepted engine after 20 non-reference tests or one year, whichever occurs first, and after an engine overhaul. One set (base reference fuel and base fuel plus additive) of acceptable reference fuel tests is required.

12.1.2.2. A new or rebuilt engine is considered an existing stand. An engine top-end overhaul is required after 40 non-reference tests (5,000 hours) and a complete overhaul after 80 non-reference tests (10,000 hours).

12.1.2.3. Special Circumstances—Any laboratory that does not run a reference test within two years from the completion of the last acceptable calibration sequence is considered a new laboratory. The TMC may schedule more frequent reference (calibration) tests (or approve less frequent reference tests) at its discretion. Under special circumstances (i.e. extended downtime due to industry-wide parts or fuel outages) the TMC may extend reference periods. Non-reference tests conducted during the extended time allowance shall be annotated in the test note section of the report.

12.2. *Reference Fuel* - The two reference fuels are described in 9.10.1 and 9.10.2. The fuels have been

chosen to represent specific performance levels. The fuel additive is available from the TMC.

12.3. *Specified Test Parameters* The specified test parameters for determination of test acceptance are:

12.3.1. Deposit level, CRC rating.

12.3.2. Feed Port Depositing

12.3.3. Injector Flow Loss

12.4. *Acceptance of Calibration Tests* Refer to the Test Monitoring Center's Test Monitoring System for calibration test targets and acceptance criteria.

12.5. *Failing Reference Fuel Calibration Tests* Failure of a calibration test to meet test acceptance bands can indicate a testing stand problem, testing laboratory problem, or industry-wide problem, or it can be a false alarm. When this occurs, the laboratory, in conjunction with the TMC, shall attempt to determine the problem source.

12.6. *Test Reporting* Use the report forms and data dictionary available from the ASTM Test Monitoring Center. These can be downloaded from the ASTM Test Monitoring Web page at http://tmc.astm.cmri.cmu.edu/ or they can be obtained in hardcopy format from the TMC[3]

12.6.1. Flow rates before and after test and flow losses shall be reported on Form 6, to one decimal place. Average flow rate is calculated to one decimal place. Use ASTM E-29 rounding off method for all values.

12.6.2. Report injector plunger deposit rating details on Form 7. Individual ratings are to be calculated to two decimal places and the average, reported on Forms 4 and 6, to one decimal place. Use ASTM E-29 rounding off method for all values.

12.6.3. Summarize engine operations on Form 5. Data logging frequency shall be a minimum of once per hour. Report downtime and operational outliers on Form 8.

12.6.4. Provide photos of each plunger, showing two sides 180º opposite.

12.7 *Electronic Transmission of Test Results* Electronic transfer of the test report can be done utilizing the ASTM Data Communications Committee Test Report Transmission Model (see Section 2 - Flat File Transmission Format), available from the TMC[3].

## 13. Precision and Bias

13.1 *Precision*

13.1.1. Test precision is established on the basis of operationally valid reference test results monitored by the TMC. This data, developed prior to establishment of this method, is available from the TMC.

13.1.1.1. Intermediate Precision (r) is the difference between two test results obtained by a laboratory using the same test method and the same fuel additive. For this test method, intermediate precision can be expected to exceed the values in Table 5 in one case in twenty.

13.1.1.2. Reproducibility (R) is the difference between two test results obtained by different laboratories, within a short time period, using the same test method and the same fuel additive. For this test method, reproducibility can be expected to exceed the values shown in Table 5 in one case in twenty.

13.1.2. Test precision, as of December 1, 1999, is shown in Table 5.

13.1.3. The TMC will update precision data as it becomes available.

13.2. *Bias*

13.2.1. As of December 1, 1999, no determination of bias is available.

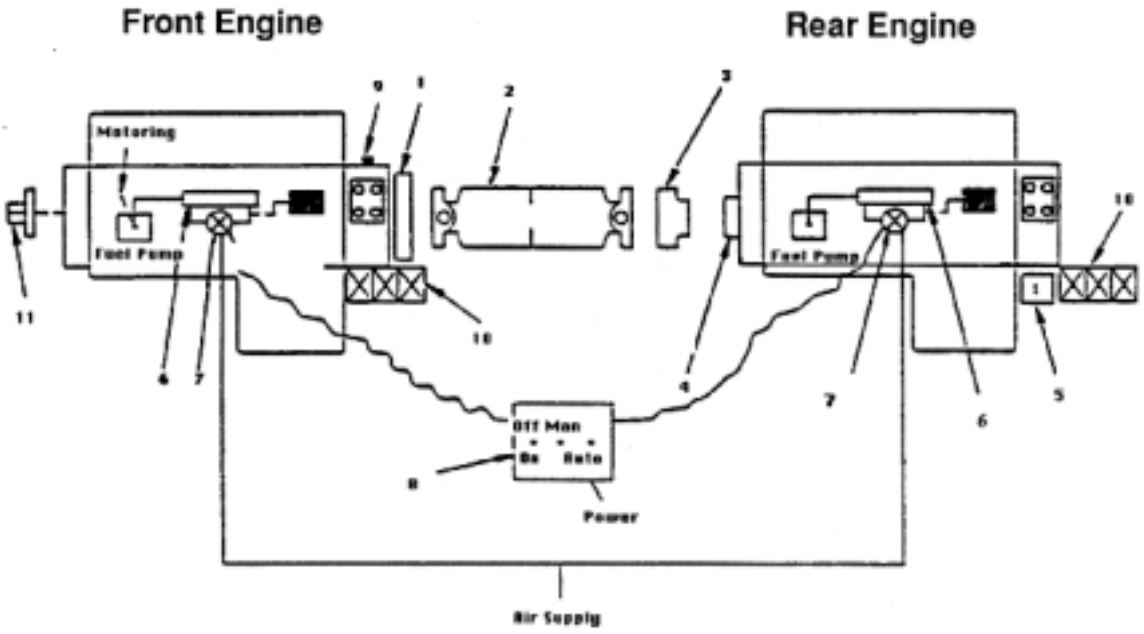
**Table 5 Test Precision**

| | Measured Units | |
|---|---|---|
| Test Result | Intermediate Precision, (r) | Reproducibility (R) |
| Injector Deposits, demerits | 7.5 | 7.3 |

## 14. Key Words

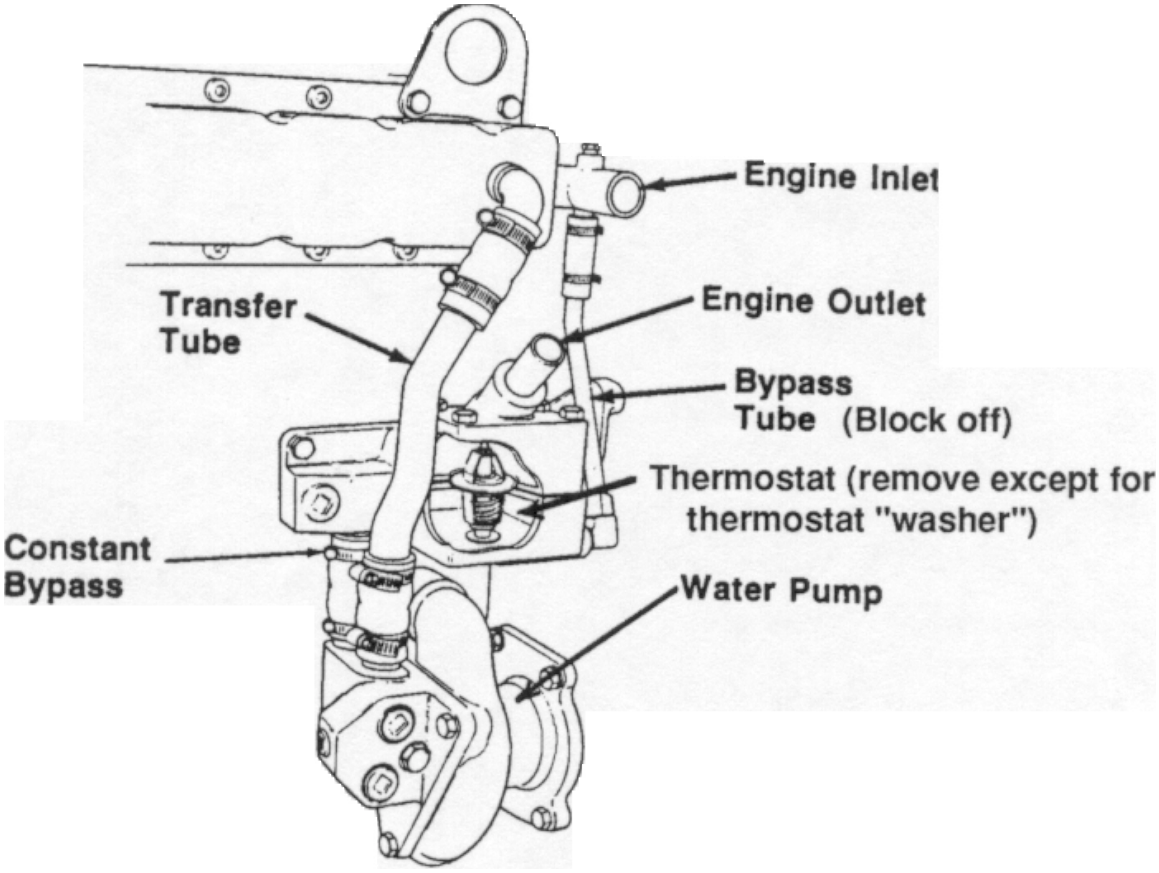
14.1 detergency; diesel engine; diesel fuel; flow loss; fuel additive; fuel injector; injector deposits; L10.

## A1.1 SCHEMATIC TANDEM ENGINE SET-UP



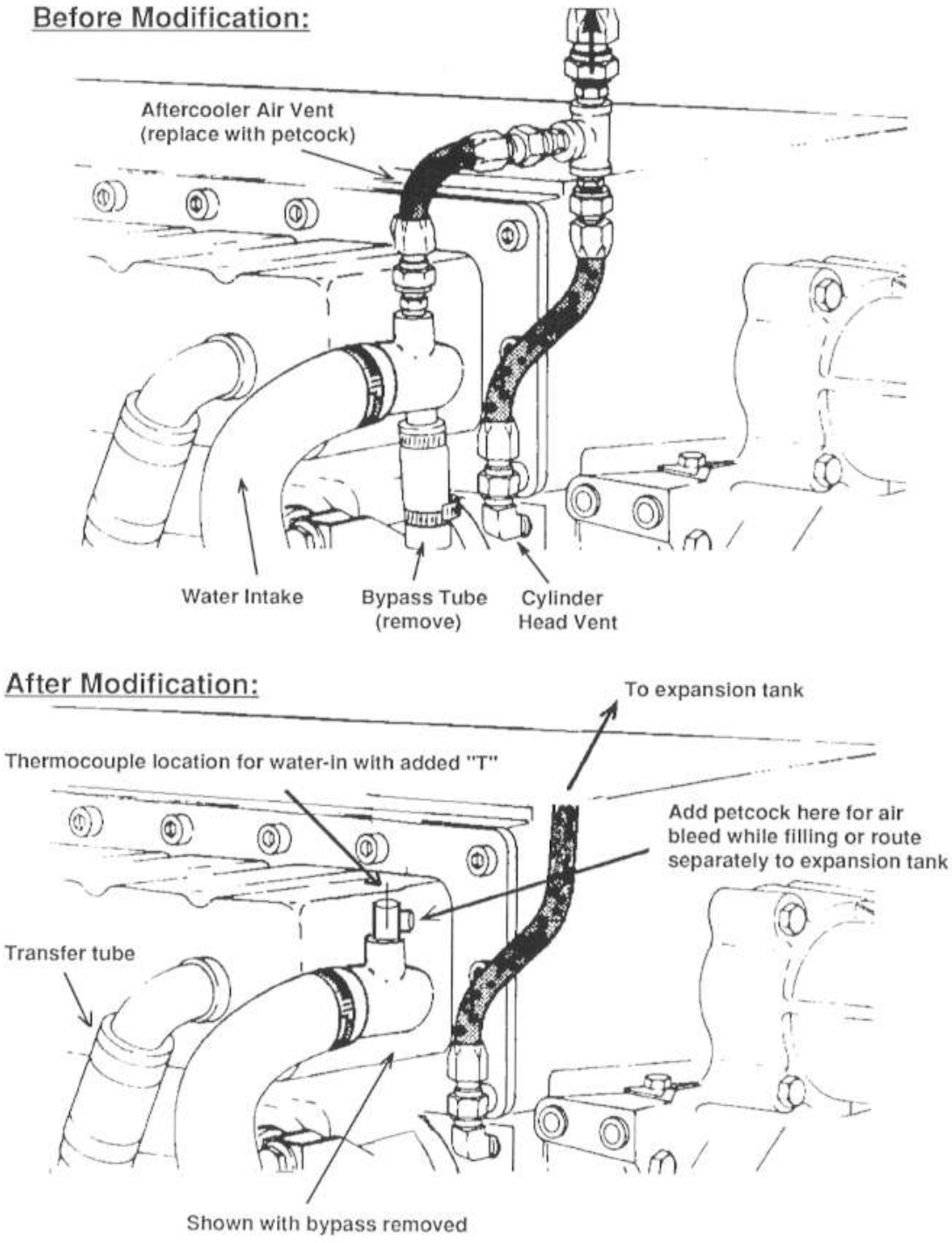

1. Flywheel to driveshaft adapter
2. Driveshaft
3. Driveshaft to crankshaft adapter
4. Crankshaft adapter
5. Engine speed sensor
6. Pneumatic air cylinder (2-way)
7. Solenoid
8. Cycle box 15 second/15 second
9. Optional: Accelerometer - safety engine shutdown
10. Air starters
11. Adapter to bar engines over - off of crankshaft

## A1.2 LOW FLOW COOLING SYSTEM MODIFICATIONS
## (Air Bleed Not Shown)

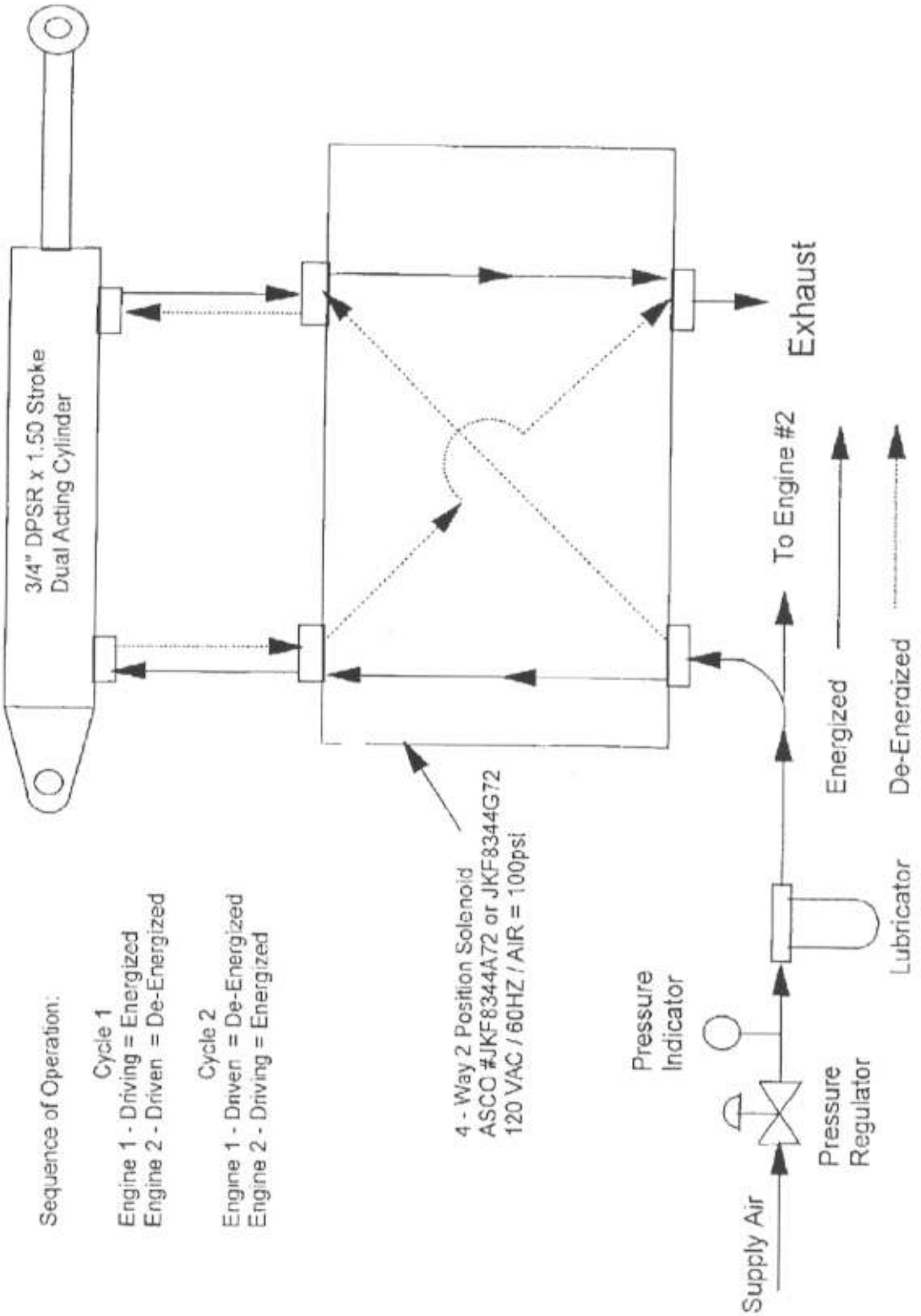



**Note: See A1.3 for air bleed modifications**

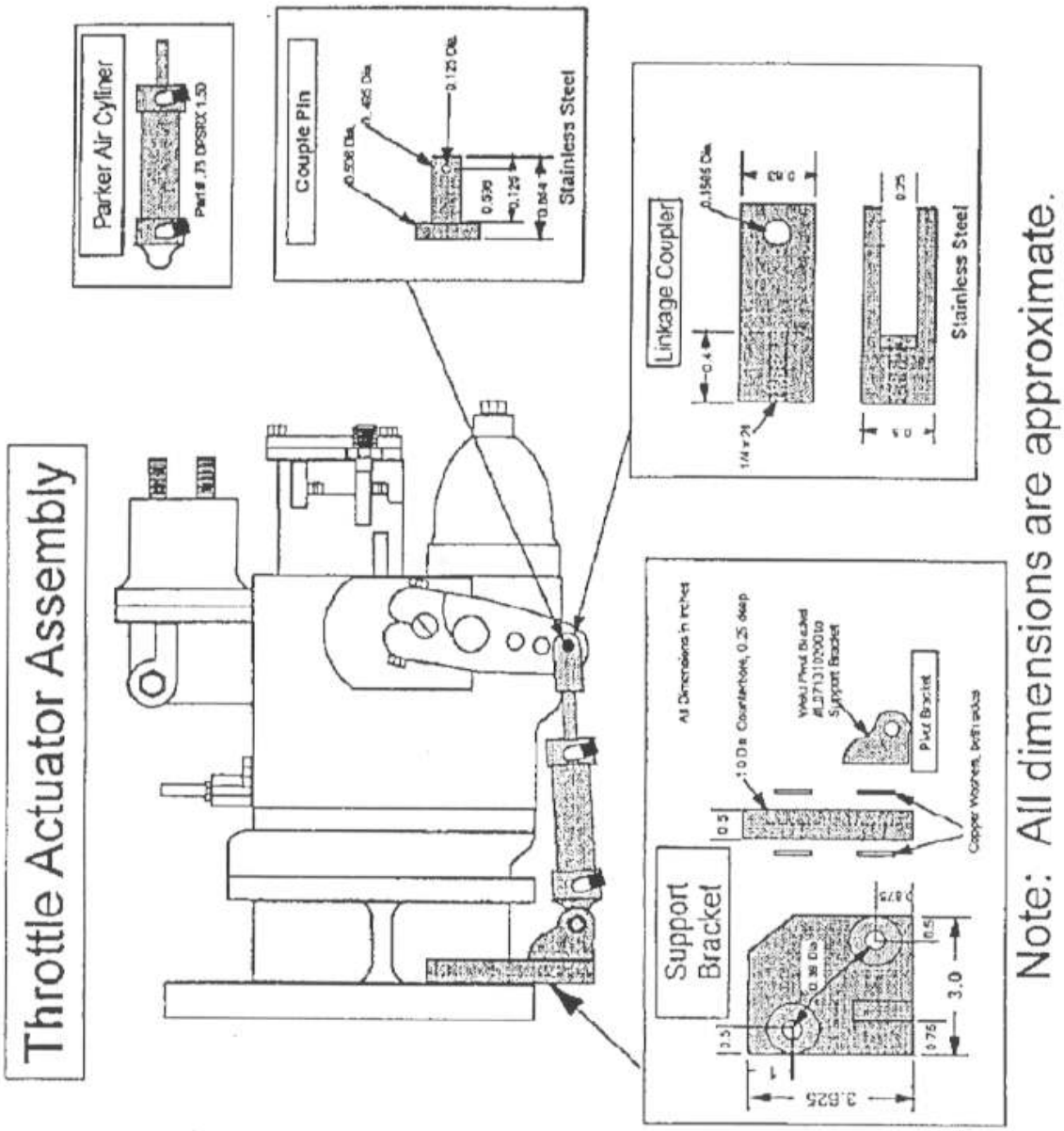
## A1.3 AIR BLEED ARRANGEMENT



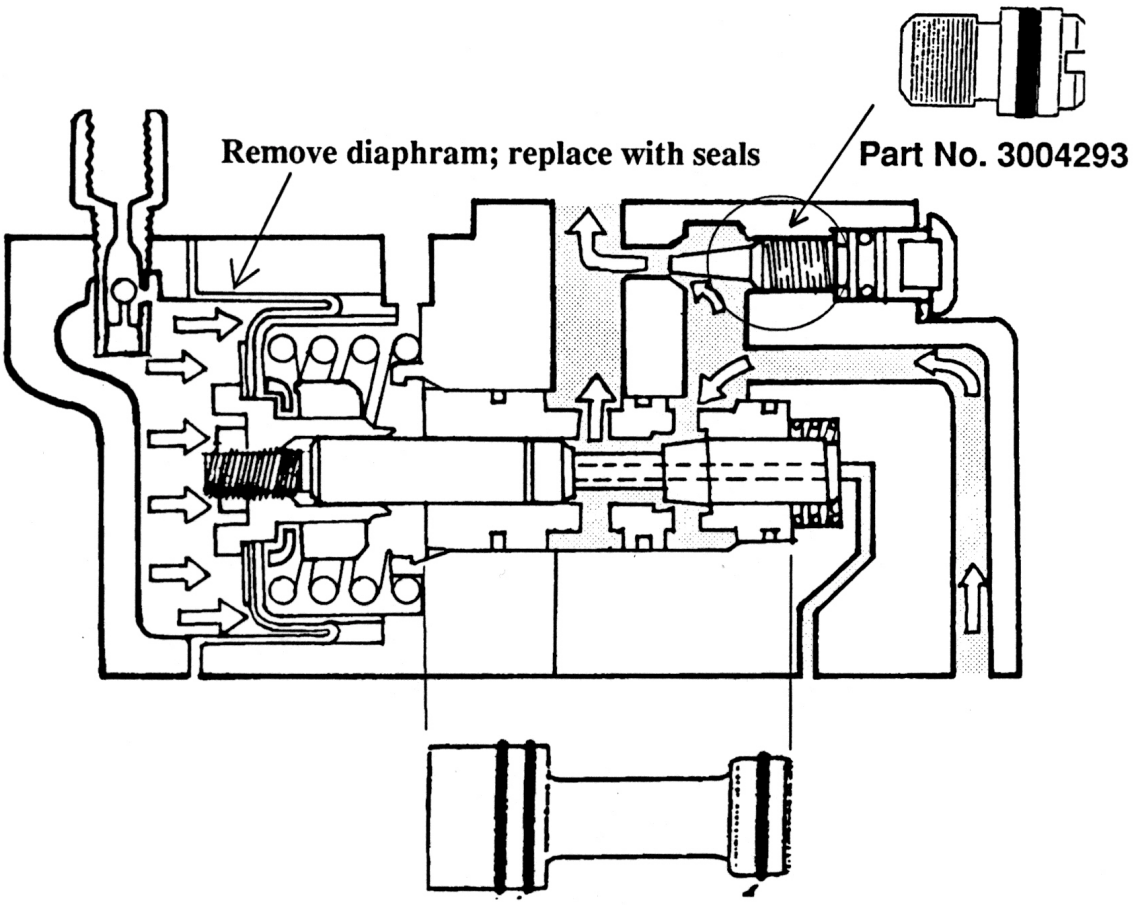
## A1.4 THROTTLE CONTROL SYSTEM



## A1.5 THROTTLE ACTUATOR

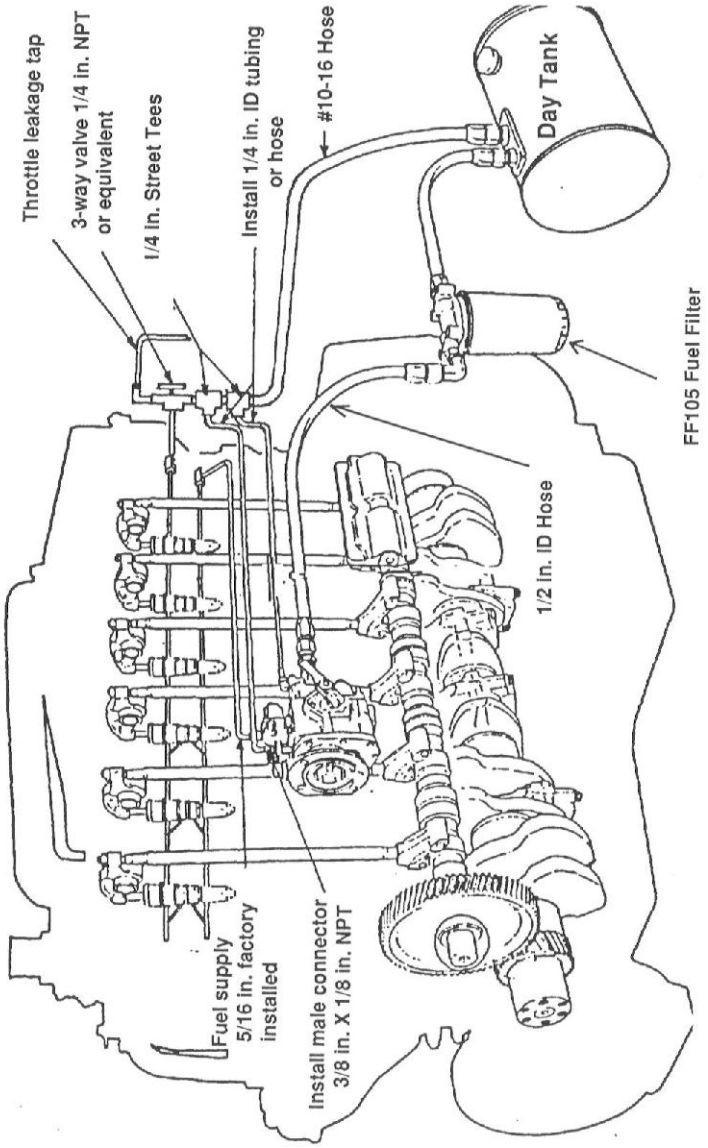


## A1.6 PT FUEL PUMP BARREL PLUGS FOR AFC CAVITY (TO ELIMINATE AF CONTROL)

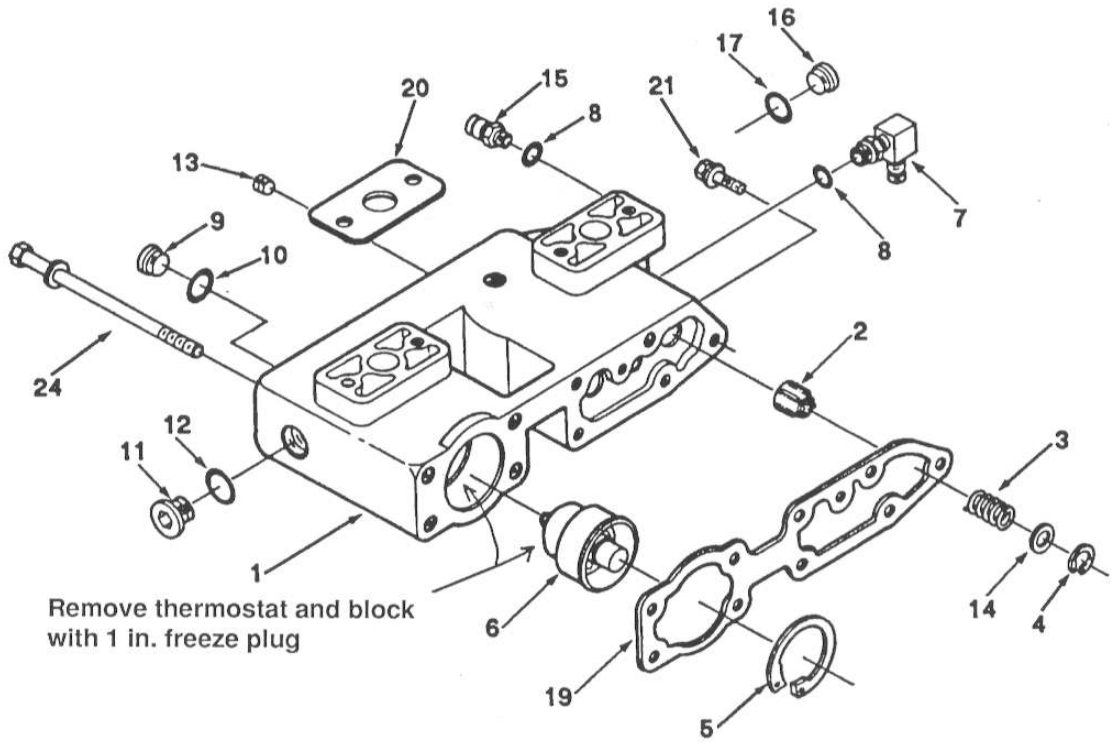



Part No. 3028347 (Note that the replacement has two "O" rings on one side; the original only one.)

## A1.7 FUEL SYSTEM ARRANGEMENT WITH LEAKAGE MEASUREMENT MODIFICATIONS



## A1.8 FILTER HEAD OPTION: SINGLE FILTER WITH THERMOSTAT BLOCKED

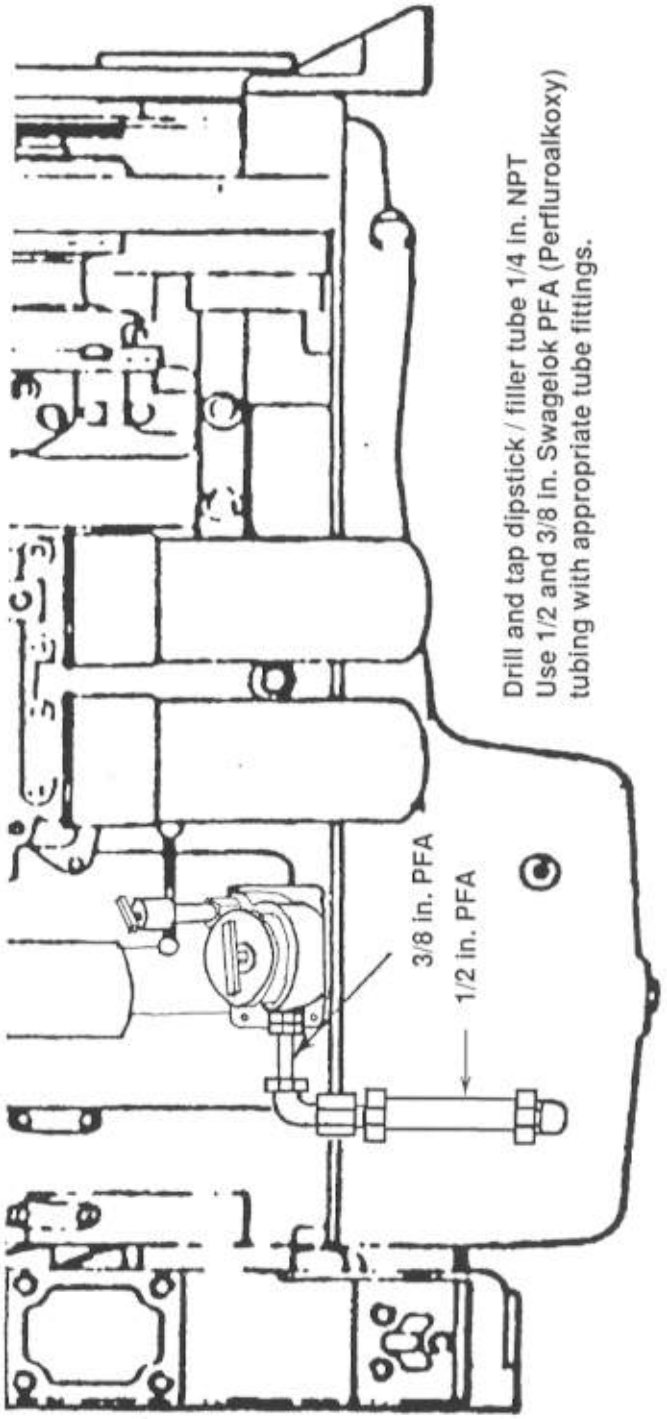



**Note: See A1.9 for part numbers**

## A1.9 PART NUMBERS FOR FILTER HEAD OPTION SHOWN IN A1.9

| Ref No. | Part Number | Part Name | Req. | Remarks |
|---|---|---|---|---|
| | | LUBRICATING OIL COOLER OPTION LC2706 | | This is a combination oil cooler filter head option with an oil thermostat and a filter head designed for use with the full flow/ bypass combo oil filter element mounted direct. For use on engines less engine brake or with customer supplied engine brake. The lube oil cooler is a two pass engine coolant design |
| 1 | 3895147 | Head, Lube Oil Filter | 1 | |
| 2 | 3820320 | Plunger, Bypass Valve | 1 | |
| 3 | 3882586 | Spring, Compression | 1 | |
| 4 | 3820631 | Ring, Retaining | 1 | |
| 5 | 3820782 | Ring, Retaining | 1 | |
| 6 | 3059408 | Thermostat | 1 | |
| 7 | 3819616 | Nipple, Coupling | 1 | 9/16 – 18 inch |
| 8 | 3037537 | Seal, O Ring | 1 | |
| | 3046202 | Plug, Threaded | 1 | |
| 9 | (3040810) | Plug, Threaded | 1 | ¾ - 16 inch |
| 10 | 3046201 | Seal, O Ring | 1 | |
| | 3040815 | Plug, Threaded | 1 | |
| 11 | (3040816) | Plug, Threaded | 1 | 7/8 – 14 inch |
| 12 | 3040817 | Seal, O Ring | 1 | |
| 13 | 3008466 | Plug, Pipe | 1 | ¼ NPT |
| 14 | 3882585 | Plug, Expansion | 1 | 7/8 inch |
| 15 | 3042619 | Nipple, Coupling | 1 | |
| 8 | 3037537 | Seal, O Ring | 1 | |
| | 3202101 | Plug, Threaded | 1 | 1 1/16 –12 |
| 16 | (3050897) | Plug, Threaded | 1 | ¾ - 16 inch |
| 17 | 3046943 | Seal, O Ring | 1 | |
| 18 | 3883394 | Screw, Hexagon Head Cap | 2 | M10 x 1.50 x 30 |
| 19 | 3820629 | Gasket, Filter Head | 1 | |
| 20 | 3892625 | Gasket, Oil Cooler Supply | 2 | |
| 21 | 3819448 | Screw, Captive Washer Cap | 3 | M10 x 1.50 x 30 |
| 22 | 3081359 | Cooler, Lubricating Oil | 1 | |
| 23 | 3034836 | Screw, Hexagon Head Cap | 6 | M10 x 1.50 x 30 |
| 24 | 3892106 | Screw, Captive Washer Cap | 6 | M10 x 1.50 x 170 |
| 25 | 3080769 | Seal, Rectangular Ring | 2 | |
| 26 | 109080 | Seal, O Ring | 2 | |
| 27 | 3080400 | Retainer, Connection | 1 | |
| 28 | 3080401 | Adapter, O Ring | 2 | |

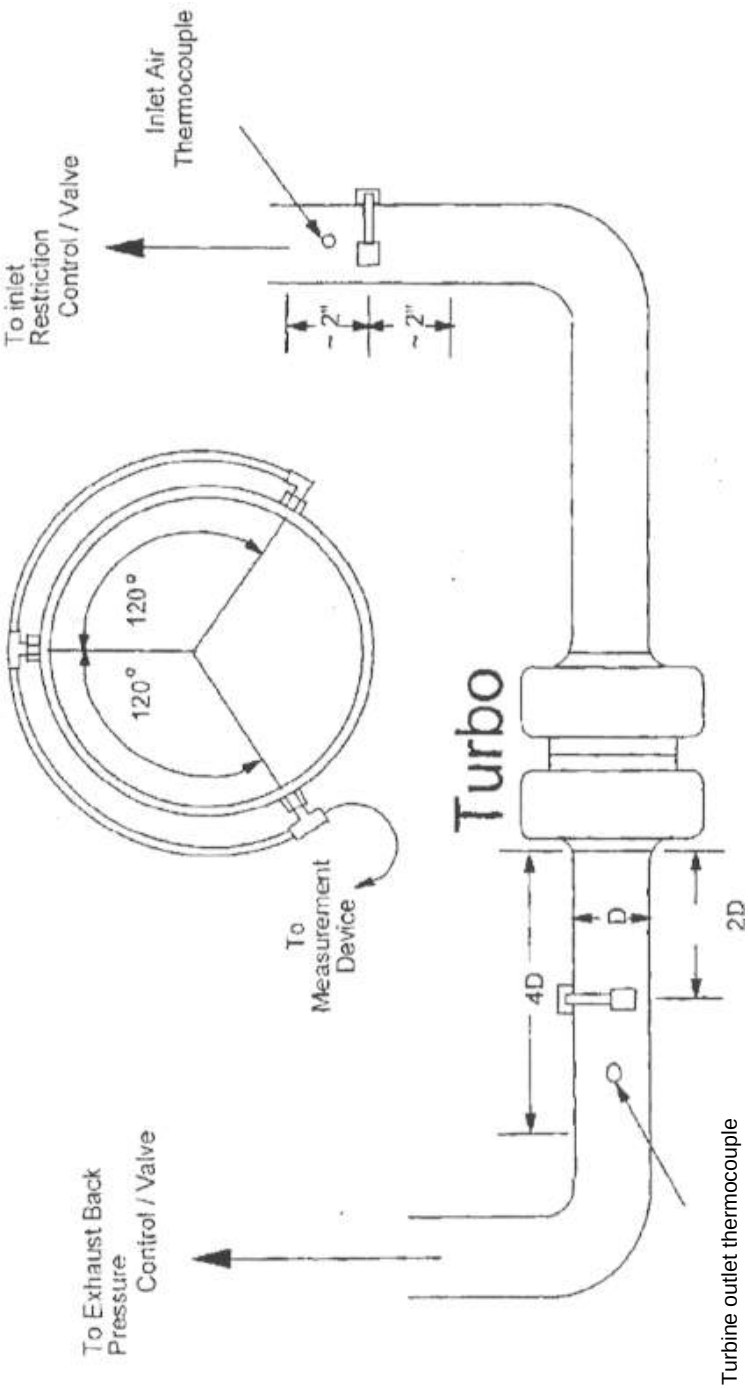
## A1.10 SIGHT GLASS OIL ADDITION (OPTIONAL)



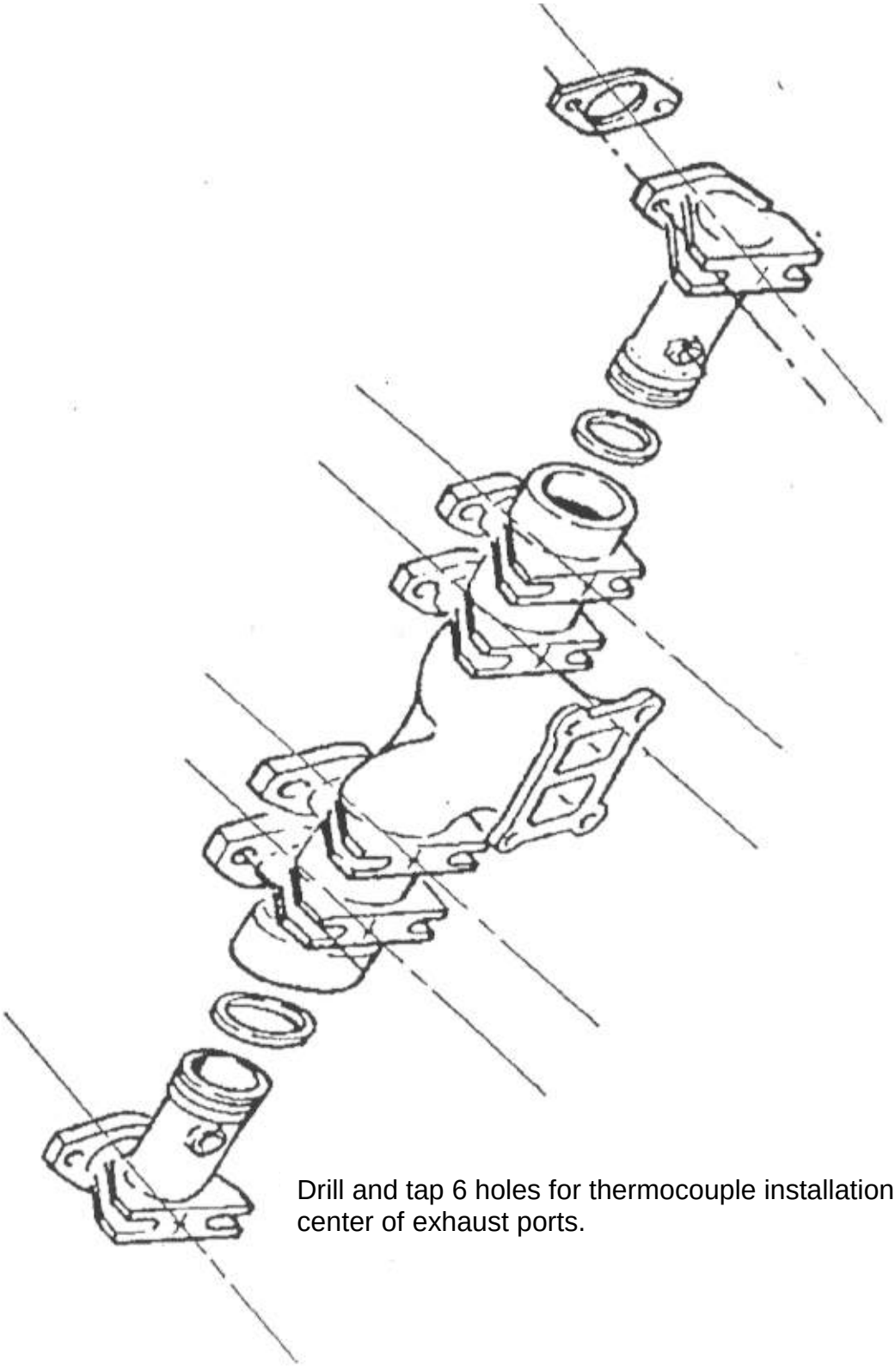
## A1.11 EXHAUST BACK PRESSURE AND INLET AIR RESTRICTION

**SPECIFICATIONS:**

* 14 GA round seamless tubing.
*1/8 diameter holes drilled in three places.
*NPTF half couplings, centered, welded, and gas tight - three places.
*One elbow and two branch tees to fit half couplings.
*Tubing to connect elbow and tees.
*All connections must be gas tight. All internal passages should be 1/8 in. or greater to allow free movement of exhaust and combustion air.

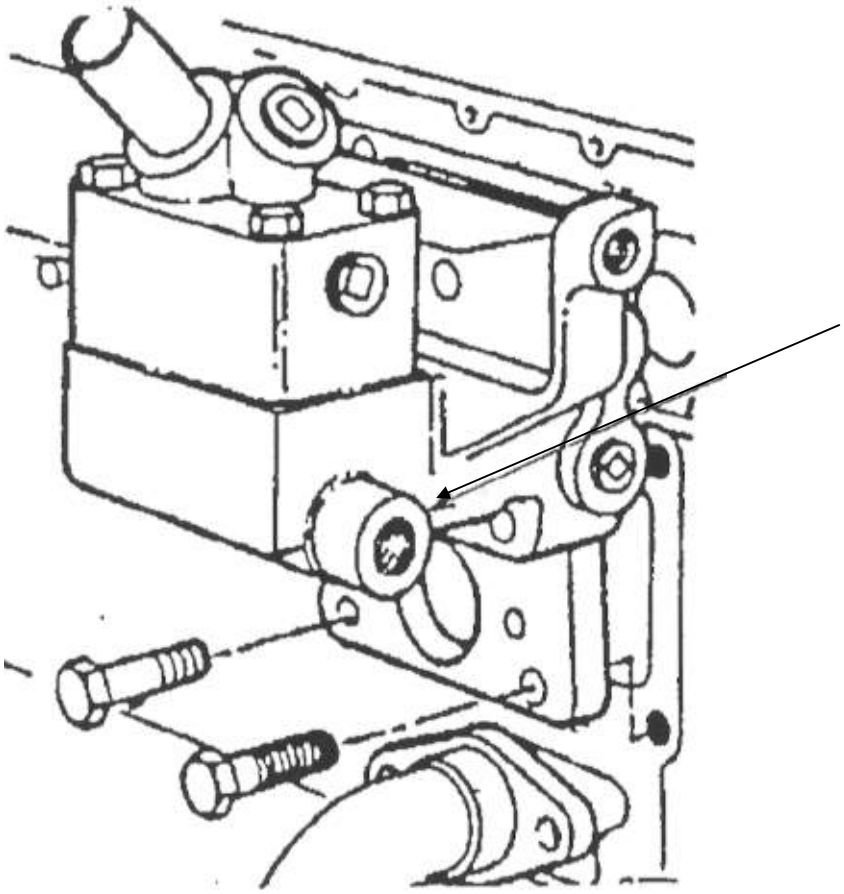


## A1.12 EXHAUST THERMOCOUPLE LOCATIONS



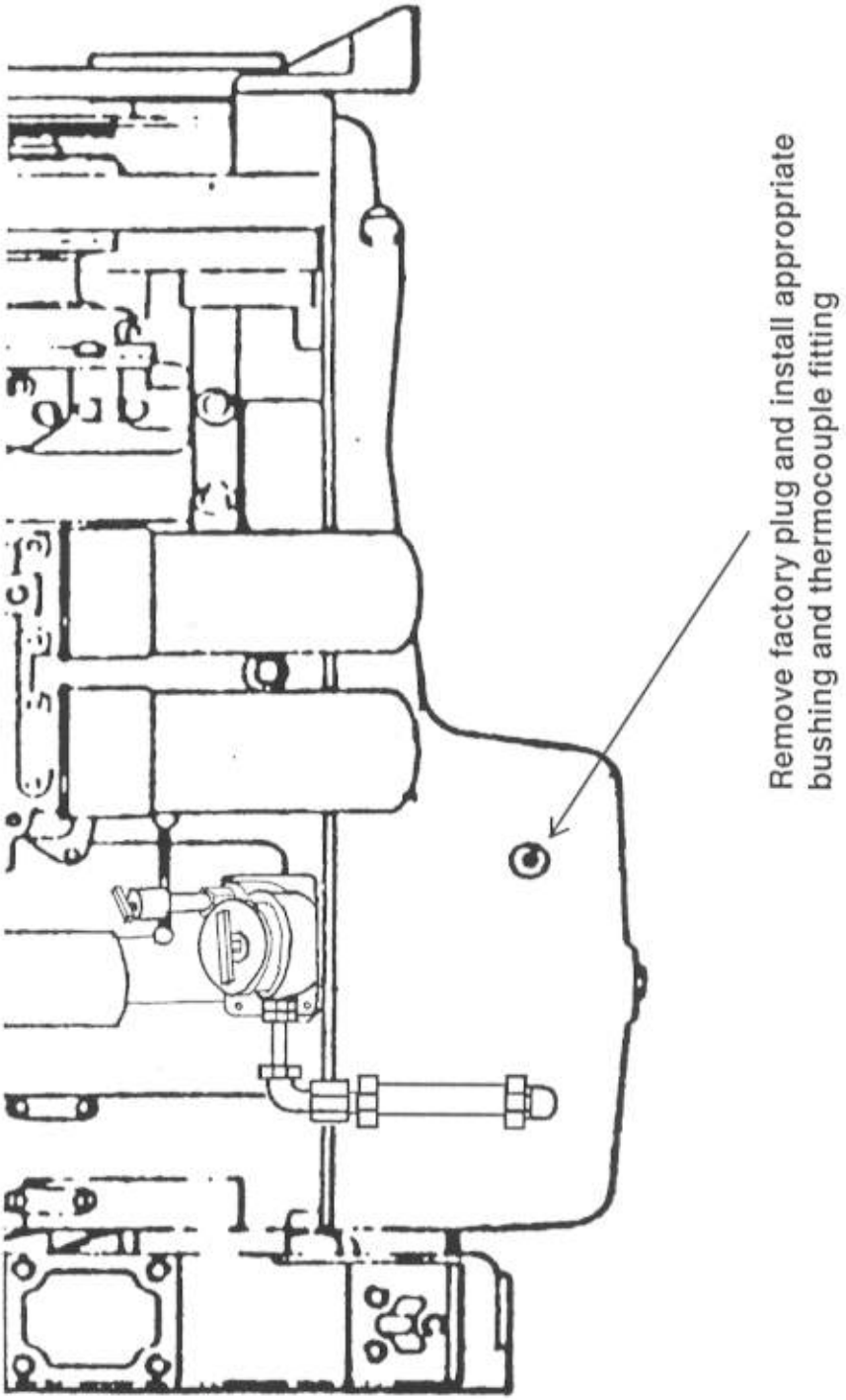
Drill and tap 6 holes for thermocouple installation in center of exhaust ports.

## A1.13 COOLANT OUTLET

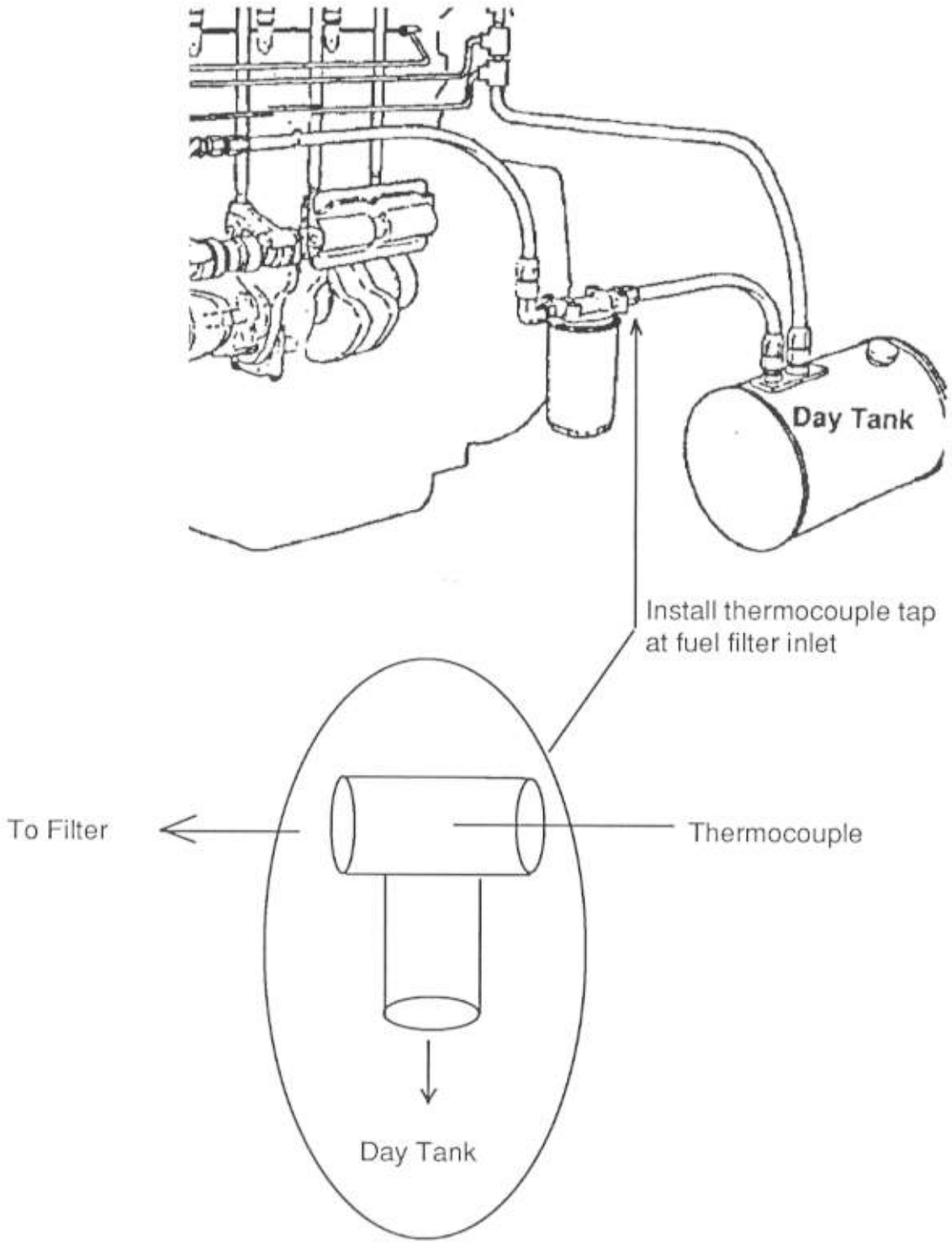



NOTE: For coolant-in thermocouple location see Figure A1.3, bottom.

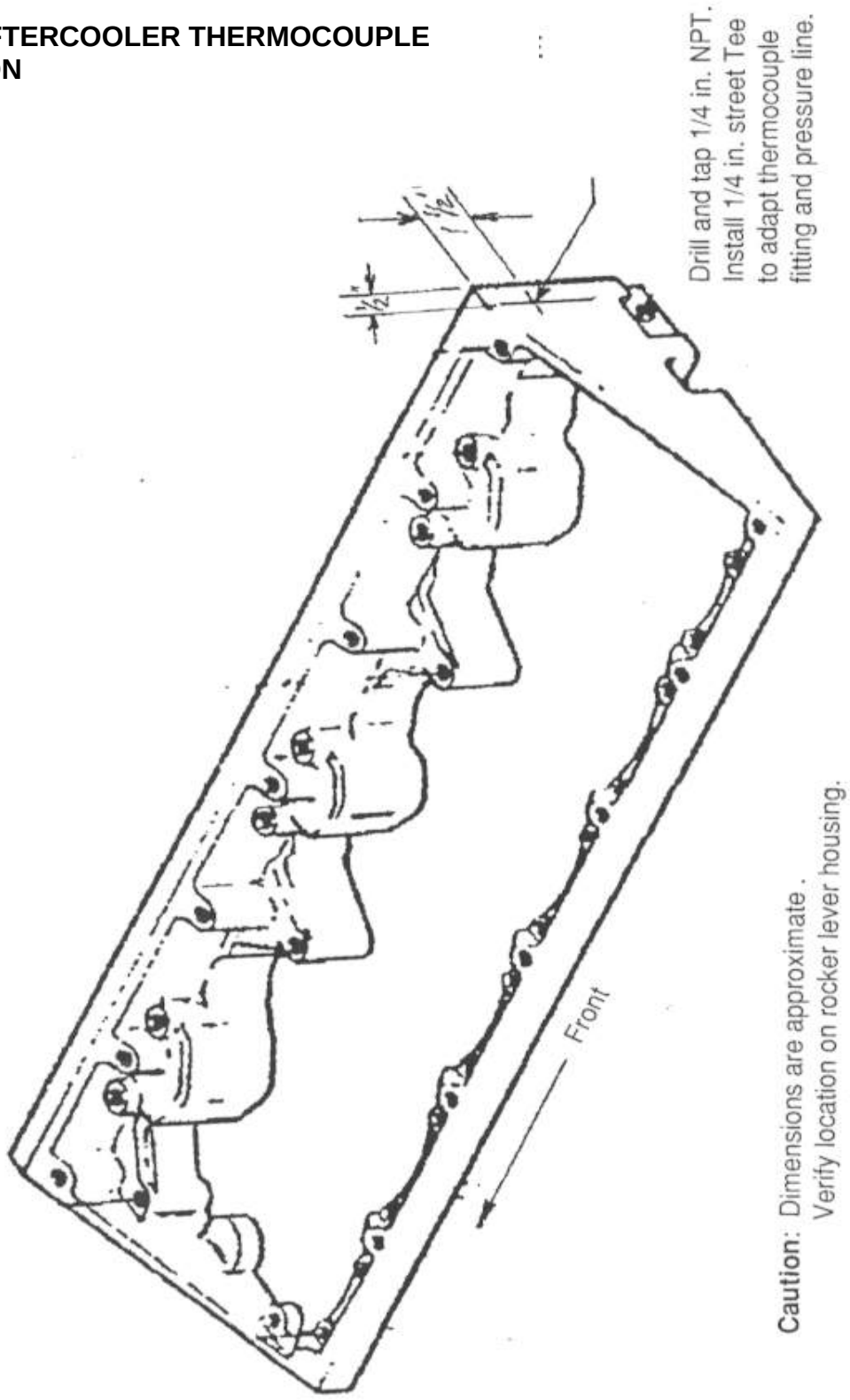
## A1.14 OIL SUMP TEMPERATURE



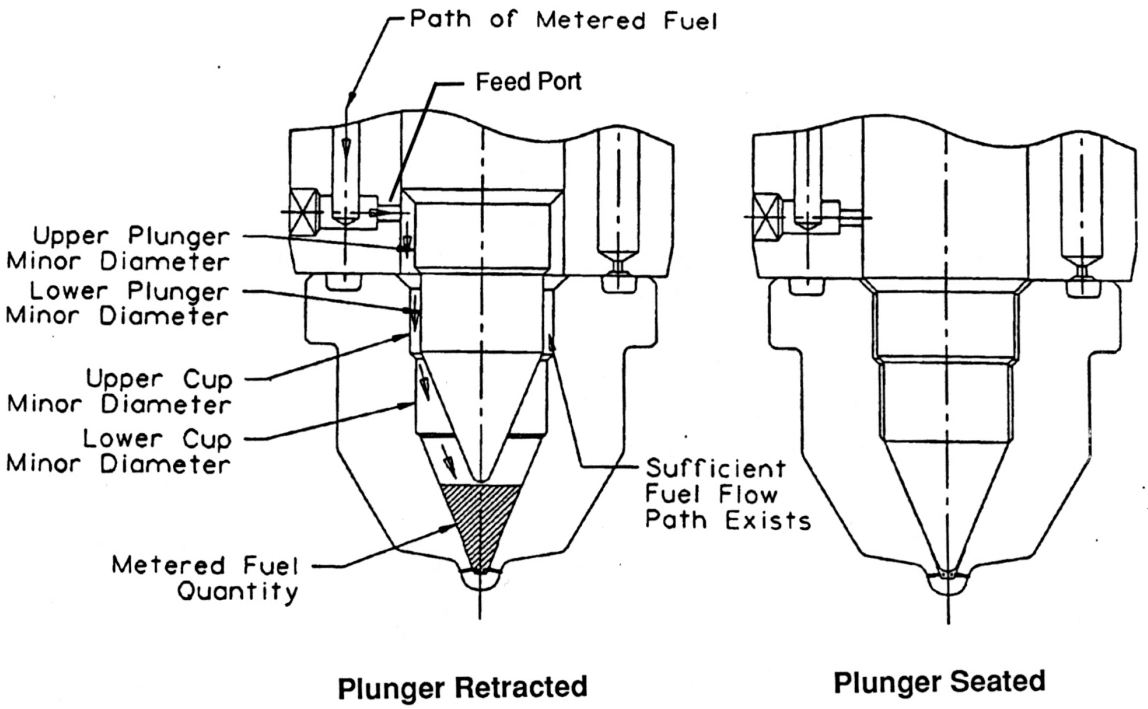
## A1.15 FUEL INLET THERMOCOUPLE



## A1.16 AFTERCOOLER THERMOCOUPLE LOCATION



## A1.17 SIMPLIFIED VIEW OF STEPPED-PLUNGER-AND-CUP INJECTOR



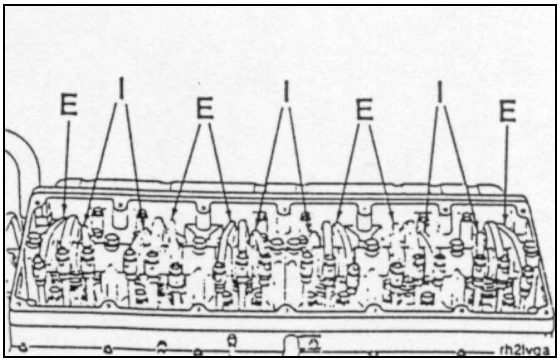
## A1.18

(a)

Each cylinder has three rocker levers:

- The long rocker lever (E) is the exhaust lever.
- The center rocker lever is the injector lever.
- The short rocker lever (I) is the intake lever.

Refer to the accompanying chart for valve rocker lever locations.




(b)

The valves and injectors on the same cylinders are not adjusted at the same index mark on the accessory drive pulley.

One pair of valves and one injector are adjusted at each pulley index mark before rotating the accessory drive to the next index mark.

Two crankshaft revolutions are required to adjust all the valves and injectors.

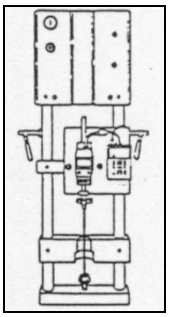
Injector and Valve Adjustment Sequence

| Bar Engine in Direction of Rotation | Pulley Position | Set Cylinder | |
|---|---|---|---|
| | | Injector | Valve |
| Start | A | 3 | 5 |
| Advance to | B | 6 | 3 |
| Advance to | C | 2 | 6 |
| Advance to | A | 4 | 2 |
| Advance to | B | 1 | 4 |
| Advance to | C | 5 | 1 |
| Firing Order: 1-5-3-6-2-4 | | | |

**(c)**

Injector Preload Adjustment – Top Stop Injectors

NOTE: Top stop injector plunger travel can only be adjusted when the injectors are removed from the engine. Part NO. 3822696 Adjusting Tool Must be used to make this adjustment. Refer to the Top Stop Injector Shop Manual, Bulletin No. 3810344, for adjustment procedures.

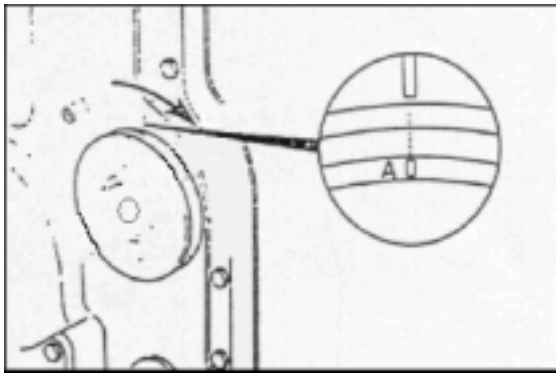


**(d)**

Injector Adjustment Procedures – No Preload, Zero Lash

NOTE: The adjustment can begin on any valve set mark. In the following example the adjustment will begin on the “A” valve set mark with cylinder number five valves closed and cylinder number three injector ready for adjustment.

Rotate the crankshaft clockwise until the “A” valve set mark on the accessory drive pulley is aligned with the pointer.

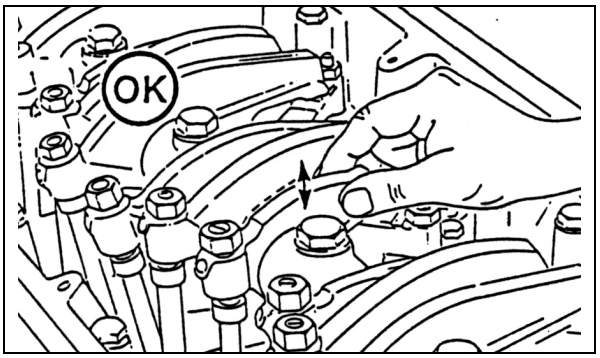


## A.1.18 (continued)

(e)

Check the valve rocker levers on cylinder number five to see if both valves are closed.

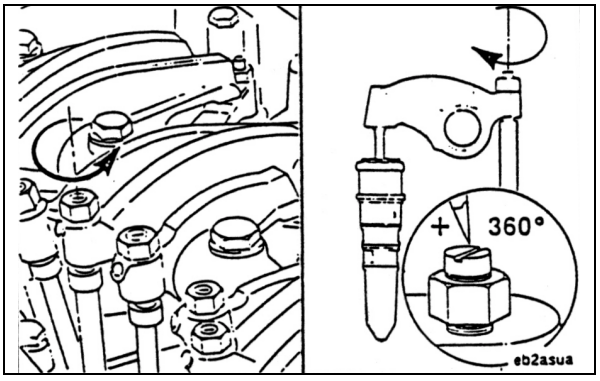
NOTE: Both valves are closed when both rocker levers are loose and can be moved from side to side. If both valves are **not** closed, rotate the accessory drive one complete revolution; and align the "A" mark with the pointer again.




(f)

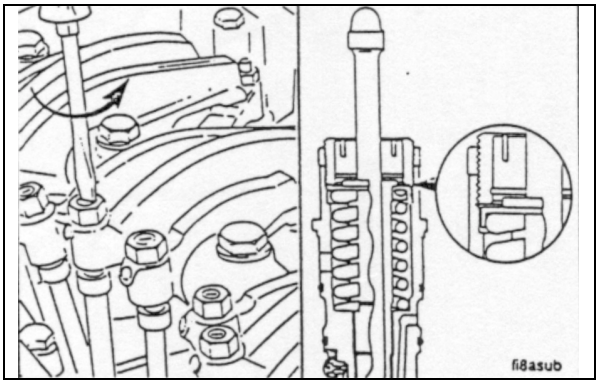
Loosen the lock nut on the injector adjusting screw on cylinder number three. Tighten the adjusting screw until all the clearance is removed from the injector train.

Tighten the adjusting screw one additional turn to correctly seat the link.




(g)

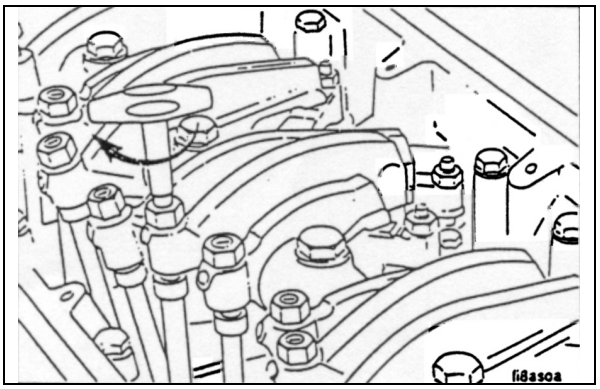
Loosen the injector adjusting screw until the injector spring retainer washer touches the top stop screw.




(h)

**Caution: An overtightened setting on the injector adjusting screw will produce increased stress on the injector train and camshaft injector lobe which can result in engine damage.**

Tighten adjusting screw until injector plunger <u>just</u> bottoms in injector cup – set with NO preload – ZERO lash.



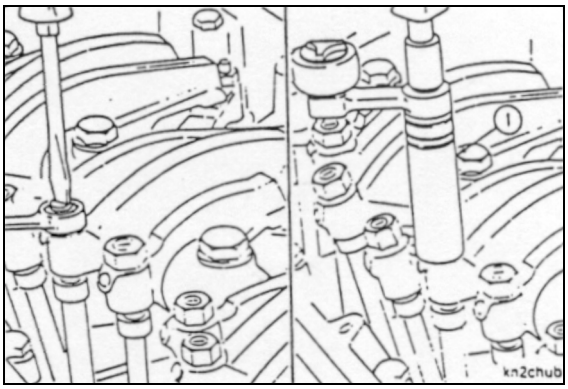
## A1.18 (continued)

(i)

Hold the adjusting screw in this position. The adjusting screw **must not** turn when the lock nut is tightened.

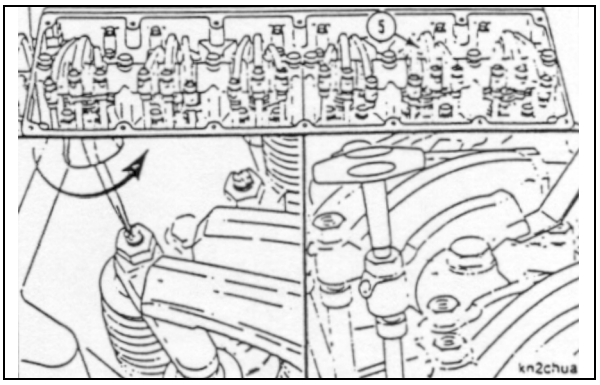
Torque Value:

- Without Torque Wrench Adapter: 60 N-m [45 ft-lb]
- With Torque Wrench Adapter: 45 N-m [35 ft-lb]
  (Part Number ST-669 (1))



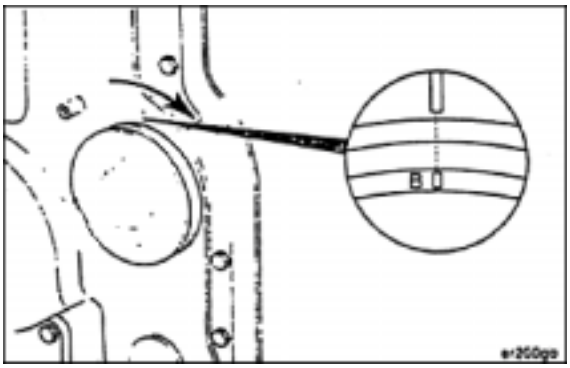

(j)

Adjust the crossheads, if applicable, and valves on cylinder number five **before** rotating the accessory drive to the next valve set mark.




(k)

After adjusting the crossheads and valves on cylinder number five, rotate the crankshaft and align the next valve set mark on the accessory drive pulley with the pointer on the gear cover.



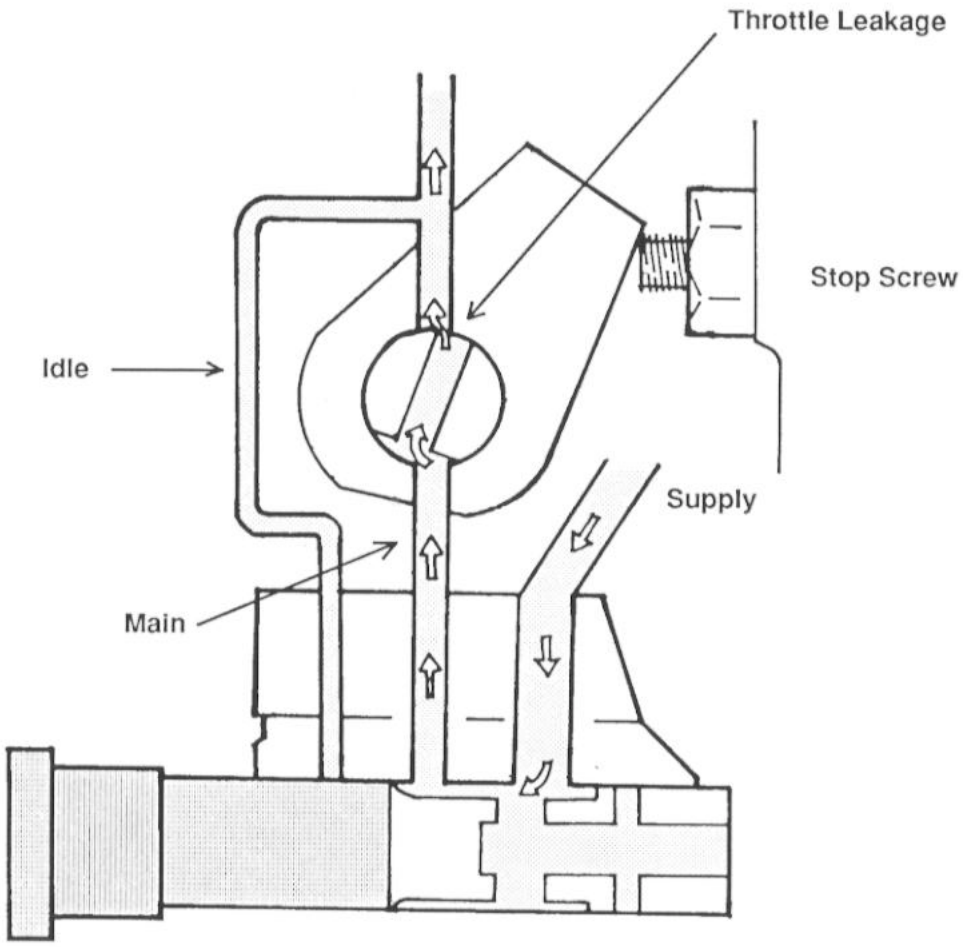
(l)

Adjust the appropriate injector, crossheads, and valves following the Injector and Valve Adjustment Sequence Chart.

Repeat the process to adjust all injectors, crossheads, and valves.

| Injector and Valve Adjustment Sequence | | | |
|---|---|---|---|
| Bar Engine in Direction of Rotation | Pulley Position | Set Cylinder Injector | Valve |
| Start | A | 3 | 5 |
| Advance to | B | 6 | 3 |
| Advance to | C | 2 | 6 |
| Advance to | A | 4 | 2 |
| Advance to | B | 1 | 4 |
| Advance to | C | 5 | 1 |
| Firing Order: 1-5-3-6-2-4 | | | |

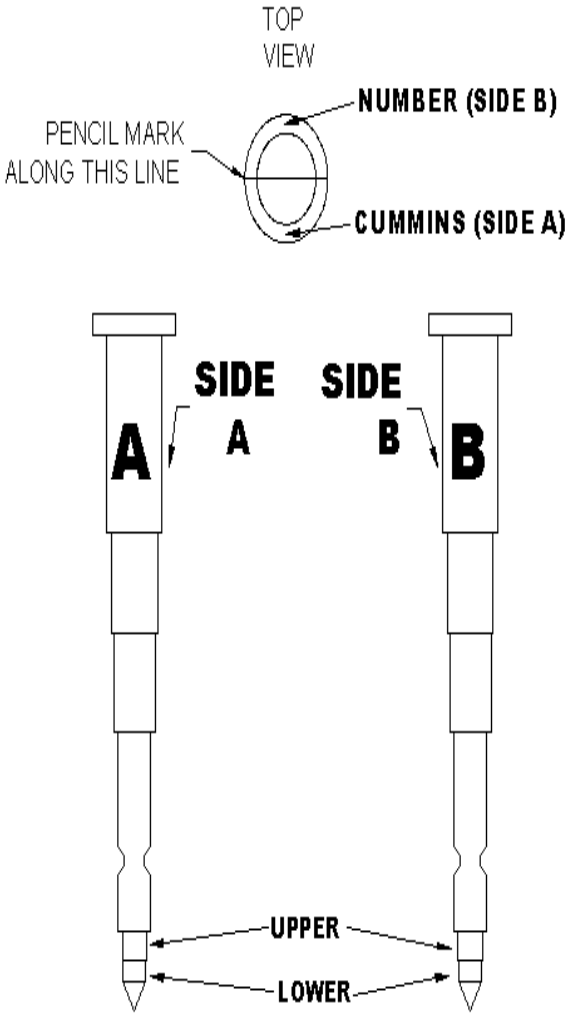
## A1.19 THROTTLE SHAFT LEAKAGE



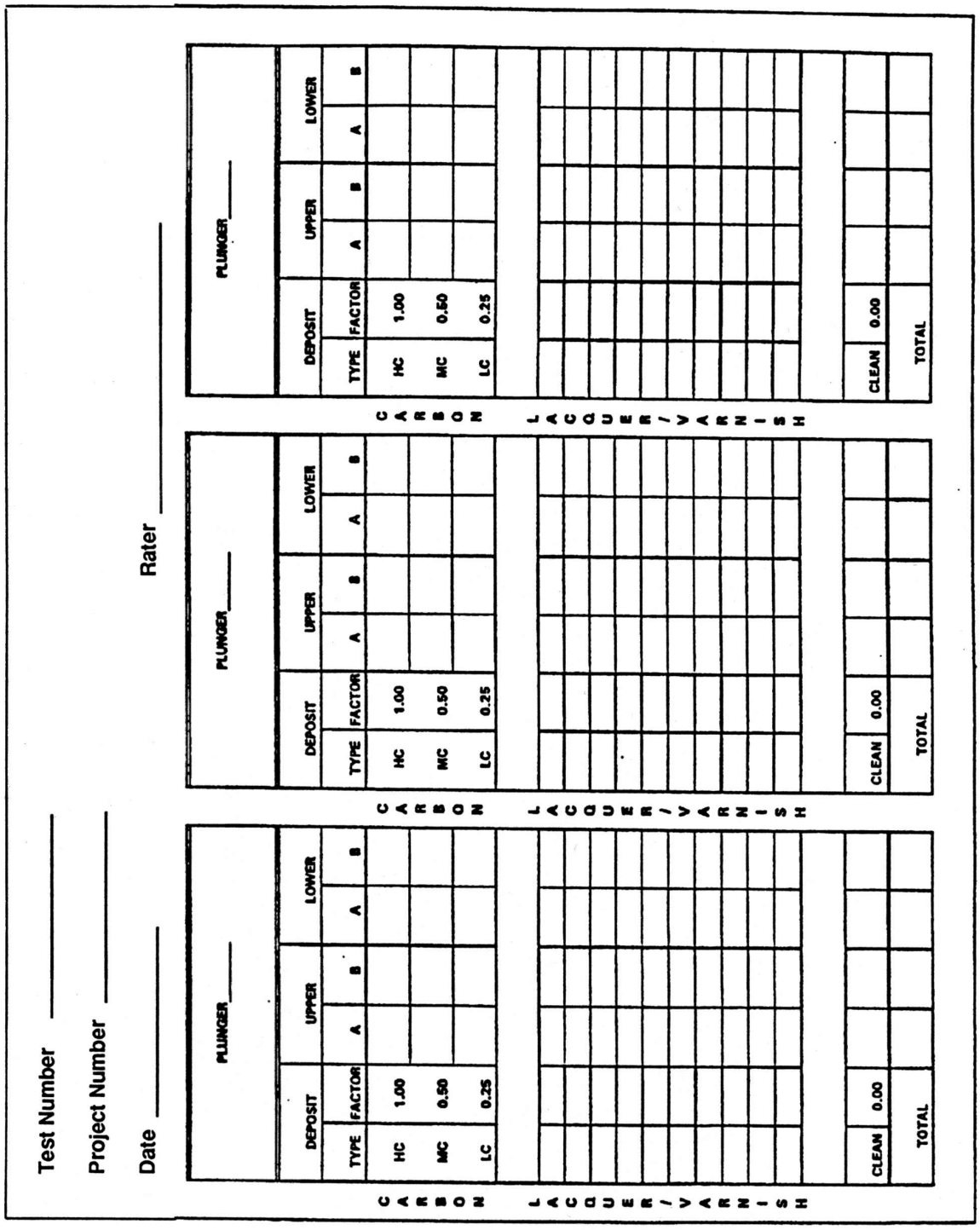
## A2.0 REFERENCE FUEL SPECIFICATION: HALTERMANN PRODUCTS 0.4% SULFUR DIESEL

| TEST | ASTM METHOD | SPECIFICATION MIN | SPECIFICATION MAX | TYPICAL VALUE |
|---|---|---|---|---|
| Distillation, °F IBP | D86 | Report | | 420 |
| 10% | | Report | | 470 |
| 50% | | 500 | | 522 |
| 90% | | 590 | | 614 |
| EP | | | 650 | 668 |
| Gravity, API | D287 | 33.0 | | 34.5 |
| Density | D287 | | 35.0 | 0.852 |
| Pour Point, °F | D97 | | | +15 |
| Cloud Point, °F | D2500 | | | +24 |
| Basic sediment & water, vol% | D1796 | | 0.1 | <0.05 |
| Ash, wt% | D482 | | 0.01 | 0.001 |
| Ramsbottom carbon, 10% residue, wt.% | D524 | | 0.20 | 0.10 |
| Cetane Number | D613 | 47.0 | | 52.6 |
| | | | 53.0 | |
| Natural Sulfur, wt.% | D4294 | 0.38 | | 0.40 |
| Natural Sulfur, wt% | D2622 | 0.42 | | 0.410 |
| Acid Number, mg KOH/g | D664 | Report | | 0.006 |
| Flash point, °F | D93 | | | 202 |
| Kinematic viscosity, cSt @ 40°C | D445 | 0.15 | | 3.2 |
| Copper Corrosion @ 100°C | D130 | 140 | | 1 |
| Cracked stocks | | 2.0 | | None |
| | | 4.0 | | |
| | | | 2 | |
| | | None | | |
| Hydrocarbon Composition, vol.% | D1319 | | | |
| Aromatics | | Report | | |
| Olefins | | Report | | |
| Saturates | | Report | | |
| Aliphatic paraffins | D2425 | 45.0 | | 46.47 |
| Monocycloparaffins | | 65.0 | | 9.22 |
| Dicycloparrafins | | Report | | 13.16 |
| Tricycloparrifins | | 0.0 | | 3.72 |
| | | 15.0 | | |
| | | Report | | |
| Alkylbenzenes | | 5.0 | | 6.81 |
| Indanes/Tetralins | | 10.0 | | 5.33 |
| Indenes | | Report | | 2.00 |
| Napthalene | | Report | | 0.33 |
| | | Report | | |
| Napthalenes | | 5.0 | | 8.69 |
| Acenaphthenes | | 15.0 | | 2.22 |
| Acenapthalenes | | Report | | 1.09 |
| Tricyclic aromatics | | Report | | 0.96 |
| | | Report | | |

## A3.1 L10 INJECTOR PLUNGER RATING AREAS



## A3.2 CRC SAMPLE RATING FORM



## A4.1 L10 IDT HEAD SETTINGS

Technician _____ Date _____
Fuels Test # _____ Fuel Code Frt. _____
Data Storage # _____ Fuel Code Rear _____

| Front Engine | | CYL 1 | CYL 2 | CYL 3 | CYL 4 | CYL 5 | CYL 6 |
|---|---|---|---|---|---|---|---|
| START | INJECTOR TRAVEL | | | | | | |
| | EXH VALVE LASH | | | | | | |
| | INT VALVE LASH | | | | | | |
| EOT | INJECTOR TRAVEL | | | | | | |
| | EXH VALVE LASH | | | | | | |
| | INT VALVE LASH | | | | | | |

| Rear Engine | | CYL 1 | CYL 2 | CYL 3 | CYL 4 | CYL 5 | CYL 6 |
|---|---|---|---|---|---|---|---|
| START | INJECTOR TRAVEL | | | | | | |
| | EXH VALVE LASH | | | | | | |
| | INT VALVE LASH | | | | | | |
| EOT | INJECTOR TRAVEL | | | | | | |
| | EXH VALVE LASH | | | | | | |
| | INT VALVE LASH | | | | | | |

## INJECTOR REPLACEMENT

| Front Engine | | CYL 1 | CYL 2 | CYL 3 | CYL 4 | CYL 5 | CYL 6 |
|---|---|---|---|---|---|---|---|
| START | INJECTOR TRAVEL | | | | | | |
| | EXH VALVE LASH | | | | | | |
| | INT VALVE LASH | | | | | | |
| EOT | INJECTOR TRAVEL | | | | | | |
| | EXH VALVE LASH | | | | | | |
| | INT VALVE LASH | | | | | | |
| | TEST HOURS | | | | | | |
| | DATE | | | | | | |

| Rear Engine | | CYL 1 | CYL 2 | CYL 3 | CYL 4 | CYL 5 | CYL 6 |
|---|---|---|---|---|---|---|---|
| START | INJECTOR TRAVEL | | | | | | |
| | EXH VALVE LASH | | | | | | |
| | INT VALVE LASH | | | | | | |
| EOT | INJECTOR TRAVEL | | | | | | |
| | EXH VALVE LASH | | | | | | |
| | INT VALVE LASH | | | | | | |
| | TEST HOURS | | | | | | |
| | DATE | | | | | | |