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An American National Standard

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Standard Test Method for Cetane Number of Diesel Fuel Oil[1]

This standard is issued under the fixed designation D 613; 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 parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This test method determines the rating of diesel fuel oil in terms of an arbitrary scale of cetane numbers using a standard single cylinder, four-stroke cycle, variable compression ratio, indirect injected diesel engine.

1.2 The cetane number scale covers the range from zero (0) to 100 but typical testing is in the range of 30 to 65 cetane number.

1.3 The values for operating conditions are stated in SI units and are considered standard. The values in parentheses are the historical inch-pounds units. In addition, the engine measurements continue to be in inch-pounds units because of the extensive and expensive tooling that has been created for these units.

1.4 *This standard does not purport to address all of the safety concerns, 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.* For more specific warning statements, see Annex A1.

2. Referenced Documents

2.1 *ASTM Standards:*

D 975 Specification for Diesel Fuel Oils[2]
D 1193 Specification for Reagent Water[3]
D 2500 Test Method for Cloud Point of Petroleum Products[2]
D 4057 Practice for Manual Sampling of Petroleum and Petroleum Products[4]
D 4175 Terminology Relating to Petroleum, Petroleum Products, and Lubricants[4]
D 4177 Practice for Automatic Sampling of Petroleum and Petroleum Products[4]
E 1 Specification for ASTM Thermometers[5]
E 456 Terminology Relating to Quality and Statistics[6]
E 542 Practice for Calibration of Laboratory Volumetric Apparatus[7]
E 832 Specification for Laboratory Filter Papers[7]

3. Terminology

3.1 *Definitions:*

3.1.1 *accepted reference value (ARV)*, *n*—a value that serves as an agreed-upon reference for comparison, and which is derived as: (*1*) a theoretical or established value, based on scientific principles, or (*2*) an assigned or certified value, based on experimental work of some national or international organization, or (*3*) a consensus or certified value, based on collaborative experimental work under the auspices of a scientific or engineering group. **E 456**

3.1.1.1 *Discussion*—In the context of this test method, accepted reference value is understood to apply to the cetane number of specific reference materials determined empirically under reproducibility conditions by the National Exchange Group or another recognized exchange testing organization.

3.1.2 *cetane number*, *n*—a measure of the ignition performance of a diesel fuel oil obtained by comparing it to reference fuels in a standardized engine test. **D 4175**

3.1.2.1 *Discussion*—In the context of this test method, ignition performance is understood to mean the ignition delay of the fuel as determined in a standard test engine under controlled conditions of fuel flow rate, injection timing and compression ratio.

3.1.3 *compression ratio*, *n*—the ratio of the volume of the combustion chamber including the precombustion chamber with the piston at bottom dead center to the comparable volume with the piston at top dead center.

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[1] This test method is under the jurisdiction of ASTM Committee D02 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.01 on Combustion Characteristics.

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[2] *Annual Book of ASTM Standards*, Vol 05.01.
[3] *Annual Book of ASTM Standards*, Vol 11.01.
[4] *Annual Book of ASTM Standards*, Vol 05.02.
[5] *Annual Book of ASTM Standards*, Vol 14.03.
[6] *Annual Book of ASTM Standards*, Vol 14.02.
[7] *Annual Book of ASTM Standards*, Vol 14.04.

***A Summary of Changes section appears at the end of this standard.**

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3.1.4 *ignition delay*, *n*—that period of time, expressed in degrees of crank angle rotation, between the start of fuel injection and the start of combustion.

3.1.5 *injection timing (injection advance)*, *n*—that time in the combustion cycle, measured in degrees of crank angle, at which fuel injection into the combustion chamber is initiated.

3.1.6 *repeatability conditions*, *n*—conditions where independent test results are obtained with the same method on identical test items in the same laboratory by the same operator using the same equipment within short intervals of time. **E 456**

3.1.6.1 *Discussion*—In the context of this method, a short time interval between two ratings on a sample fuel is understood to be not less than the time to obtain at least one rating on another sample fuel between them but not so long as to permit any significant change in the sample fuel, test equipment, or environment.

3.1.7 *reproducibility conditions*, *n*—conditions where test results are obtained with the same method on identical test items in different laboratories with different operators using different equipment. **E 456**

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *cetane meter (ignition delay meter)*, *n*—the electronic instrument which displays injection advance and ignition delay derived from input pulses of multiple transducers (pickups).

3.2.2 *Check Fuels*, *n*—for quality control testing, a diesel fuel oil of selected characteristics having a cetane number accepted reference value determined by round-robin testing under reproducibility conditions.

3.2.3 *combustion pickup*, *n*—pressure transducer exposed to cylinder pressure to indicate the start of combustion.

3.2.4 *handwheel reading*, *n*—an arbitrary numerical value, related to compression ratio, obtained from a micrometer scale that indicates the position of the variable compression plug in the precombustion chamber of the engine.

3.2.5 *injector opening pressure*, *n*—the fuel pressure that overcomes the resistance of the spring which normally holds the nozzle pintle closed, and thus forces the pintle to lift and release an injection spray from the nozzle.

3.2.6 *injector pickup*, *n*—transducer to detect motion of the injector pintle, thereby indicating the beginning of injection.

3.2.7 *primary reference fuels*, *n*— *n*-cetane, heptamethyl nonane (HMN) and volumetrically proportioned mixtures of these materials which now define the cetane number scale by the relationship:

$$\text{Cetane Number} = \%\ n\text{-cetane} + 0.15\ (\%\ \text{HMN}) \tag{1}$$

3.2.7.1 *Discussion*—*In the context of this test method*, the arbitrary cetane number scale was originally defined as the volume percent of *n*-cetane in a blend with alpha-methylnaphthalene (AMN) where *n*-cetane had an assigned value of 100 and AMN an assigned value of zero (0). A change from alpha-methylnaphthalene to heptamethylnonane as the low cetane ingredient was made in 1962 to utilize a material of better storage stability and availability. Heptamethylnonane was determined to have a cetane number accepted reference value (CN_{ARV}) of 15 based on engine testing by the ASTM Diesel National Exchange Group, using blends of *n*-cetane and AMN as primary reference fuels.

3.2.7.2 *Discussion*—*In the context of this test method*, the Diesel National Exchange Group of Subcommittee D02.01[8] is composed of petroleum industry, governmental, and independent laboratories. It conducts regular monthly exchange sample analyses to generate precision data for this engine test standard and determines the CN_{ARV} of reference materials used by all laboratories.

3.2.8 *reference pickups*, *n*—transducer(s) mounted over the flywheel of the engine, triggered by a flywheel indicator, used to establish a top-dead-center (tdc) reference and a time base for calibration of the ignition delay meter.

3.2.9 *secondary reference fuels*, *n*—volumetrically proportioned blends of two selected, numbered, and paired hydrocarbon mixtures designated *T Fuel* (high cetane) and *U Fuel* (low cetane) that have been rated by the ASTM Diesel National Exchange Group using primary reference fuels to determine a cetane number accepted reference value for each individually and for various combinations of the two.

4. Summary of Test Method

4.1 The cetane number of a diesel fuel oil is determined by comparing its combustion characteristics in a test engine with those for blends of reference fuels of known cetane number under standard operating conditions. This is accomplished using the bracketing handwheel procedure which varies the compression ratio (handwheel reading) for the sample and each of two bracketing reference fuels to obtain a specific ignition delay permitting interpolation of cetane number in terms of handwheel reading.

5. Significance and Use

5.1 The cetane number provides a measure of the ignition characteristics of diesel fuel oil in compression ignition engines.

5.2 This test method is used by engine manufacturers, petroleum refiners and marketers, and in commerce as a primary specification measurement related to matching of fuels and engines.

5.3 Cetane number is determined at constant speed in a precombustion chamber type compression ignition test engine. The relationship of test engine performance to full scale, variable speed, variable load engines is not completely understood.

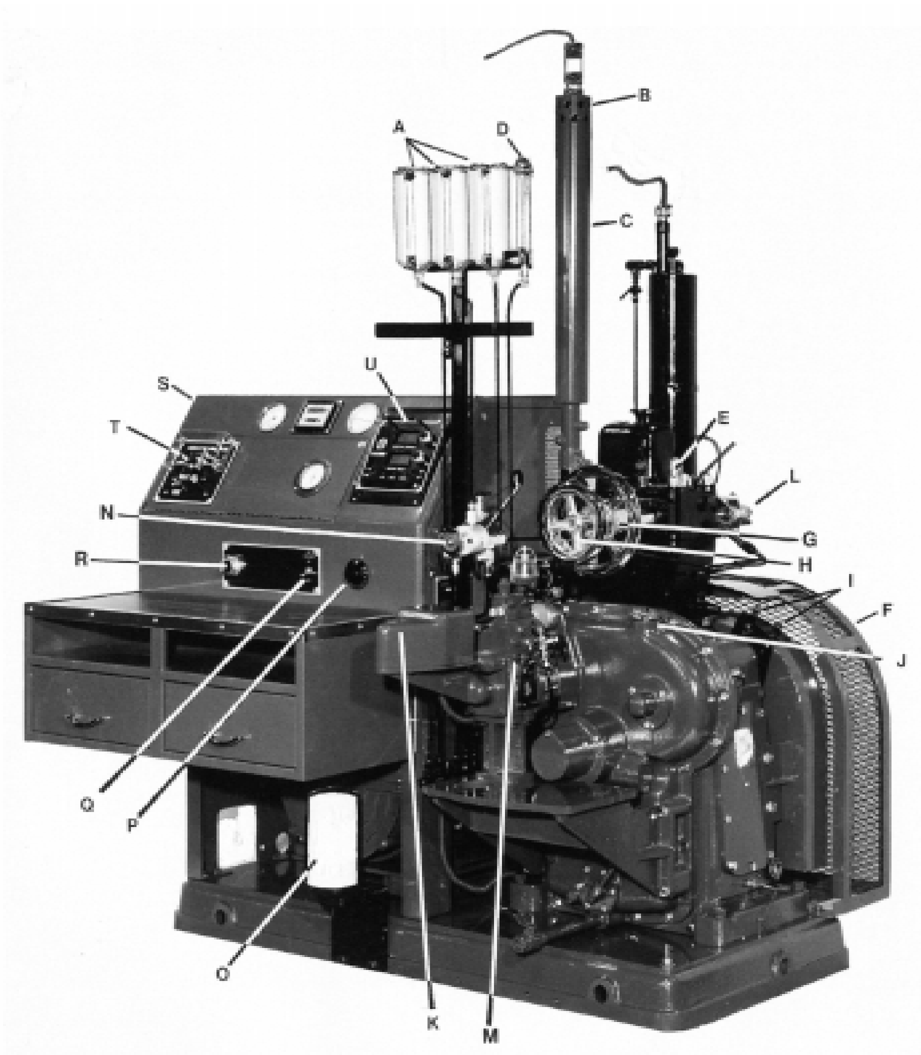
5.4 This test method may be used for unconventional fuels such as synthetics, vegetable oils, and the like. However, the relationship to the performance of such materials in full scale engines is not completely understood.

6. Interferences

6.1 (**Warning—**Avoid exposure of sample fuels and reference fuels to sunlight or fluorescent lamp UV emissions to minimize induced chemical reactions that can affect cetane number ratings.)[9]

[8] Bylaws governing ASTM Subcommittee D02.01 on Combustion Characteristics are available from the subcommittee or from ASTM International.

[9] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR: D02–1502.



A—Fuel Tanks
B—Air Heater Housing
C—Air Intake Silencer
D—Fuel Flow Rate Buret
E—Combustion Pickup
F—Safety Guard
G—Variable Compression Plug Handwheel
H—V.C.P. Locking Handwheel
I—Flywheel Pickups
J—Oil Filler Cap
K—Injection Pump Safety Shut-Off Solenoid
L—Injector Assembly
M—Fuel Injection Pump
N—Fuel Selector-Valve
O—Oil Filter
P—Crankcase Oil Heater Control
Q—Air Heater Switch
R—Engine Start-Stop Switch
S—Instrument Panel
T—Intake Air Temperature Controller
U—Dual Digital Cetane Meter

FIG. 1 Cetane Method Test Engine Assembly

6.1.1 Exposure of these fuels to UV wavelengths shorter than 550 nm for a short period of time may significantly affect cetane number ratings.

6.2 Certain gases and fumes present in the area where the cetane test engine is located may have a measurable effect on the cetane number test result.

6.3 This test method is not suitable for rating diesel fuel oils with fluid properties that interfere with unimpeded gravity flow of fuel to the fuel pump or delivery through the injector nozzle.

7. Apparatus

7.1 *Engine Equipment*[10]—This test method uses a single cylinder engine which consists of a standard crankcase with fuel pump assembly, a cylinder with separate head assembly of the precombustion type, thermal syphon recirculating jacket coolant system, multiple fuel tank system with selector valving, injector assembly with specific injector nozzle, electrical controls, and a suitable exhaust pipe. The engine is belt connected to a special electric power-absorption motor which acts as a motor driver to start the engine and as a means to absorb power at constant speed when combustion is occurring (engine firing). See Fig. 1.

7.1.1 See Annex A2 for detail and description of all critical, non-critical and equivalent engine equipment.

7.2 *Instrumentation*[10]—This test method uses an electronic instrument to measure injection and ignition delay timing as well as conventional thermometry, gages and general purpose meters.

7.2.1 *A Cetane Meter*, (Ignition Delay Meter) is critical and shall be used for this test method.

7.2.2 See Annex A3 for detail and description of all critical, non-critical and equivalent instrumentation.

[10] The sole source of supply of the engine equipment and instrumentation known to the committee at this time is Waukesha Engine, Dresser Inc., 1000 West St. Paul Avenue, Waukesha, WI 53188. Waukesha Engine also has CFR engine authorized sales and service organizations in selected geographical areas. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee [1], which you may attend.

7.3 *Reference Fuel Dispensing Equipment*—This test method requires repeated blending of two secondary reference fuel materials in volumetric proportions on an as-needed basis. Measurement shall be performed accurately because rating error is proportional to blending error.

7.3.1 *Volumetric Blending of Reference Fuels*—Volumetric blending has historically been employed to prepare the required blends of reference fuels. For volumetric blending, a set of two burets or accurate volumetric ware shall be used and the desired batch quantity shall be collected in an appropriate container and thoroughly mixed before being introduced to the engine fuel system.

7.3.1.1 Calibrated burets or volumetric ware having a capacity of 400 or 500 mL and a maximum volumetric tolerance of $\pm$ 0.2 % shall be used. Calibration shall be verified in accordance with Practice E 542.

7.3.1.2 Calibrated burets shall be outfitted with a dispensing valve and delivery tip to accurately control dispensed volume. The delivery tip shall be of such size and design that shutoff tip discharge does not exceed 0.5 mL.

7.3.1.3 The rate of delivery from the dispensing system shall not exceed 500 mL per 60 s.

7.3.1.4 The set of burets for the reference and standardization fuels shall be installed in such a manner and be supplied with fluids such that all components of each batch or blend are dispensed at the same temperature.

7.3.1.5 See Appendix X1, Volumetric Reference Fuel Blending Apparatus and Procedures, for typical dispensing system information.

7.3.2 *Gravimetric Blending of Reference Fuels*—Use of blending systems that allow preparation of the volumetrically-defined blends by gravimetric (mass) measurements based on the density of the individual components is also permitted, provided the system meets the requirement for maximum 0.2 % blending tolerance limits.

7.3.2.1 Calculate the mass equivalents of the volumetrically-defined blend components from the densities of the individual components at 15.56°C (60°F).

7.4 *Auxiliary Apparatus*:

7.4.1 *Injector Nozzle Tester*—The injector nozzle assembly shall be checked whenever the injector nozzle is removed and reassembled to ensure the initial pressure at which fuel is discharged from the nozzle is properly set. It is also important to inspect the type of spray pattern. Commercial injector nozzle testers which include a lever-operated pressure cylinder, fuel reservoir and pressure gage are available from several sources as common diesel engine maintenance equipment.

7.4.2 *Special Maintenance Tools*—A number of specialty tools and measuring instruments should be utilized for easy, convenient and effective maintenance of the engine and testing equipment. Lists and descriptions of these tools and instruments are available from the manufacturers of the engine equipment and those organizations offering engineering and service support for this test method.

8. Reagents and Reference Materials

8.1 *Cylinder Jacket Coolant*—Water shall be used in the cylinder jacket for laboratory locations where the resultant boiling temperature shall be 100 $\pm$ 2°C (212 $\pm$ 3°F). Water with commercial glycol-based antifreeze added in sufficient quantity to meet the boiling temperature requirement shall be used when laboratory altitude dictates. A commercial multi-functional water treatment material should be used in the coolant to minimize corrosion and mineral scale that can alter heat transfer and rating results.

8.1.1 Water shall be understood to mean reagent water conforming to Type IV of Specification D 1193.

8.2 *Engine Crankcase Lubricating Oil*—An SAE 30 viscosity grade oil meeting service classification SF/CD or SG/CE shall be used. It shall contain a detergent additive and have a kinematic viscosity of 9.3 to 12.5 cSt (mm^2 per s) at 100°C (212°F) and a viscosity index of not less than 85. Oils containing viscosity index improvers shall not be used. Multi-graded oils shall not be used. (**Warning**—Lubricating oil is combustible, and its vapor is harmful. See Annex A1.)

8.3 *Primary Reference Fuels*—(**Warning**—Primary Reference Fuel—Combustible. Vapor Harmful. See Annex A1.)[10,11]

8.3.1 *n-Cetane (n-hexadecane)*—With a minimum purity of 99.0 % as determined by chromatographic analysis shall be used as the designated 100 cetane number component.

8.3.2 *Heptamethylnonane (2,2,4,4,6,8,8-heptamethylnonane)*—With a minimum purity of 98 % as determined by chromatographic analysis shall be used as the designated 15 cetane number component.

8.4 *Secondary Reference Fuels*[10,12]—(**Warning**—Secondary Reference fuel—Combustible. Vapor Harmful. See Annex A1.)

8.4.1 *T Fuel*—Diesel fuel with a CN_{ARV} typically in the range of 73 to 75.

8.4.2 *U Fuel*—Diesel fuel with a CN_{ARV} typically in the range of 20 to 22.

8.4.3 Storage and use of *T Fuel* and *U Fuel* should be at temperatures above 0°C (32°F) to avoid potential solidification, particularly of *T Fuel*. Before a container that has been stored at low temperature is placed in service, it should be warmed to a temperature of at least 15°C (27°F) above its Cloud Point. (See Test Method D 2500.) It should be held at this temperature for a period of at least 30 min and then the container should be thoroughly remixed.

8.5 *Check Fuels*[13]—Diesel fuel oils typical of Specification D 975 grade No. 2-D distillate fuel oil. (**Warning**—Check Fuel—Combustible. Vapor Harmful. See Annex A1.)

8.5.1 *Low Cetane Check Fuel*—With a CN_{ARV} typically in the range of 38 to 42.

8.5.2 *High Cetane Check Fuel*—With a CN_{ARV} typically in the range of 50 to 55.

9. Sampling

9.1 Collect samples in accordance with Practice D 4057 or D 4177.

[11] The sole source of supply of primary reference fuels known to the committee at this time is Humphrey Chemical Co., Devine Street, North Haven, CT 06473.

[12] The sole source of supply of the secondary reference and check fuels known to the committee at this time is Chevron Phillips Chemical Company LP., 1301 McKinney, Suite 2130, Houston, TX 77010–3030.

[13] Blend Tables for batches of *T Fuel* and *U Fuel* can be obtained from the fuel supplier or by requesting Research Report RR: D02–1302 from ASTM International.

9.1.1 *Protection from Light*—Collect and store sample fuels in an opaque container such as a dark brown glass bottle, metal can, or a minimally reactive plastic container to minimize exposure to UV emissions from sources such as sunlight or fluorescent lamps.

9.2 *Fuel Temperature*—Samples shall be brought to room temperature typically 18 to 32°C (65 to 90°F) before engine testing.

9.3 *Filtration*—Samples may be filtered through a Type I, Class A filter paper at room temperature and pressure before engine testing. See Specification E 832.

10. Basic Engine and Instrument Settings and Standard Operating Conditions

10.1 *Installation of Engine Equipment and Instrumentation*—Installation of the engine and instrumentation requires placement of the engine on a suitable foundation and hook-up of all utilities. Engineering and technical support for this function is required, and the user shall be responsible to comply with all local and national codes and installation requirements.

10.1.1 Proper operation of the test engine requires assembly of a number of engine components and adjustment of a series of engine variables to prescribed specifications. Some of these settings are established by component specifications, others are established at the time of engine assembly or after overhaul and still others are engine running conditions that must be observed or determined by operator adjustment, or both, during the testing process.

10.2 *Conditions Based on Component Specifications*:

10.2.1 *Engine Speed*—900 ± 9 rpm, when the engine is operating with combustion with a maximum variation of 9 rpm occurring during a rating. Engine speed when combustion is occurring shall not be more than 3 rpm greater than that for motoring without combustion.

10.2.2 *Valve Timing*— The engine uses a four-stroke cycle with two crankshaft revolutions for each complete combustion cycle. The two critical valve events are those that occur near top-dead-center (tdc); intake valve opening and exhaust valve closing. See Annex A4 for Camshaft Timing and Valve Lift Measurement Procedure.

10.2.2.1 Intake valve opening shall occur 10.0 ± 2.5° after-top-dead-center (atdc) with closing at 34° after-bottom-dead-center (abdc) on one revolution of the crankshaft and flywheel.

10.2.2.2 Exhaust valve opening shall occur 40° before-bottom-dead-center (bbdc) on the second revolution of the crankshaft or flywheel with closing at 15.0 ± 2.5° after-top-dead-center on the next revolution of the crankshaft or flywheel.

10.2.3 *Valve Lift*—Intake and exhaust cam lobe contours, while different in shape, shall have a contour rise of 6.223 to 6.350 mm (0.245 to 0.250 in.) from the base circle to the top of the lobe so that the resulting valve lift shall be 6.045 ± 0.05 mm (0.238 ± 0.002 in.). See Annex A4 for Camshaft Timing and Valve Lift Measurement Procedure.

10.2.4 *Fuel Pump Timing*—Closure of the pump plunger inlet port shall occur at a flywheel crank angle between 300 and 306°. on the engine compression stroke when the fuel flow-rate-micrometer is set to a typical operating position and the variable timing device lever is at full advance (nearest to operator). See Annex A4 for detailed instructions on setting and checking the fuel pump timing.

10.2.5 *Fuel Pump Inlet Pressure*—A minimum fuel head established by assembly of the fuel tanks (storage reservoirs) and flow rate measuring buret so that the discharge from them is 635 ± 25 mm (25 ± 1 in.) above the centerline of the fuel injection pump inlet.

10.3 *Assembly Settings and Operating Conditions*:

10.3.1 *Direction of Engine Rotation*—Clockwise rotation of the crankshaft when observed from the front of the engine.

10.3.2 *Injection Timing*—13.0° before-top-dead-center (btdc), for the sample and reference fuels.

10.3.3 *Injector Nozzle Opening Pressure*—10.3 ± 0.34 MPa (1500 ± 50 psi).

10.3.4 *Injection Flow Rate*—13.0 ± 0.2 mL/min (60 ± 1 s per 13.0 mL).

10.3.5 *Injector Coolant Passage Temperature*—38 ± 3°C (100 ± 5°F).

10.3.6 *Valve Clearances*:

10.3.6.1 *Engine Stopped and Cold*—Clearance between the valve stem and valve rocker half-ball set to the following approximate measurements upon assembly before the engine is operated will typically provide the controlling engine running and hot clearance:

Intake Valve	0.075 mm (0.004 in.)
Exhaust Valve	0.330 mm (0.014 in.)

These clearances should ensure that both valves have sufficient clearance to cause valve seating during engine warmup. The adjustable-length valve push-rods shall be set so that the valve rocker adjusting screws have adequate travel to permit the final clearance setting.

10.3.6.2 *Engine Running and Hot*—The clearance for both intake and exhaust valves shall be set to 0.20± 0.025 mm (0.008 ± 0.001 in.), measured under standard operating conditions with the engine running at equilibrium conditions on a typical diesel fuel oil.

10.3.7 *Oil Pressure*—172 to 207 kPa (25 to 30 psi). See Annex A4 for the Adjusting Crankcase Lubricating Oil Pressure procedure.

10.3.8 *Oil Temperature*—57 ± 8°C (135 ± 15°F).

10.3.9 *Cylinder Jacket Coolant Temperature*—100 ± 2°C (212 ± 3°F).

10.3.10 *Intake Air Temperature*—66 ± 0.5°C (150 ± 1°F).

10.3.11 *Basic Ignition Delay*—13.0° for the sample and reference fuels.

10.3.12 *Cylinder Jacket Coolant Level*:

10.3.12.1 *Engine Stopped and Cold*—Treated water/coolant added to the cooling condenser—cylinder jacket to a level just observable in the bottom of the condenser sight glass will typically provide the controlling engine running and hot operating level.

10.3.12.2 *Engine Running and Hot*—Coolant level in the condenser sight glass shall be within ±1 cm (0.4 in.) of the LEVEL HOT mark on the coolant condenser.

10.3.13 *Engine Crankcase Lubricating Oil Level*:

10.3.13.1 *Engine Stopped and Cold*—Oil added to the crankcase so that the level is near the top of the sight glass will typically provide the controlling engine running and hot operating level.

10.3.13.2 *Engine Running and Hot*—Oil level shall be approximately mid-position in the crankcase oil sight glass.

10.3.14 *Crankcase Internal Pressure*—As mentioned by a gage or manometer connected to an opening to the inside of the crankcase through a snubber orifice to minimize pulsations, the pressure shall be less than zero (a vacuum) and typically from 25 to 150 mm (1 to 6 in.) of water less than atmospheric pressure. Vacuum shall not exceed 255 mm (10 in.) of water.

10.3.15 *Exhaust Back Pressure*—As measured by a gage or manometer connected to an opening in the exhaust surge tank or main exhaust stack through a snubber orifice to minimize pulsations, the static pressure should be as low as possible, but shall not create a vacuum nor exceed 254 mm (10 in.) of water differential in excess of atmospheric pressure.

10.3.16 *Exhaust and Crankcase Breather System Resonance*—The exhaust and crankcase breather piping systems shall have internal volumes and be of such length that gas resonance does not result. See Appendix X2 for a suitable procedure to determine if resonance exists.

10.3.17 *Piston Over-Travel*—Assembly of the cylinder to the crankcase shall result in the piston protruding above the top of the cylinder surface 0.381 ± 0.025 mm (0.015 ± 0.001 in.) when the piston is at top-dead-center. Proper positioning is accomplished through the use of plastic or paper gaskets, available in several thicknesses and selected by trial and error for assembly between the cylinder and crankcase deck.

10.3.18 *Belt Tension*—The belts connecting the flywheel to the absorption motor shall be tightened, after an initial break-in, so that with the engine stopped, a 2.25 kg (5 lb) weight suspended from one belt half way between the flywheel and motor pulley shall depress the belt approximately 12.5 mm (0.5 in.).

10.3.19 *Setting Injector Nozzle Assembly Pressure and Spray Pattern Check*—(**Warning**—Personnel shall avoid contact with the spray pattern from injector nozzles because of the high pressure which can penetrate the skin. Spray pattern performance checks shall be made in a hood or where adequate ventilation insures that inhalation of the vapors is avoided.)

10.3.19.1 *Injector Opening or Release Pressure*—The pressure adjusting screw is adjustable and shall be set to release fuel at a pressure of 10.3 ± 0.34 MPa (1500 ± 50 psi). Check this setting using an injector nozzle bench tester, each time the nozzle is reassembled and after cleaning. Use of a commercial injector nozzle bench tester is recommended. See Annex A4 for procedural detail.

10.3.19.2 *Injector Spray Pattern*—Check the spray pattern for symmetry and characteristic by inspection of the impression of a single injection made on a piece of filter paper or other slightly absorbent material placed at a distance of approximately 7.6 cm (3 in.) from the nozzle. A typical spray pattern is illustrated in Fig. 2.

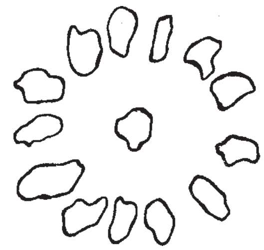


FIG. 2 Typical Injector Spray Pattern

10.3.20 *Indexing Handwheel Reading*—Handwheel readings are a simple and convenient indication of engine compression ratio which is a critical variable in the cetane method of test. The actual compression ratio is not important but an indication of compression ratio which relates to cetane number is a useful guide for selecting reference fuels to bracket the sample of diesel fuel oil. The following procedure shall be used to index the handwheel reading when the engine is new or anytime the matched handwheel assembly/cylinder head combination is interchanged or mechanically reassembled. See Appendix X3 for handwheel assembly reworking instructions.

10.3.20.1 *Handwheel Micrometer Drum and Scale Setting*—Refer to Table 1 to select the appropriate handwheel reading to be used in aligning the drum and scale.

10.3.20.2 *Basic Setting of Variable Compression Plug*—Position the variable compression plug so that the flat surface is just visible and exactly in line with the edge of the threads of the combustion pickup hole, as verified with a straightedge.

10.3.20.3 *Setting Handwheel Reading*—Tighten the small locking handwheel snugly by hand to ensure that the variable compression plug is held in place in the bore. Loosen the lock nut of the large handwheel and remove the locking L-shaped key. Turn the large handwheel so that the edge of the drum is in alignment with the 1.000 graduation on the horizontal scale. Reinstall the L-shaped key in the nearest keyway slot of the large handwheel with the shorter leg in the handwheel. A slight shifting of the handwheel to achieve slot line-up will not affect the indexing. Tighten the lock nut hand-tight to hold the key in place. Remove the locating screw from the drum and rotate the drum so that the zero graduation mark is in line with the selected reading from Table 1. Locate the screw hole in the drum which lines up with the handwheel hub hole and reinstall the locating screw. Wrench tighten the large handwheel lock nut and recheck that the variable compression plug is properly positioned and the handwheel reading is in accordance with the value in Table 1.

10.3.21 *Basic Compression Pressure*—At a handwheel reading of 1.000, the compression pressure for an engine operated at standard barometric pressure of 760 mm Hg. (29.92 in. Hg) shall be 3275 ± 138 kPa (475 ± 20 psi) when read as quickly as possible after shutdown of the engine which had been at standard operating conditions. If the condition is not within limits, recheck the basic handwheel setting and, if

TABLE 1 Handwheel Setting for Various Cylinder Bore Diameters

Cylinder Diameter, in.		Handwheel Reading
3.250	(Standard Bore)	1.000
3.260	(Rebored 0.010 in. Oversize)	0.993
3.270	(Rebored 0.020 in. Oversize)	0.986
3.280	(Rebored 0.030 in. Oversize)	0.978

necessary, perform mechanical maintenance. See Annex A4 for the Checking Compression Pressure procedure.

10.3.21.1 For engines operated at other than standard barometric pressure, the compression pressure will typically be in proportion to the ratio of the local barometric pressure divided by standard barometric pressure. As an example, an engine located where the barometric pressure is 710 mm Hg would be expected to have a compression pressure of approximately 3060± 138 kPa (444 ± 20 psi). (**Warning**—In addition to other precautions, compression pressure testing using a compression pressure gage should be completed in as short a period of time as possible to avoid the possibility of combustion occurrence due to the presence of any small amount of oil in the gage or combustion chamber.)

$$\text{Compression Pressure}_{(\text{LocalBaro.,mmHg})} = 3275\text{ kPa} \times \text{Local Baro./Standard Baro.} \tag{2}$$

$$\text{Example: Compression Pressure}_{710\text{mmHg}} = 3275 \times 710/760 = 3060\text{ kPa}$$

10.3.22 *Fuel Pump Lubricating Oil Level*—With the engine stopped, sufficient engine crankcase lubricating oil shall be added to the pump sump so that the level is at the mark on the dip stick. (**Warning**—As a result of engine operation, especially when the pump barrel/plunger assembly begins to wear, the level in the sump will increase due to fuel dilution as observed through a clear plastic side plate on the pump housing. When the level rises appreciably, the sump should be drained and a fresh charge of oil added.)

10.3.23 *Fuel Pump Timing Gear Box Oil Level*—With the engine stopped, unplug the openings on the top and at the mid-height of either side of the gear box. Add sufficient engine crankcase lubricating oil through the top hole to cause the level to rise to the height of the side opening. Replug both openings. (**Warning**—The pump and timing gear box oil sumps are not connected to each other and the lubrication for the two is independent.)

10.3.24 *Instrumentation*—Positioning of the reference pickups and injector pickup is important to ensure that timing of the injection and ignition delay functions is uniform and correct.

10.3.24.1 *Setting Reference Pickups*—These two pickups are identical and interchangeable. They are installed in a bracket positioned over the flywheel so that they clear the flywheel indicator which triggers them.

10.3.24.2 Position each pickup in the bracket so that it is properly referenced to the flywheel indicator in accordance with the instructions supplied with the specific pickup.

10.3.24.3 Measurement of pickup to flywheel indicator clearance, if required, shall be made using a non-magnetic feeler gage.

10.3.25 *Setting Injector Pickup Gap*—Set the air gap to typically 1 mm (0.040 in.) with the engine stopped.

10.3.25.1 Individual pickups may require more or less air gap to obtain steady meter operation when the engine is ultimately running but too little gap can cause the ignition delay angle display to drive off scale.

11. Calibration and Engine Qualification

11.1 *Engine Compliance*—It is assumed that the engine has been commissioned and that all settings and operating variables are at equilibrium and in compliance with basic engine and instrument settings and standard operating conditions.

11.1.1 Engine warmup requires typically 1 h to ensure that all critical variables are stable.

11.2 *Checking Performance on Check Fuels*—This engine test does not have any satisfactory standardization fuel blend or blends to qualify the engine. The Check Fuels are the most helpful means available to permit judgement of good performance.

11.2.1 Test one or more of the Check Fuels.

11.2.2 Engine performance is judged satisfactory if the cetane rating obtained on a Check Fuel is within the Check Fuel tolerance limits calculated as follows:

$$\text{Tolerance Limits} = CN_{ARV} \pm 1.5 \times S_{ARV} \tag{3}$$

where:

CN_{ARV} = the cetane number accepted reference value of the Check Fuel,

1.5 = a selected tolerance limit factor (K) for normal distributions,

S_{ARV} = the standard deviation of the Check Fuel data used to determine CN_{ARV}.

11.2.2.1 *In the context of this test method*, the statistical tolerance limit factor (K), based on a sample size (n), permits an estimation of the percentage of engines that would be able to rate the Check Fuel within the calculated tolerance limits. Based on a data set of 17 to 20 ratings used to determine the Check Fuel CN_{ARV}, and a value of $K = 1.5$, it is estimated that in the long run, in 19 cases out of 20, at least 70 % of the engines would rate the Check Fuel within the calculated tolerance limits.

11.2.3 If the results are outside this tolerance range, the engine is not acceptable for rating samples and a check of all operating conditions is warranted followed by mechanical maintenance which may require critical parts replacement. The injector nozzle can be a very critical factor and this should be the first item checked or replaced to achieve rating compliance.

12. Procedure

12.1 *Bracketing by Handwheel Procedure*—See Appendix X2 for the details of engine operation and the adjustment of each of the individual operating variables.

12.1.1 Check that all engine operating conditions are in compliance and equilibrated with the engine running on a typical diesel fuel oil. (**Warning**—In addition to other precautions, always position the ignition delay meter (Mark II and earlier models) to CALIBRATE before proceeding with fuel switching so that violent meter needle full-scale pegging does not occur. Calibration adjustment should be checked before each rating but never changed during a rating.)

12.1.2 Introduce the sample to an empty fuel tank, rinse the fuel buret, purge any air from the fuel line to the pump and position the fuel-selector valve to operate the engine on this fuel. (**Warning**—Sample and Fuel—Combustible. Vapor Harmful. See Annex A1.)

12.1.3 *Fuel Flow Rate*—Check the fuel flow rate and adjust the flow-rate-micrometer of the fuel pump to obtain 13 mL per min consumption. The final flow rate measurement shall be made over a full 60 ± 1 s period. Note the flow-rate-micrometer reading for reference.

12.1.4 *Fuel Injection Timing*—After establishing the fuel flow rate, adjust the injection-timing-micrometer of the fuel pump assembly to obtain a 13.0 ± 0.2° injection advance reading. Note the injection-timing-micrometer reading for reference.

12.1.5 *Ignition Delay*—Adjust the handwheel to change the compression ratio and obtain a 13.0 ± 0.2° ignition delay reading. Make the final handwheel adjustment in the clockwise direction (viewed from front of engine) to eliminate backlash in the handwheel mechanism and a potential error.

12.1.6 *Equilibration*—It is important to achieve stable injection advance and ignition delay readings.

12.1.6.1 Stable readings should typically occur within 5 to 10 min.

12.1.6.2 The time used for the sample and each of the reference fuels should be consistent and shall not be less than 3 min.

12.1.7 *Handwheel Reading*—Observe and record the handwheel reading as the representative indication of the combustion characteristic for this fuel sample.

12.1.8 *Reference Fuel No. 1*—Select a secondary reference fuel (*T Fuel* and *U Fuel*) blend close to the estimated cetane number of the sample.

NOTE 1—The handwheel reading vs cetane number relationship based on this procedure is engine and overhaul dependent but it can be established for each engine as testing experience is gained after each overhaul. A plot or table of handwheel readings provides a simple guide to selection of the reference fuel.

12.1.8.1 Prepare a fresh 400 or 500 mL batch of the selected reference blend.

12.1.8.2 Introduce Reference Fuel No. 1 to one of the unused fuel tanks taking care to flush the fuel lines in the same manner as noted for the sample.

12.1.8.3 Perform the same adjustment and measurement steps used for the sample and record the resulting handwheel reading.

12.1.9 *Reference Fuel No. 2*—Select another secondary reference fuel blend which can be expected to result in a handwheel reading that causes the two reference fuel handwheel readings to bracket that for the sample. The difference between the two reference fuel blends shall not exceed 5.5 cetane numbers. Typically, blends differing by 5 volume percent *T Fuel* will span about 2.7 cetane numbers and those differing by 10 volume percent *T Fuel* will span about 5.3 cetane numbers.

12.1.9.1 Prepare a fresh 400 or 500 mL batch of the selected reference fuel blend.

12.1.9.2 Introduce Reference Fuel No. 2 to the third fuel tank taking care to flush the fuel lines in the same manner as noted for the sample.

12.1.9.3 Perform the same adjustment and measurement steps used for the sample and first reference fuel and record the resulting handwheel reading.

NOTE 2—Typically, the fuel-flow-rate should be the same for both reference fuels because they are sufficiently similar in composition.

12.1.9.4 If the handwheel reading for the sample is bracketed by those of the reference fuel blends, continue the test; otherwise try an additional reference fuel blend(s) until this requirement is satisfied.

12.1.10 *Repeat Readings*—After operation on a satisfactory second reference fuel blend, perform the necessary steps to rerun Reference Fuel No. 1, then the sample and finally Reference Fuel No. 2. For each fuel, be certain to check all parameters carefully and allow operation to reach equilibrium before recording the handwheel readings. The fuel switching shall be as illustrated in Fig. 3 Sample and Reference Fuel Reading Sequence A.

12.1.10.1 If a sample is tested immediately following one for which the Reference Fuel No. 2 will be applicable, that reference fuel handwheel reading can be utilized for the new sample. The fuel switching shall thus be as illustrated in Fig. 3, Sample and Reference Fuel Reading Sequence B.

13. Calculation of Cetane Number

13.1 Calculate the average handwheel readings for the sample and each of the reference fuel blends.

13.2 Calculate the cetane number by interpolation of these average handwheel readings proportioned to the cetane numbers of the bracketing reference fuel blends in accordance with Eq 4. See Fig. 4.

13.2.1 For the Handwheel Bracketing Procedure:

$$CN_S = CN_{LRF} + \left(\frac{HW_S - HW_{LRF}}{HW_{HRF} - HW_{LRF}}\right)(CN_{HRF} - CN_{LRF}) \quad (4)$$

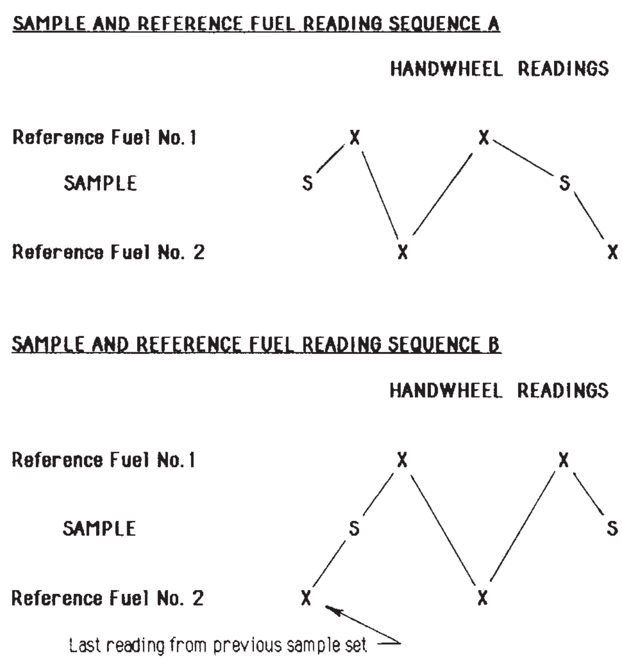
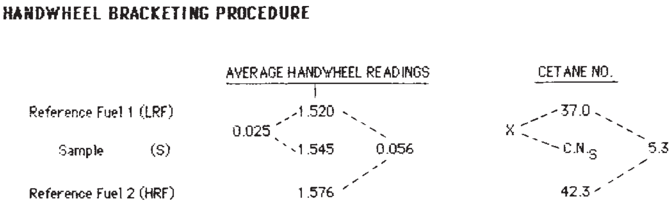


FIG. 3 Sample and Reference Fuel Reading Sequence



$$CN_S = CN_{LRF} + \left(\frac{HW_S - HW_{LRF}}{HW_{HRF} - HW_{LRF}}\right)(CN_{HRF} - CN_{LRF})$$

$$= 37.0 + \left(\frac{1.545 - 1.520}{1.576 - 1.520}\right)(42.3 - 37.0)$$

$$= 37.0 + (0.446)(5.3) \qquad = \underline{39.4}$$

FIG. 4 Example of Cetane Number Calculations

where:

CN_S	=	cetane number of sample,
CN_{LRF}	=	cetane Number of low reference fuel,
CN_{HRF}	=	cetane number of high reference fuel,
HW_S	=	handwheel reading of sample,
HW_{LRF}	=	handwheel reading of low reference fuel, and
HW_{HRF}	=	handwheel reading of high reference fuel.

13.2.2 Do not interpolate using reference fuel blend volume percent of *T Fuel* values and convert that equivalent percent to cetane number.

13.3 Round the calculated cetane number to the nearest tenth. Any cetane number ending in exactly 5 in the second decimal place shall be rounded to the nearest even tenth number; for example, round 35.55 and 35.65 to 35.6 cetane number.

14. Report

14.1 Report the calculated result as cetane number.

14.2 If the sample was filtered before testing, include this information in the report.

15. Precision and Bias

15.1 *Handwheel Bracketing Procedure Precision*—The precision of this test method and procedure based on statistical examination of interlaboratory test results is as follows:

15.1.1 *Repeatability*—The difference between two test results, obtained on identical test samples under repeatability conditions would, in the long run, in the normal and correct operation of the test method, exceed the values in Table 2 only in 1 case in 20.

TABLE 2 Cetane Number Repeatability and Reproducibility Limits

Average Cetane Number Level[A]	Repeatability Limits, Cetane Number	Reproducibility Limits Cetane Number
40	0.8	2.8
44	0.9	3.3
48	0.9	3.8
52	0.9	4.3
56	1.0	4.8

[A] Values for cetane numbers intermediate to those listed above, may be obtained by linear interpolation.

15.1.2 *Reproducibility*—The difference between two single and independent results obtained on identical test samples under reproducibility conditions would, in the long run, in the normal and correct operation of the test method, exceed the values in Table 2 only in 1 case in 20.

15.1.3 Repeatability precision limits are based on the ASTM National Exchange Group (NEG) monthly sample testing program data from mid-1978 through 1987. During this period each exchange sample was rated twice on the same day by the same operator on one engine in each of the Member laboratories.[14]

15.1.4 Reproducibility precision limits are based on the combined NEG monthly sample testing program data from mid-1978 through mid-1992, the Institute of Petroleum monthly sample data for 1988 through mid-1992 and the Institut Francais du Petrole monthly sample data for 1989 through early 1992.

15.1.5 The combination of the large number of sample sets and the fact that each sample is tested by 12 to 25 laboratories provides a comprehensive picture of the precision achievable using this test method. Analyzed graphically, the respective sample standard deviations were plotted vs cetane number. The variation in precision with respect to cetane number level for these data is best expressed by a linear regression of the values. The average standard deviation for each cetane number level has been multiplied by 2.772 to obtain the respective limit values.

15.2 *Bias*—The procedure in this test method for cetane number of diesel fuel oil has no bias because the value of cetane number can be defined only in terms of the test method.

16. Keywords

16.1 cetane number; diesel performance; ignition delay

[14] Supporting data (a listing of the data and the analyses used to establish the precision statements) have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR: D02–1303.

ANNEXES

(Mandatory Information)

A1. WARNING INFORMATION

A1.1 Introduction

A1.1.1 In the performance of the standard test method there are hazards to personnel. These are indicated in the text. For more detailed information regarding the hazards, refer to the appropriate Material Safety Data Sheet (MSDS) for each of the applicable substances to establish risks, proper handling, and safety precautions.

A1.2 Warning

A1.2.1 Combustible. Vapor harmful.

A1.2.2 *Applicable Substances*:

A1.2.2.1 Diesel fuel oil.

A1.2.2.2 Reference material.

A1.2.2.3 Reference fuel.

A1.2.2.4 *n*-cetane.

A1.2.2.5 Heptamethylnonane.

A1.2.2.6 Alpha-methylnaphthalene.

A1.2.2.7 Secondary reference fuels, *T Fuel* and *U Fuel*

A1.2.2.8 Check Fuel.

A1.2.2.9 Kerosine.

A1.2.2.10 Warmup fuel.

A1.2.2.11 Engine crankcase lubricating oil.

A1.3 Warning

A1.3.1 Flammable. Vapors harmful if inhaled. Vapors may cause flash fire.

A1.3.2 *Applicable Substances*:

A1.3.2.1 Petroleum based solvent.

A1.4 Warning

A1.4.1 Poison. May be harmful or fatal if inhaled or swallowed.

A1.4.2 *Applicable Substances*:

A1.4.2.1 Ethylene glycol based antifreeze

A2. ENGINE EQUIPMENT DESCRIPTION AND SPECIFICATIONS

A2.1 Engine Equipment

A2.1.1 The single cylinder cetane test engine is manufactured as a complete unit by Waukesha Engine Division, Dresser Industries, Inc. and consists of both critical and non-critical equipment. The Waukesha Engine Division designation is Model CFR F-5 Cetane Method Diesel Fuel Rating Unit. Waukesha Engine Division Part Numbers or References are included in parenthesis after the items where applicable.

A2.1.1.1 See Table A2.1.

TABLE A2.1 General Engine Characteristics and Information

Item	Description
Crankcase	Model CFR-48 (Preferred), High or Low Speed Models (Optional)
Cylinder Type	Single bore cast iron with integral coolant jacket
Cylinder Head Type	Cast Iron with turbulence precombustion chamber, variable compression plug passage, integral coolant passages, and in-head valve assembly
Compression Ratio	Adjustable 8:1 to 36:1 by external handwheel assembly
Cylinder Bore (Diameter), in.	3.250 (Standard), Reboring to 0.010, 0.020, 0.030 over is acceptable
Stroke, in.	4.50
Displacement, cu in	37.33
Valve Mechanism	In-head with enclosure
Intake and Exhaust Valves	Stellite faced, plain type without shroud
Piston	Cast iron, flat top
Piston Rings:	
Compression Type	4, Ferrous, straight sided (Top may be chrome plated—Optional)
Oil Control	1, Cast iron, one piece, slotted (Type 85)
Camshaft Over lap, degree	5
Fuel System	Injection pump with variable timing device and injector
Injector	Holder with by-pass pressure release valve
Spray Nozzle	Closed, differential-needle, hydraulically-operated, pintle type
Weight of Engine	Approximately 400 kg (880 lb)
Weight of Complete Test Unit	Approximately 1250 kg (2750 lb)

A2.2 **Critical Equipment**—Critical engine components and primary assemblies which shall be used for this test method are listed. The bearings, gears, seals, covers, special fittings or hardware and gaskets manufactured by Waukesha Engine Division and applicable to each critical assembly shall also be considered critical.

A2.2.1 *Crankcase Assembly*—Model CFR-48 (109520D) specified to include the following major items (See Fig. A2.1):

A2.2.1.1 Crankshaft Assembly (A109511H).

A2.2.1.2 Piston Assembly (0023204B).

A2.2.1.3 Rings, Piston, Compression, Straight (106222A), 4 required.

NOTE A2.1—Ring, Piston, Compression, Straight, Chrome (106222B), Use of a chrome ring in the top groove is optional with 3 compression rings (106222A) in the other 3 compression ring grooves.

A2.2.1.4 Ring, Piston, Oil (23505).

A2.2.1.5 Connecting Rod Assembly (BA111666).

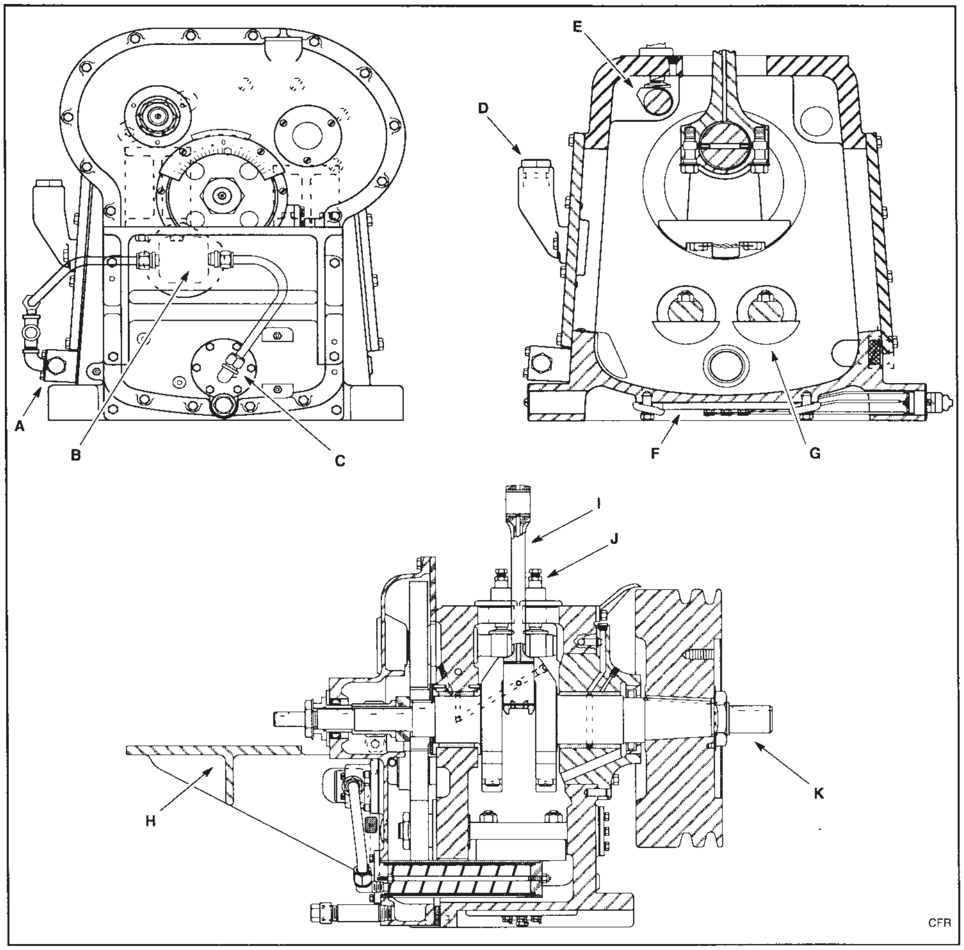
A2.2.1.6 Camshaft (109583B).

A2.2.1.7 Balancing Shaft, 2 required (109510A).

A2.2.1.8 Counterweight for Balancing Shaft, (109565) 2 required.

A2.2.1.9 Flywheel (109501H) (applicable for 50 or 60 Hz units).

A2.2.1.10 Oil Pump Assembly (110150A).



A	Oil Pressure Control Valve	G	Balancing Shafts (2)
B	Oil Pump	H	Fuel Pump Support
C	Oil Suction Pump	I	Connecting Rod
D	Crankcase Breather Body	J	Valve Lifters (2)
E	Camshaft	K	Crankshaft
F	Oil Heater		

FIG. A2.1 CFR-48 Crankcase—Sectional Views

A2.2.1.11 Oil Suction Screen Assembly (0109552).

A2.2.1.12 Oil Pressure Control Valve Assembly (A109538A).

A2.2.1.13 Crankcase Breather Assembly (Group 070.00).

A2.2.1.14 Accessory Bracket, Fuel Pump (109515A).

A2.2.1.15 Stud Assembly, Crankcase to Cylinder (B839.4 required: B5764.2 required).

A2.2.1.16 Stud Nuts, Cylinder (105361, 6 required).

A2.2.2 *Cylinder Assembly*—(0105081) of cast iron with internal coolant passages and a basic bore diameter of 3.250 in., specified to include the following (See Fig. A2.2):

A2.2.2.1 Stud Assembly, Cylinder to Head (B-8200, 5 required).

A2.2.2.2 Stud Nuts, Cylinder Head (105361, 7 required).

A2.2.2.3 Crankcase to Cylinder Spacer Gasket Set—Selection of one or more gaskets must be made at the time of cylinder assembly to achieve the specified piston over travel. Available gaskets are:

Gasket, Cylinder Base—0.021 in. thick (105181)
Gasket, Cylinder Base—0.015 in. thick (105181A)
Gasket, Cylinder Base—0.010 in. thick (105181B)
Gasket, Cylinder Base—0.003 in. thick (105181C)

A2.2.3 *Cylinder Head Assembly*—(AF105082B) of cast iron with internal coolant passages, a flat-top combustion chamber surface, a horizontal and cylindrical precombustion chamber to accept a matched and pinned, variable compression ratio handwheel housing on one end and including a passage for insertion of an injector assembly at the other end. An angled passage, 0.5 in. square in cross-section, connects the precombustion chamber to the main combustion chamber. The assembly is specified to include the following major items (See Fig. A2.2 and Fig. A2.3):

A2.2.3.1 Integral but replaceable, hardened, Valve Seat Inserts (105987A),

A2.2.3.2 Integral but replaceable Valve Guides (23109A),

A2.2.3.3 Intake and Exhaust Valve (106625),

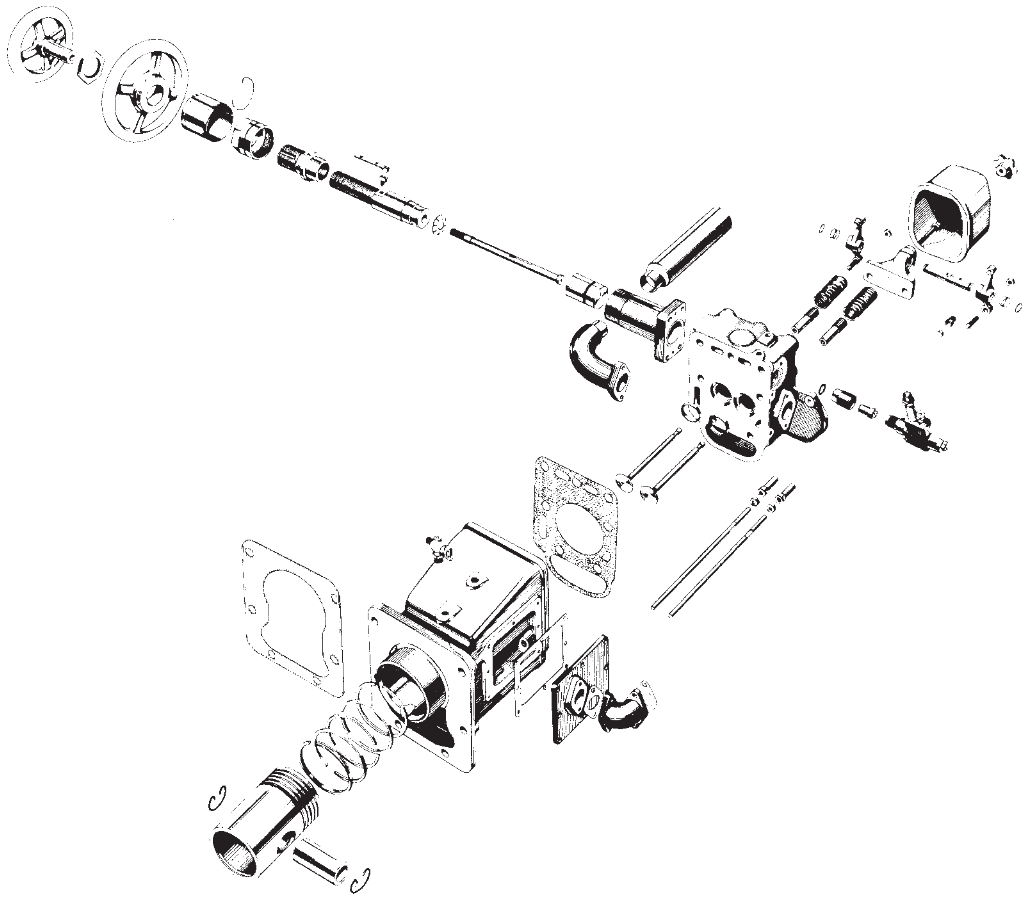


FIG. A2.2 Exploded View of Cetane Cylinder and Head Assembly

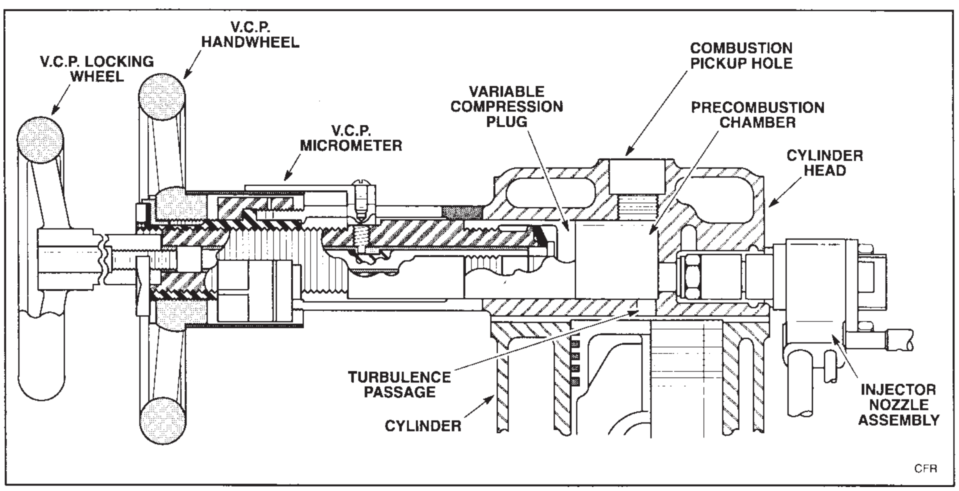


FIG. A2.3 Cylinder Head and Handwheel Assembly—Sectional View

A2.2.3.4 Valve Spring, Rotator Assembly (G-806-3) including spring (109659), spacer (110200), felt (B4680), rotator (110165B) and tapers (109658),

A2.2.3.5 Valve Rocker Arm Subassembly (Group G-002.10).

A2.2.4 *Handwheel*—Variable Compression Plug Assembly—(A105097) including an expandable plug that is screwed in or out of the handwheel housing, an adjusting handwheel, a micrometer scale and barrel vernier to indicate plug position, and a locking wheel to cause a dished, split-washer to flatten and expand the variable compression plug to seal the precombustion chamber. See Fig. A2.3.

A2.2.5 *Cylinder Coolant System Assembly*, specified to include the following major items.

A2.2.5.1 Condenser Body Assembly (A109264A) including condenser coil subassembly, baffle tube and sight glass subassembly.

A2.2.5.2 Condenser Water Pipe Assembly (0109131B).

A2.2.5.3 Water Inlet Pipe (105083).

A2.2.6 *Inlet Air System Assembly* (Group G-841-9) specified to include the following major items:

A2.2.6.1 Air Silencer Elbow (105188), with gaskets, nuts and washers.

A2.2.6.2 Air Heater Silencer Assembly (AA110468).

A2.2.6.3 Air Inlet Heater Assembly (A106583E).

A2.2.7 *Fuel System*—Components required to permit constant pressure introduction of sample or reference fuel blends to an injection pump, the injection pump with adjustment for flow rate, an integral variable timing device, a pump gallery air trap device, a high pressure fuel delivery tubing and an injector nozzle assembly with mechanism to permit sensing of the time of injection. Critical Equipment is specified to include the following major items:

A2.2.7.1 *Fuel Injection Pump Assembly (C106941C)*

Bosch specification APE 1B-50P-5625C Injection Pump equipped with a 5 mm Barrel and Plunger Assembly (110754).

A2.2.7.2 *Fuel Selector-Valve Assembly (A111388)*

Including pump inlet fitting (105303A).

A2.2.7.3 *Fuel Line Air Trap Assembly (Group G-808-9)*

Including pump outlet fitting (105302).

A2.2.7.4 *Variable Timing Device Assembly (Group G-808-10)*

For integral mounting to the pump housing and including the Timing Device (110778) and associated Disk Coupling (B9496).

A2.2.7.5 *Shaft Coupling Assembly (Group G-808-11)*

For connection of the variable timing device shaft to the engine camshaft.

A2.2.7.6 *Fuel Injection Tube or Line (A106318E)*

For connection of the fuel pump to the injector assembly. This tube shall be 28 in. long of ¼ in. OD, ¹⁄₁₆ in. ID steel tubing.

A2.2.7.7 *Fuel Injector Assembly (A75067E)*

Including an O.M.T., S.p.A. specification SP8-S-1003/W Injector Nozzle (110700), a nozzle opening pressure adjustment, an extended pintle feeler pin for indication of time of injection and a fuel by-pass valve to release injection pump fuel pressure from the nozzle.

A2.2.8 *Power Absorption Motor*

Reluctance-type, synchronous, single-speed, electric motor for belt drive connection to the engine and capable of both starting the engine and absorbing the power developed when combustion is in process. Waukesha Engine Division is the sole supplier of this item in order to insure meeting the following speed and load absorbing specifications. Part numbers are dependent on the three-phase electrical service voltage and frequency available at the site of unit installation.

A2.2.8.1 *Speed*

1200 rpm ± 1 % for 60 Hz, three-phase power; 1500 rpm ± 1 % for 50 Hz, three-phase power.

A2.3 Engine Dimensions

A2.3.1 See Table A2.2.

A2.4 Equivalent Equipment

A2.4.1 *Crankcase Assembly*—Commonly known as the standard or low-speed crankcase which was the original model developed in 1933. Parts for this crankcase are no longer manufactured.

A2.4.2 *Crankcase Assembly*—Commonly known as the high-speed crankcase, this model was the standard version manufactured from about 1939 through 1954. Parts for this crankcase are no longer manufactured.

A2.4.3 *Cylinder Assembly*—(0105081) which has, through operational wear, exceeded the basic bore diameter tolerance and has been successfully rebored to 0.010, 0.020, or 0.030 in. oversize.

A2.4.4 *Piston Assembly* for rebored cylinder assemblies as follows:

A2.4.4.1 For 0.010 in. oversize cylinders (23204B1).

A2.4.4.2 For 0.020 in. oversize cylinders (23204B2).

A2.4.4.3 For 0.030 in. oversize cylinders (23204B3).

A2.4.5 *Ring, Piston, Compression, Straight* for rebored cylinder assemblies as follows:

A2.4.5.1 For 0.010 in. oversize pistons (106222A1) or chrome (106222B1).

A2.4.5.2 For 0.020 in. oversize pistons (106222A2) or chrome (106222B2).

A2.4.5.3 For 0.030 in. oversize pistons (106222A3) or chrome (106222B3).

A2.4.6 *Ring, Piston, Oil* for rebored cylinder assemblies as follows:

A2.4.6.1 For 0.010 in. oversize pistons (23505-1).

A2.4.6.2 For 0.020 in. oversize pistons (23505-2).

A2.4.6.3 For 0.030 in. oversize pistons (23505-3).

A2.4.7 *Injector Nozzle*, American Bosch ADN-30S-3/1 (110700) which was the predecessor to the current SP8-S-1003/W but which is no longer manufactured.

A2.5 *Non-Critical Equipment and Specifications*—A number of components and devices are required to integrate the critical equipment items into a complete working system or unit. Many of these are common hardware, tubing, fasteners and electrical items potentially available from multiple sources. In some cases, however, selection of specific sizes or specification criteria are important to achieve the proper conditions for the cetane testing equipment unit. Important criteria for a component are included when applicable.

A2.5.1 *Foundation and Bedplate*:

A2.5.1.1 *Foundation*

Typically, in the form of a reinforced concrete block, site poured, the foundation should be approximately 700 mm wide, 1320 mm long and a minimum of 280 mm high (28 in. wide, 52 in. long and a minimum of 11 in. high). Height of the foundation should be minimized so that the fuel sample reservoirs are at an elevation for safe pouring of fuel oil by operators of average height without the use of a raised platform or step in front of the engine. If the unit is placed on an industrial building floor of reinforced concrete approximately 200 mm or 8 in. thick, no special support for the foundation is required.

TABLE A2.2 Engine Dimensions, Manufacturing Tolerances and Replacement Limits

Item	Basic Dimension	Manufacutring Tolerances	Replacement Limits
Crankcase:			
Oil Passages in Crankcase	Pass ¼ in. rod		
Crankshaft Bearings:			
Front Main:			
Journal Diameter	3.00		
Journal to Bearing Clearance		0.0035 to 0.0049	0.006 max
Rear Main:			
Journal Diameter	3.00		
Journal to Bearing Clearance	...	0.0035 to 0.0049	0.006 max
Main Bearing to Case Clearance (Both)		0.0005 to 0.002	...
Crankshaft End-play	...	0.006 to 0.008	0.010 max
Connecting Rod Bearing (Big-End):			
Crankshaft Journal Diameter	2.50		
Journal to Bearing Clearance	...	0.0011 to 0.0036	0.005 max
End-play	...	0.008 to 0.014	0.016 max
Connecting Rod Bearing (Piston Pin End):			
Rod End to Piston Boss Clearance	1⁄16 min	...	...
Piston Pin to Bushing Clearance	...	0.0005 to 0.0010	0.015 max
Connecting Rod Alignment:			
(1)	Piston wall perpendicular to axis of journal within 0.003		
(2)	Piston pin twist in length of big-end bearing within 0.002		
(3)	Centerline of rod perpendicular to axis of bearings within 0.003		
Camshaft Bearings:			
Camshaft Journal Diameter:			
Front		1.7795 to 1.7805	
Rear		1.2485 to 1.2495	
Front Journal to Bearing Clearance	...	0.0015 to 0.003	0.004 max
Rear Journal to Bearing Clearance	...	0.002 to 0.0035	0.004 max
Bearing to Case Clearance (Both)	...	0.0005 to 0.002	...
End-play	...	0.002 to 0.005	0.007 max
Balancing Shaft Bearings:			
Balancing Shaft Journal Diameter		1.748 to 1.749	
Shaft to Bearing Clearance (Both)	...	0.0015 to 0.003	0.004 max
Bearing to Case Clearance (Both)	...	0.0005 to 0.002	
End-play	...	0.002 to 0.006	0.010 max
Idler Gear:			
Stub Shaft Diameter		0.9980 to 0.9985	
Stub Shaft to Bearing Clearance	...	0.0015 to 0.003	0.004 max
End-play	...	0.002 to 0.004	0.008 max
Gear Tooth Backlash	...	0.002 to 0.004	0.006 max
Tappet Guide Clearance	...	0.0005 to 0.002	0.003 max
Valve Timing (Based on 0.008 ± 0.001 valve clearance):			
Inlet Valve Opens	10° atdc ± 2.5°		
Inlet Valve Closes	34° abdc		
Exhaust Valve Opens	40° bbdc		
Exhaust Valve Closes	15° atdc ± 2.5°		
Flywheel:			
Side Face Runout	...	0.005 max	0.007 max
Rim Surface Eccentricity	...	0.003 max	0.005 max
Piston:			
Piston Diameters:			
Top Land	3.235 to 3.237	NOTE:	
Second/Fifth Lands	3.242 to 3.244	oversize piston diameter dimensions increase	
Skirt Diameter	3.2465 to 3.2475	0.010, 0.020 and 0.030 in respectively	
Piston to Cylinder Clearance			
Top Land	...	0.013 to 0.015	
Second/Fifth Lands	...	0.006 to 0.008	
Skirt	...	0.0025 to 0.0035	0.0045
Ring to Land Side Clearances:			
Top		0.001 to 0.003	0.004
All Others	...	0.001 to 0.0025	0.0035
Ring Gap Clearances:			
Compression Rings	...	0.007 to 0.017	0.030
Oil Ring	...	0.010 to 0.018	0.030
Piston Pin Diameter		1.2495 to 1.2498	
Pin to Piston Clearance		0.0002 to 0.0004	0.002
Piston Pin Retainers (Truarc):			
Free Diameter after Compression	1.340 min		
Piston Pin Hole Alignment		0.001 max.	0.0015
Piston Over-Travel:			
Piston top above top of cylinder	0.014 to 0.016		
Standard Cylinder:			
Internal Diameter	3.250	3.250 to 3.2515	0.006 over original bore

NOTE A2.2—Reboring of cylinders to + 0.010, + 0.020, or + 0.030 inch oversize is permitted with a tolerance of 0.0000 to + 0.0015 inch.

TABLE A2.2 *Continued*

Item	Basic Dimension	Manufacutring Tolerances	Replacement Limits
Bore Out of Round	...	0.0005 max.	0.0025
Bore Surface Quality	...	10 to 20 microinches	Scored and/or pitted
Hardness, Bore Surface		200 to 235 Brinell	...
Wall Thickness		0.312 to 0.375	...
Cylinder Head:			
Hardness, Combustion Chamber Surface		180 to 220 Brinell	...
Combustion Pick-up Hole Depth			
(Top face to bottom of variable compression plug hole)		2.2812 to 2.3125	...
Variable Compression Plug Hole Diameter	1.6250	1.6245 to 1.6250	1.630 max.
Nozzle Hole Diameter		0.554 to 0.557	
Nozzle Seat Counter Bore (O.D.)		0.4062 to 0.4375	
Nozzle Sealing Ring Groove:			
Diameter		1.333 to 1.343	...
Width		0.187 to 0.192	...
Hole Diameter for Guide		0.6250 to 0.6255	
Valve Port			
Concentricity to Valve Axis		±0.031	...
Rocker Arms:			
Bearing Clearance, plain		0.001 to 0.002	...
Bearing Shaft Diameter		0.6230 to 0.6235	
Ball Seats		Smooth and fit ball	
Valves, Intake and Exhaust:			
Stem Diameter	0.3725	0.3725 to 0.3720	0.3705 min.
Face Angle, degrees	45	...	...
Concentricity, Stem to Face (Run-out)	...		0.0015 max.
Valve Guides, Intake and Exhaust:			
Internal Diameter	0.3750	0.3750 to 0.3765	0.3785 max.
Valve Guide to Valve Stem Clearance:		0.003 to 0.004	0.005 max.
Valve Seat Inserts, Intake and Exhaust:			
Concentricity, Seat to Guide	...	0.0010 max.	...
Seat Width	...	0.050 to 0.060	0.070 max.
Face Angle, degrees		45°	...
NOTE—For interference angle approach, use face angle of 46 to 47° on seats.			
Valve Head Recess from Cylinder Head Surface	0.020 min.	0.020 to 0.025	0.060 max.
Valve Springs:			
Free Length (rotator type)		2.125 min.	2.125 min.
Handwheel Assembly:			
Variable Compression Plug:			
External Diameter		1.6230 to 1.6235	
Internal Diameter (At Head)		1.4585 to 1.4590	
Split Locking Washer Diameter (Ground)		1.457 to 1.458	
Housing Nut to Sleeve Clearance		0.010 max.	0.010 max.
Fuel Injection Pump:			
Plunger Diameter	5 mm		
Plunger Lift at Port Closure		0.075 to 0.091	
Fuel Injector Nozzle:			
Pintle Lift		0.004 to 0.006	0.006 max.
Fuel Injection Tube or Line (High Pressure):			
Bore	1⁄16		
Length	28		

A2.5.1.2 *Bedplate (27671H)*, of cast iron, 24 in. wide, 48 in. long and 4 in. high such that the engine and power absorption motor can be solidly mounted and aligned as well as providing a platform for assembly of accessory electrical equipment, controls, instrumentation and utility connections.

A2.5.2 *Heater for Crankcase (B3109A)*, dual element, 300 watt maximum, surface mounting, flat, circular electrical heater.

A2.5.3 *Exhaust Discharge System Assembly (023242A and A109887E)*—Piping, with or without water cooling, suitable to discharge exhaust fumes from the combustion chamber to atmosphere and having adequate volume and length to comply with the specified operating conditions for exhaust back pressure without resonance.

A2.5.4 *Filter Assembly for Crankcase Oil (AA111345)*.

A2.5.5 *Fuel Oil Sample and Reference Fuel Reservoir Assembly (Groups 216 and 400)*—Minimum of three (3) fuel tanks each of 300 mL minimum capacity with a sight glass assembly to indicate fuel level and including discharge tubing of stainless steel or other material impervious to diesel fuel oil. Discharge tubing diameter shall be as small as practical to minimize system holdup but shall not be smaller than that of either 10 mm OD or 5⁄16 in. OD standard tubing.

A2.5.6 *Belting, Engine Flywheel to Power Absorption Motor*—Set of two "C" section, typically of 2160 mm or 85 in. length (027970 for 60 Hz power; OB5500 for 50 Hz power).

A2.5.7 *Electrical Switchgear*, including input connections and circuit protection for three phase power to operate the power absorption motor and single phase power to operate start-stop circuitry, controls, heaters, safety devices and instrumentation. Circuit design shall ensure that failure of either the single or three phase power source will disconnect the other source.

A3. INSTRUMENTATION DESCRIPTION AND SPECIFICATIONS

A3.1 Instrumentation

A3.1.1 The single cylinder cetane test engine is manufactured by Waukesha Engine Division, Dresser Industries and includes both critical and non-critical instrumentation. Waukesha Engine Division Part Numbers are included in parenthesis after the items where appropriate.

A3.2 *Critical Instrumentation*—Critical instrumentation components or specifications for instrumentation which shall be used for this test method are listed.

A3.2.1 *Cetane Meter Specification*—The instrumentation shall be capable of sensing diesel engine combustion cycle events. The parameters which shall be indicated are as follows:

A3.2.1.1 *Injection Advance*, in terms of the crank angle degrees before top-dead-center at which fuel injection is initiated.

A3.2.1.2 *Ignition Delay*, in terms of the crank angle degrees from the time of fuel injection to the first indication of combustion.

A3.2.1.3 The crank angle degree values shall be stable average measurements of the results of multiple combustion cycles presented in either analog or digital form. The range shall be 0 to 18°. The readability shall be at least 0.1°.

A3.2.2 *Cetane Meter*, Waukesha Dual Digital Cetane Meter (A111462B).

A3.2.3 *Cetane Meter Transducers*—Pickups required to provide input pulses to the dual digital cetane meter to indicate critical engine cycle events.

A3.2.3.1 *Reference Pickups (111464A)*

Two are required to establish a crank angle degree time base for calibration of the dual digital cetane meter.

A3.2.3.2 *Injection Pickup (111465A)*

To sense the beginning of fuel injection.

A3.2.3.3 *Combustion Pickup (111463A)*

To sense the beginning of combustion as evidenced by a significant increase in the rate-of-change of pressure in the combustion chamber.

A3.3 Equivalent Instrumentation

A3.3.1 *Ignition Delay Meter, Model Mark I*, which is no longer manufactured or serviced but which, as the predecessor to the Mark II, meets the requirements of the specifications with the exception that it is only readable to 0.25°.

A3.3.2 *Ignition Delay Meter, Model Mark II (A111462)*, which is no longer manufactured but meets the requirements of the specifications with the exception that it is only readable to 0.25°.

A3.3.3 *Expanded Scale Meter Kit with Ignition Delay Meter, Mark II*—The Expanded Scale Meter Kit (made in limited quantity and no longer manufactured or serviced) upgrades the Mark II instrument so that crank angle events can be read to 0.1°.

A3.3.4 *Cetane Meter Transducers*—pickups required to provide input pulses to the Cetane Meter to indicate critical engine cycle events.

A3.3.4.1 Reference Pickups (111464) 2 required to establish a crank angle degree time base for calibration of the Mark I and Mark II Ignition Delay Meters.

A3.4 Non-Critical Instrumentation

A3.4.1 *Temperature Measurement*:

A3.4.1.1 *Intake Air Thermometer Assembly (0106317A)*, using Thermometer (106317A) having a range from 15 to 70°C graduated in 1°C divisions (60 to 160°F graduated in 1°F divisions) and conforming to the requirements for Thermometer 83C (83F) in Specification E 1.

A3.4.1.2 *Intake Air Temperature Controller*, with associated thermal sensor, for on/off (AA111412B) or proportional temperature control to within the specified limits as measured by the Intake Air Thermometer.

A3.4.1.3 *Cylinder Jacket Coolant Thermometer Assembly (0105180)*, using Thermometer (105180) having a range from −15 to 105°C graduated in 1°C divisions (0 to 220°F graduated in 2°F divisions) and conforming to the requirements for Thermometer 82C (82F) in Specification E 1.

A3.4.1.4 *Injector Coolant Passage Thermometer Assembly (0105180)*, using Thermometer (105180) having a range from −15 to 105°C graduated in 1°C divisions (0 to 220°F graduated in 2°F divisions) and conforming to the requirements for Thermometer 82°C (82°F) in Specification E 1.

A3.4.1.5 *Engine Crankcase Lubricating Oil Temperature Indicator (105321D)*, having a range of 15 to 85°C readable to 3°C (60 to 180°F readable to 5°F).

A3.4.2 *Pressure Measurement*:

A3.4.2.1 *Crankcase Internal Pressure Gage (pressure/vacuum gage) (109929)*, with a range that includes −500 to 500 mm (−20 to 20 in.) of water. A water manometer may be substituted.

A3.4.2.2 *Exhaust Back Pressure Gage*—with a range that includes 0 to 500 mm (0 to 20 in.) of water. A water manometer is a satisfactory alternative.

A3.4.3 *Flow Rate Measurement*:

A3.4.3.1 *Fuel Buret (106334)*, 16 mm I.D. glass buret, 176 mm long with 1 mL graduations.

A3.4.3.2 *Fuel Flow Rate Micrometer Assembly (0109427)*, readable to 0.025 mm (0.001 in.).

A3.4.4 *Time Measurement:*

A3.4.4.1 *Fuel Flow Rate Timer*

Any commercial stop watch or electrical timer having a range in excess of 60 s and graduated in tenths of 1 s.

A3.4.4.2 *Fuel Injection Timing Micrometer Assembly (0109427)*

Readable to 0.025 mm (0.001 in.).

A4. APPARATUS ASSEMBLY AND SETTING INSTRUCTIONS

A4.1 *Camshaft Timing & Valve Lift Measurement:* The camshaft for the Model CFR-48 crankcase used for the cetane method has intake and exhaust cam lobes both ground to produce a valve lift of 0.238 in. Each lobe is designed to include a quieting ramp at the beginning and end of the contour change from the base circle diameter. These quieting ramps are flat spots in the contour which occur at 0.008 to 0.010 in. rise from the base circle of the lobe and which extend for typically 4 to 6° of crank angle rotation. Actual valve lift does not take place until valve clearance is overcome and this is essentially coincident with the flat spot of the quieting ramp. The maximum height of the lobe from the base circle is typically 0.248 in.

A4.1.1 *Measurement Principle:* It is difficult to define the actual point at which a valve should open or close because the event takes place on the quieting ramp where the rate-of-change of the cam profile is minimal. The following procedure uses a point higher up on the contour of the lobes where maximum lift velocity occurs. Thus, all timing events are referenced to the flywheel crank angle degree readings which occur at a rise of 0.054 in. off the cam lobe base circle. Timing of the camshaft can be judged by measurement of the intake valve opening event which along with the exhaust valve closing event are the so-called "top end" events that are most critical. Fig. A4.1 illustrates both the intake and exhaust lobe profiles and their relationship in the 720° of rotation of the flywheel during one combustion cycle.

A4.1.2 *Timing Check Procedure*:

A4.1.2.1 Measurement is best made when the cylinder assembly is removed from the crankcase although it is possible with the cylinder, head and valve mechanism in place.

A4.1.2.2 Assemble a dial indicator on the deck of the crankcase so that it can be positioned to indicate the lift of the intake valve tappet.

A4.1.2.3 The dial indicator must have a minimum travel of 0.250 in. and read to 0.001 in.

A4.1.2.4 Position the flywheel to top dead center (tdc) on the compression stroke and zero the dial indicator to zero.

A4.1.2.5 Rotate the flywheel in the normal direction until the valve tappet rises causing movement of the dial indicator.

A4.1.2.6 Continue flywheel rotation until the dial indicator reading is 0.054 in.

A4.1.2.7 Read the flywheel crank angle and compare it to the specification which is 30°.

A4.1.2.8 If the observed crank angle is within 30 ± 2°, the timing is satisfactory. Otherwise, the camshaft needs retiming either by shifting the cam gear with respect to the crankshaft or by locating the cam gear on its shaft by using one of the other three keyways. Changing the point of mesh of the cam gear with respect to the crankshaft gear by one full gear tooth makes a 9.5° change on the flywheel for a given mark. Four keyways in the cam gear permit shifts of timing in 1°, 11 min increments for a given mark. Cam gears are supplied with an X mark at the tooth to be aligned with the corresponding X mark on the crankshaft gear. If another keyway is used, the gear X mark is

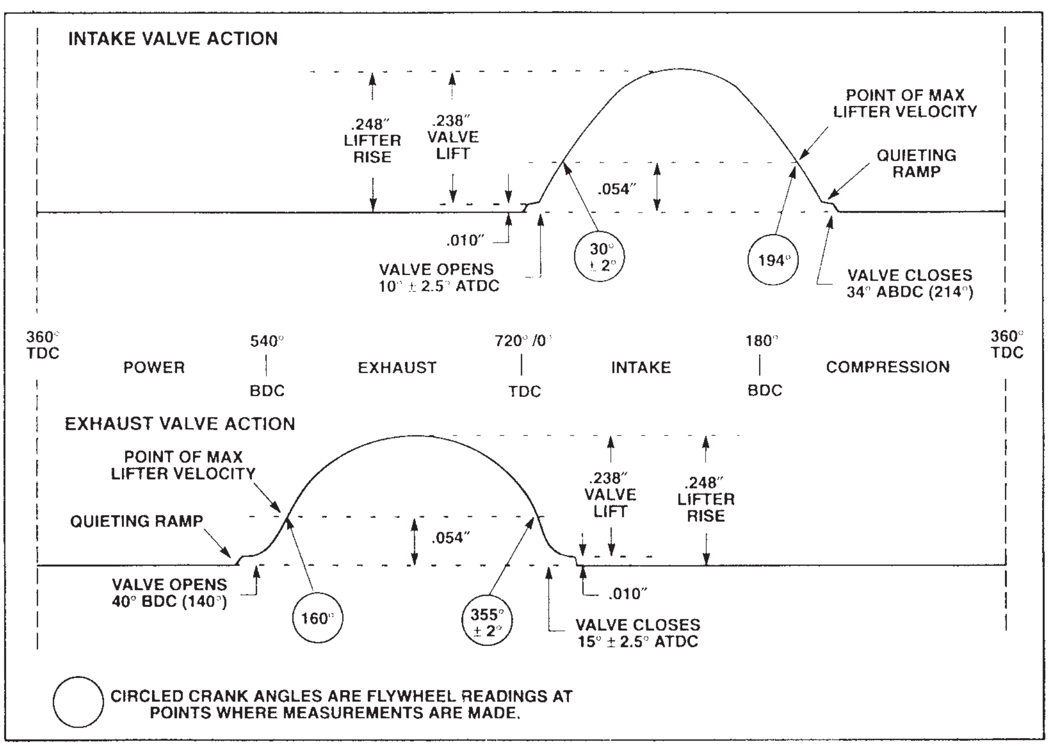


FIG. A4.1 Camshaft Timing Diagram

irrelevant and the proper tooth for the unmarked keyway must be determined. Greater detail is available from the engine manufacturer.

NOTE A4.1—The other valve opening and closing events may also be checked but the single measurement based on the intake valve opening event is sufficient to make the judgement as to proper camshaft timing.

A4.1.3 *Valve Lift Check Procedure*:

A4.1.3.1 With the dial indicator still positioned over the intake valve tappet, continue rotation of the flywheel until a maximum reading is obtained on the dial indicator.

A4.1.3.2 Read the dial indicator and compare it to the specification which is 0.246 to 0.250 in. If the rise is less than 0.246 from the base circle of the cam, wear of the lobe has occurred and camshaft replacement is indicated.

A4.1.3.3 Valve lift for the exhaust cam lobe should also be checked by repeating the procedure with the dial indicator positioned over that valve tappet. The lift specification is the same as for the intake valve.

A4.2 *Fuel Pump Timing*—Pump timing involves coupling the drive shaft of the variable timing device of the pump assembly to the engine camshaft so that the time of fuel injection occurs at the proper point in the combustion cycle. With the pump shaft rotated to cause the pump plunger to just close the fuel inlet ports, the engine flywheel shall be positioned between 300 and 306° on the compression stroke.

A4.2.1 Fuel pump timing is required whenever the pump is disassembled or when critical pump parts are replaced. Fig. A4.2 illustrates the important parts related to the timing procedure.

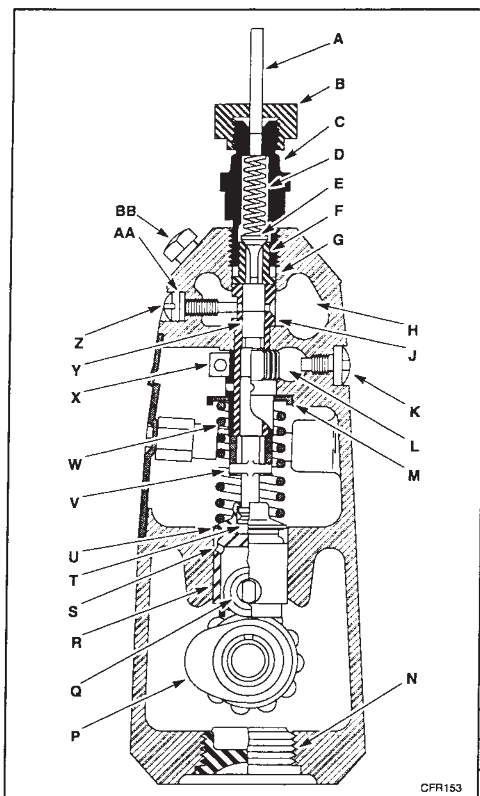
A4.2.2 Disconnect the fuel injection tube from the fuel pump outlet and remove delivery valve holder C, spring D and delivery valve E from the pump as shown in Fig. A4.2. (**Warning**—Wear gloves to protect lapped or polished surfaces that could be etched by body acid if handled with bare fingers.) (**Warning**—Immerse all disassembled parts in a container of diesel fuel oil such as secondary reference fuel. Any mated parts, such as delivery valve and seat or barrel and plunger assembly, must be kept together. When making replacements always use a complete mated assembly. Wash each part in a clean diesel fuel oil and wipe it with a clean, lint-free cloth. Check replacement parts by number and visual inspection. Lubricate moving parts with SAE 30 engine crankcase lubricating oil before assembly.)

A4.2.3 Reinstall delivery valve holder C without the spring and delivery valve.

A4.2.4 Provide and install suitable items to use a rubber bulb to blow air into the delivery valve holder C when instructed.

A4.2.5 Disconnect the tube that is between buret D, Fig. 1 and the glass fuel line air trap on the injection pump. Connect a piece of plastic tubing to the fuel line air trap connection and submerge the other end of this tube in a small container of diesel fuel oil such that bubbling in the container may be observed when appropriate.

A4.2.6 Set the fuel selector-valve between, rather than on, the numbered mark for a specific fuel tank. Set the flywheel to a position at any point on the intake stroke. Remove the



A	Fuel Injection Line
B	Nipple Nut
C	Delivery Valve Holder
D	Delivery Valve Spring
E	Delivery Valve
F	Delivery Valve Seat
G	Valve Assembly Gasket
H	Fuel Gallery
J	Plunger Barrel
K	Fuel Rack Setscrew
L	Fuel Rack
M	Upper Plunger Spring Seat
N	Base Plug
P	Camshaft
Q	Tappet Roller
R	Tappet Body
S	Hole In Tappet For Disassembly
T	Tappet Spacer
U	Lower Plunger Spring Seat
V	Plunger Lug With Punch Mark Facing Inspection Door
W	Plunger Spring
X	Clamping Jaw Of Control Sleeve And Segment
Y	Pump Plunger
Z	Pump Barrel Set Screw
AA	Copper Washer
BB	Two Fittings For Connection Of Auxiliary Items To Gallery

FIG. A4.2 Fuel Injection Pump—Sectional View

machine bolt which connects the fuel rack to the safety shutoff solenoid and check that the rack is forced forward against the fuel flow-rate micrometer which should be in a typical operating position. Rotate the fuel injection timing micrometer so that the advance lever is at full advance (nearest to operator).

A4.2.7 While slowly rotating the flywheel in the clockwise direction (as seen from the front of the engine), use the rubber bulb to blow air steadily into the delivery valve holder C, Fig. A4.3, and observe air bubbles at the end of the tube submerged in the container of diesel fuel oil. When the bubbles stop, the port has just been closed by the plunger on its upward stroke. Determine this point by several trials noting the flywheel crank angle for each to establish an average point.

A4.2.8 For reference purposes, use this average flywheel position and observe the scribed line on the edge of the variable timing device drive hub and scribe a matching line on the housing if one is not already present. This reference mark may change if new components are installed in the injection pump.

A4.2.9 For proper timing, the closure of the plunger should occur at a flywheel crank angle of between 300 and 306° on the compression stroke. If not, remove the two cap screws which fasten the pump to camshaft vernier coupling disks together. Hold the pump disk at the port closing mark, rotate the flywheel to a 300° to 306° position and reinstall the two coupling cap screws using the best matching holes.

A4.2.10 Reinstall the delivery valve, spring, fuel injection tube and the tube between the fuel line air trap and the buret. Also reconnect the fuel rack safety shutoff solenoid linkage.

A4.3 *Fuel Pump Plunger Lift*—The port of the pump plunger should close when the plunger has moved up 0.076 in. from the base circle of the pump can. This setting is made at the factory and there is no provision for field adjustment.

A4.4 *Fuel Pump Safety Shutoff Solenoid Linkage Setting*—This safety solenoid is utilized to stop fuel delivery to the engine and thus prevent uncontrolled engine overspeed in the event of electrical power failure. In the power off condition, a heavy spring pulls the solenoid shaft, the connecting linkage and the fuel control rack to a zero delivery position. When the engine is running, the solenoid overcomes the force of the spring and allows the rack to move into contact with the fuel flow rate micrometer. At no time should the linkage setting permit the linkage to force movement of the solenoid core piece which typically causes loud humming or buzzing and ultimately leads to overheating of the winding. A slot in the solenoid connecting linkage permits an adequate range of freedom of micrometer adjustment to provide the proper fuel flow rate for typical fuels. The connecting linkage includes an adjustable shaft which should be set so that the slotted control yoke permits play relative to the solenoid core piece when the solenoid is energized and the fuel flow-rate micrometer is at a typical operating position. To adjust, loosen the locknut and change the length of the connecting screw appropriately and then relock the nut.

A4.5 *Fuel Injector Nozzle Assembly Opening Pressure Setting*—Fuel injection occurs when the pressure in the nozzle assembly passages forces the nozzle pintle to lift against the force of an adjustable spring in the nozzle assembly. The setting should be checked each time the nozzle is disassembled and cleaned.

A4.5.1 To adjust the injection opening pressure, assemble the injector nozzle assembly in a suitable injector nozzle tester in a ventilated hood.

A4.5.2 Loosen the locknut B, Fig. A4.4 on the pressure adjusting screw A and turn the adjusting screw as required to obtain the specified 10.3 ± 0.34 MPa (1500 ± 50 psi) injection pressure. This is a trial and error procedure whereby the pressure is checked by use of the injector tester after each screw adjustment accompanied by relocking of the locknut B. Inspection for possible nozzle pintle drip as well as spray pattern should be observed when making this setting.

A4.5.3 After setting injection opening pressure, check that the injector pickup gap is typically 1 mm (0.040 in.) before reinstalling the injector assembly in the engine.

A4.6 *Checking Compression Pressure*—Determination of the compression pressure requires use of a compression pressure gage assembly such as that illustrated in Fig. A4.5,

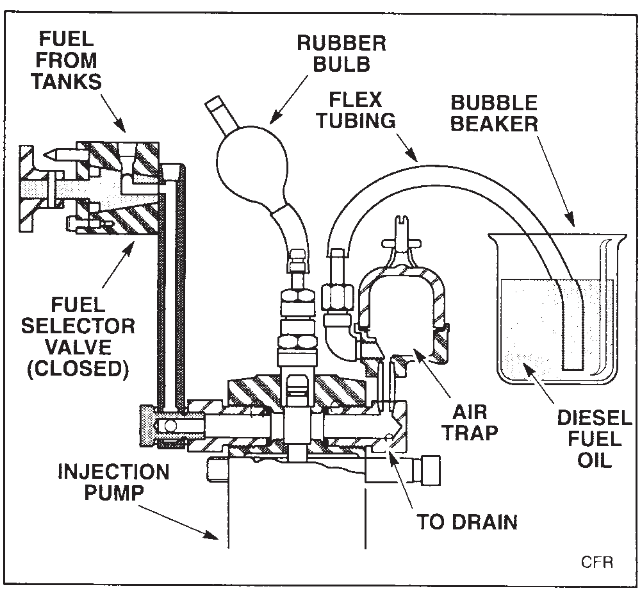


FIG. A4.3 Fuel Pump Timing Test Fittings

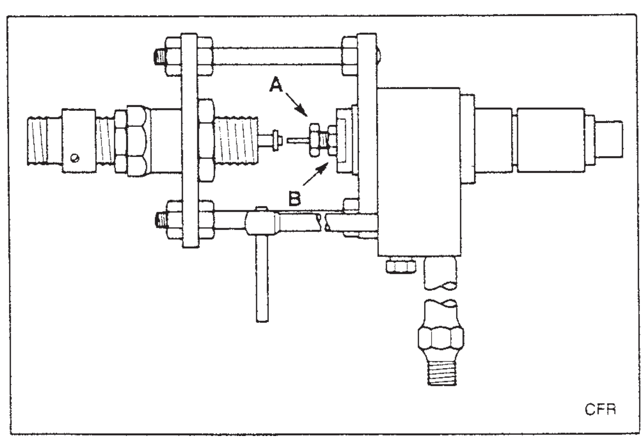


FIG. A4.4 Injector Assembly Showing Pickup Mounted

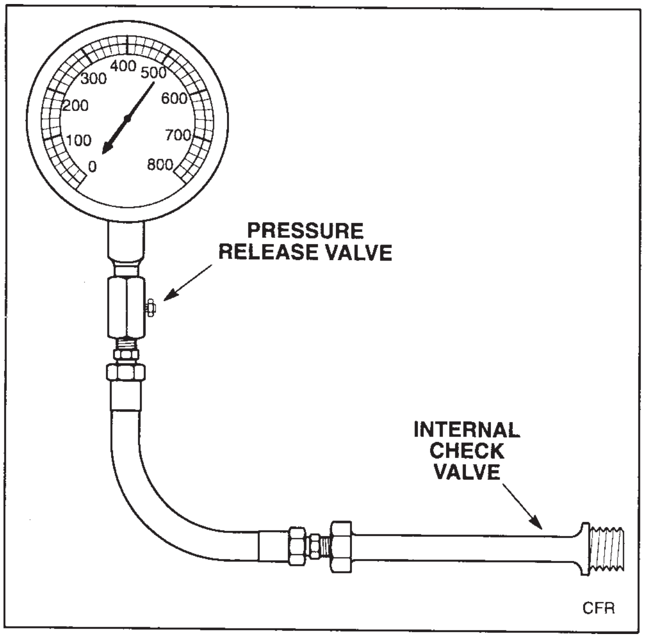


FIG. A4.5 Compression Pressure Gage Assembly

(Waukesha Part Number A110376), readable to 2.5 psi and equipped with a suitable check valve and deflator or pressure release valve.

A4.6.1 Compression pressure is measured after the engine has been thoroughly warmed up on a typical diesel fuel oil under standard operating conditions for that fuel. The following steps should be performed as quickly as possible to ensure that the pressure readings represent hot engine conditions.

A4.6.2 Collect and have ready a calibrated compression pressure gage assembly and the tools required to remove the combustion pickup and install the gage assembly in the combustion chamber pickup hole.

A4.6.3 Shut the engine down by opening the injector assembly fuel by-pass valve and then turning off the engine power switch. The by-pass valve must remain open for the remainder of the compression pressure check procedure.

A4.6.4 The fuel selector valve must be positioned so that fuel will continue to be delivered to the fuel pump to maintain proper pump barrel and plunger lubrication.

A4.6.5 Remove the combustion pickup from the cylinder head and install the compression pressure gage assembly. (**Warning**—Personnel shall avoid contact with the combustion pickup because it is extremely hot and can cause serious burns.)

A4.6.6 Set the handwheel to 1.000, regardless of the bore diameter of the cylinder in use.

A4.6.7 Restart the engine and operate in a motoring mode without any fuel being injected into the cylinder.

A4.6.8 Observe the compression pressure gage reading, release the pressure once or twice using the deflator valve and record the equilibrium pressure which results. (**Warning**—In addition to other precautions, read the compression pressure gage in whatever position it faces without twisting the gage and hose which can distort the readings.)

A4.6.9 Satisfactory basic handwheel indexing is indicated if the compression pressure is 3275 ± 138 kPa (475 ± 20 psi).

NOTE A4.2—Compression pressure values for engines operating at barometric pressures below 27 in. Hg have not been established.

A4.6.10 Shut the engine down, remove the compression pressure gage assembly, reinstall the combustion pickup with a new gasket and tighten the pickup to the specified torque setting (30 lbf-ft).

A4.7 *Adjusting Crankcase Lubricating Oil Pressure:* The oil pressure of the lubricating oil in the engine crankcase gallery is dependent on the setting of the pressure control valve located at the lower left side of the engine crankcase when viewed from in front of the engine. (See Fig. A4.6.)

A4.7.1 The oil pressure should be adjusted with the engine hot and running.

A4.7.2 Remove the acorn nut and gasket from the oil pressure control valve assembly.

A4.7.3 Loosen the gasketed locknut so that the adjusting screw is free.

A4.7.4 While observing the engine oil pressure gauge, set the adjusting screw to obtain the specified 0.17 to 0.20 MPa (25 to 30 psi) pressure.

A4.7.5 Tighten the gasketed locknut while observing that the pressure remains within limits.

A4.7.6 Reinstall the gasket and acorn nut.

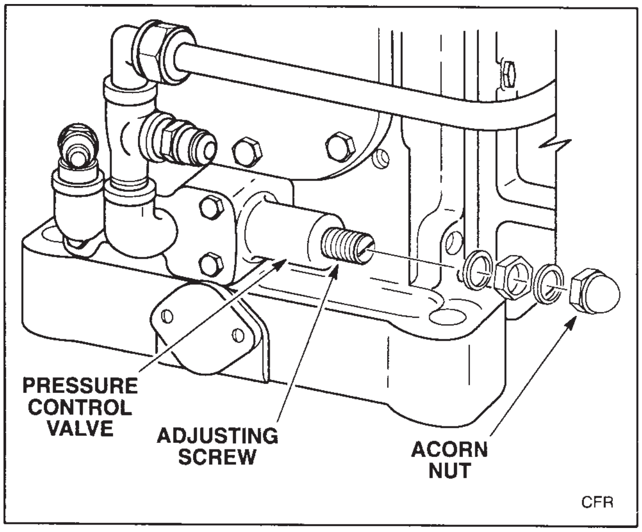


FIG. A4.6 Oil Pressure Control Valve Assembly

APPENDIXES

(Nonmandatory Information)

X1. VOLUMETRIC REFERENCE FUEL BLENDING APPARATUS AND PROCEDURES

X1.1 *Background*—Primary reference fuels which are used infrequently are usually packaged in relatively small containers and storage and dispensing is handled in the manner used for general chemicals. Secondary reference fuels are supplied in bulk containers of 5 or 55 U.S. gallon capacity (0.019 or 0.208 m^3) and for laboratory safety reasons these bulk quantities are typically stored in a special fuel storage room or outside of the engine laboratory.

X1.2 *Delivery from Storage*—Delivery of reference fuel material from the bulk storage container to a dispensing apparatus in the engine laboratory may be handled in any of several ways. The equipment and procedures required for delivery of the reference fuel material are the responsibility of the user of this standard.

X1.3 *Dispensing Equipment*—A common means of accurately measuring reference fuel blend volumes applies a matched pair of calibrated glass burets, one for each of the two secondary reference fuels. Fuel is dispensed either through an integral glass stopcock or a separate valve.

X1.3.1 Burets of glass with an automatic zero top fitting provide accurate, efficient and convenient measurement. A typical buret is illustrated in Fig. X1.1. Specifications for a typical buret are given in Table X1.1.

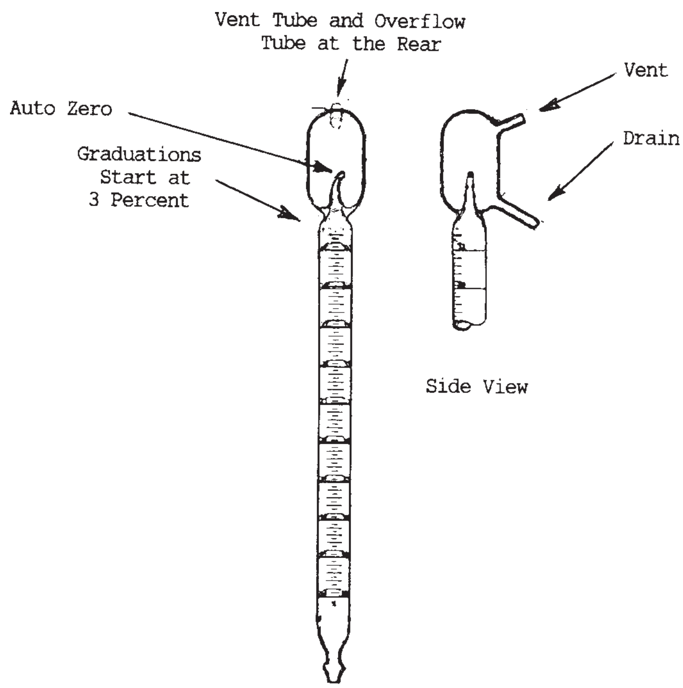


FIG. X1.1 Typical Reference Fuel Dispensing Buret

X1.3.2 *Separate Dispensing Valves*—It is common practice to utilize burets that do not have a dispensing stopcock. Bottom delivery from the buret is from a straight tubing bib which is connected by plastic tubing to a three-way valve similar to that shown in Fig. X1.2. The most important feature of such a valve assembly is the dispensing fitting which is formed so that only a very minimum of drip can occur if the collection container is inadvertently touched against the orifice tip. These valves can also be the means for controlling discharge flow rate to specification by use of the 6 mm (3⁄16 in. O.D.) tubing for the formed tip.

X1.4 *System Installation and Operation*—User experience with reference fuel systems has pointed out a number of

TABLE X1.1 Typical Buret Specifications

Buret Capacity	mL	500
Automatic Zero		YES
Graduations:		
Major Marks	%	5
Minor Marks	%	1
Internal Diameter of Graduated Tube:		
Minimum	mm	32
Maximum	mm	34
Scale Length, 5 to 100 %:		
Minimum	mm	523
Maximum	mm	591
Top of Overflow Bulb to 5 % Mark Length (nominal)	mm	100/120
Overall Length (including tip):		
Minimum	mm	650
Scale Error (Maximum)	%	0.1

important aspects that support the following recommendations:

X1.4.1 Use amber glass burets for dispensing reference fuels or provide opaque shielding around all but the calibration mark area of clear glass burets.

X1.4.2 Mount burets vertically at an elevation that permits horizontal sighting of all calibration marks.

X1.4.3 Install a separate buret for each of the reference fuels.

X1.4.4 Mount burets in a manner that ensures freedom from vibration.

X1.4.5 Store bulk reference fuel containers and provide appropriate tubing for delivery of the fuels to the dispensing burets in accordance with the instructions of the manufacturer and in compliance with all local codes and regulations.

X1.4.5.1 Avoid the use of gravity flow delivery of reference fuel to burets.

X1.4.6 Thoroughly clean reference fuel burets on a regular basis to minimize hangup or clinging on the inner surface of the buret that can lead to blending errors.

X1.4.7 Burets should not be filled until a blend is required in order to minimize any tendency for deterioration of the fuel by exposure to light.

X1.4.8 Use stainless steel tubing, or other opaque tubing that does not react with reference fuel, to connect between the bulk reference fuel container and the dispensing buret.

X1.5 *Procedure for Use of Buret System:*

X1.5.1 To fill the buret, set the valve or stopcock to“ fill” position, so that fuel rises in the buret until it overflows at the automatic zero. Stop filling by setting the valve to “off” position. Check that any bubbles are purged at the zero tip and refill the tip, if necessary.

X1.5.2 To dispense fuel, set the valve to “dispense” position, so that fuel is delivered to the collection container. Stop dispensing by setting the valve to “off” position while carefully noting the level of the fuel in the calibrated section of the buret and locating the bottom of the liquid meniscus at the desired volume percent mark.

X1.5.3 Before drawing a measured volume, make certain that the tip of the dispensing tube is full. When the measured volume has been collected, be certain not to drain any fuel from the tip of the dispensing tube as this will cause an error.

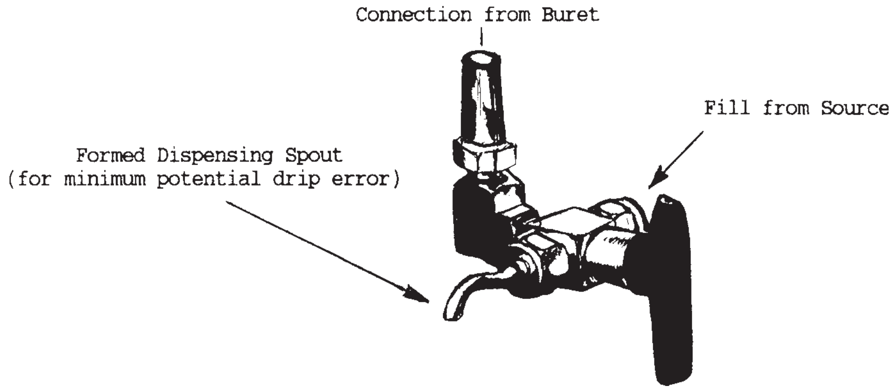


FIG. X1.2 Typical Fill/Dispense Valve

X2. OPERATING TECHNIQUES—ADJUSTMENT OF VARIABLES

X2.1 *Compression Ratio vs Handwheel Reading*—The compression ratio of the cetane engine is variable and depends upon the position of the variable compression plug in the precombustion chamber of the cylinder head. The variable compression plug is positioned by the screw action of the handwheel and the relative location of the plug is indicated by an indexed vernier scale. This handwheel reading scale extends from 0.500 to 3.000 and is inversely related to compression ratio. Low handwheel readings correspond to high compression ratio conditions while high handwheel readings reflect low compression ratio conditions.

X2.1.1 If the handwheel has been carefully indexed, the compression ratio of the cetane engine for any position of the variable compression plug can be calculated using the following equation:

$$C.R. = \frac{V_S + (V_{CC} + V_{TP} + V_{PU}) + V_{PC}}{(V_{CC} + V_{TP} + V_{PU}) + V_{PC}} \quad \text{(X2.1)}$$

where:

$C.R.$ = compression ratio,
V_S = volume swept by piston in cylinder,
V_{CC} = volume in main combustion chamber above piston at tdc including the valve recesses and piston top-land clearance,
V_{TP} = volume of turbulence passage between combustion and pre-combustion chambers,
V_{PU} = volume of threaded pickup hole with a pickup installed, and
V_{PC} = volume of pre-combustion chamber.

X2.1.2 Volumes V_{CC}, V_{TP}, and V_{PU} are independent of cylinder bore diameter and are based on the physical dimensions of the cylinder head. The sum of these volumes is 0.659 cu. in. (10.8 cc) as determined by both calculation and measurement. The equation for compression ratio, when calculated using cu. in. units is thus:

$$C.R. = \frac{V_S + V_{PC} + 0.659}{V_{PC} + 0.659} \quad \text{(X2.2)}$$

X2.2 *Adjusting Compression Ratio Using the Handwheel:*

X2.2.1 Cetane method testing requires adjustment of compression ratio (C.R.) to attain the proper ignition delay conditions for each specific diesel fuel oil or reference fuel. Changing handwheel setting changes the ignition delay period. Low cetane number fuels have inherently longer ignition delay characteristics than high cetane number fuels. The cetane method test procedure requires that all fuels operate at a specified ignition delay period and therefore changes in handwheel setting are necessary.

X2.2.2 *Handwheel Adjustment Procedure*:

X2.2.2.1 Loosen the small locking wheel of the handwheel assembly by counterclockwise rotation as viewed from the front of the engine. This releases the mechanism and permits the larger handwheel to be turned so that the variable compression plug can be properly moved in or out of the precombustion chamber.

X2.2.2.2 Set the larger handwheel to establish the required ignition delay period as indicated on the ignition delay meter. Clockwise rotation of the handwheel (viewed from in front of the engine) increases C.R. and decreases the ignition delay crank angle degree reading.

X2.2.2.3 Always make the final adjustment of the handwheel in the clockwise direction to minimize scale reading errors by eliminating the unavoidable play in the handwheel mechanism.

X2.2.2.4 Lock the mechanism by turning the small locking wheel clockwise until tight. (**Warning**—Hand tightening of the locking wheel should be adequate if the handwheel mechanism is in proper working order. The need to use additional leverage to achieve a locked condition indicates a need for handwheel assembly maintenance.)

X2.3 *Fuel System Operation:* As illustrated in Fig. X2.1 the fuel system incorporates three fuel tanks each with a drain valve ahead of a selector valve. The selector valve is positioned to deliver fuel from a specific fuel tank by rotation of the valve to the mark for that tank. The selected fuel is delivered to the fuel pump inlet and fills the fuel sump or gallery. The pump gallery also connects to the flow-rate buret through an air trap which is fitted with a drain valve. The fuel level in the buret will be the same as that in the fuel tank. When the selector valve is positioned so that the pointer is indexed between the fuel tank marks, fuel delivery from the tank is blocked. In this

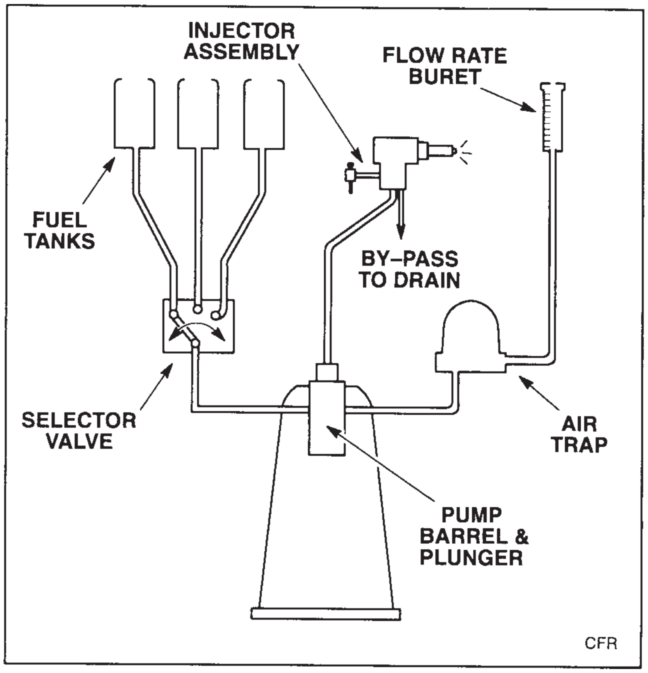


FIG. X2.1 Fuel System Schematic

mode, the engine will continue to operate on the fuel which is in the gallery and the line from the flow rate buret. Fuel flow rate measurement can thus be performed by first filling the flow rate buret from the tank with the selector valve positioned on the tank mark and then positioning the valve between tank marks so that fuel from the buret leg alone supplies the fuel pump.

X2.3.1 The fuel flow-rate-buret is mounted so that the vent hole at the top of the buret is slightly above the level of the top of the fuel tanks thus preventing fuel overflow from the buret when the tank is full. The calibration marks on the buret are in 1 mL increments so that fuel flow rate is easily measured by noting the time required for engine consumption to lower the buret fuel level by a specific number of mL.

X2.3.2 *Changing to a New Fuel*—Introduction of a diesel fuel oil involves filling a fuel tank, purging the flow-rate-buret and air trap leg and displacement of the fuel in the fuel line from the pump to the injector assembly. (**Warning**—Diesel Fuel Oil—Combustible. Vapor harmful. See Annex A1.) The typical sequence for this process is as follows:

X2.3.2.1 Check that there is sufficient fuel in the buret leg to operate the engine while filling a tank with a new fuel. (**Warning**—Do not allow the fuel pump to run dry, except during the momentary periods required to switch from one fuel to another, because the fuel pump is partly dependent on fuel for lubrication.)

X2.3.2.2 Position the selector-valve so that it is between marks but adjacent to the mark for the fuel tank into which the new fuel is to be introduced.

X2.3.2.3 Check that the selected fuel tank is empty by opening the tank drain valve.

X2.3.2.4 Introduce the fuel to the fuel tank while leaving the associated drain valve open for an instant; then alternately close and open the valve a few times to remove any entrained air from the passages before finally closing the drain valve.

X2.3.2.5 In a series of quick steps, drain the buret leg, position the selector-valve to introduce the new fuel and when fuel begins to appear in the buret, position the selector-valve to between marks so the engine operates from the buret alone. This step purges the fuel system with the exception of the line from the pump to the injector. When the engine runs out of fuel, repeat the purging sequence. Engine operation on the purge sequences will afford sufficient time to completely displace the fuel in the line from the injection pump to the injector.

NOTE X2.1—Diesel fuel oils which are highly viscous or cause discoloring of the flow-rate-buret, may require more drastic flushing action for adequate purging.

X2.3.3 *Measuring Fuel Flow Rate*:

X2.3.3.1 Fill the flow-rate-buret and turn the selector-valve to between the marks.

X2.3.3.2 Using an electric stop clock (or stop watch), measure the fuel consumption by starting the clock as the meniscus passes a millilitre graduation on the buret and stopping the clock as the meniscus passes the mark selected for the amount of fuel to be consumed (typically 13 mL below the starting mark). Turn the fuel-selector-valve back to the mark to again draw fuel from the appropriate tank.

X2.3.3.3 If the time registered by the clock is not correct (60 ± 1 s for 13 mL), readjust the fuel flow-rate-micrometer to change the pump rack position and thereby the amount of fuel being injected to the engine (see Fig. X2.2). Turn the flow rate micrometer clockwise (as viewed from in front of the engine) to increase fuel flow (shorten the clock time per unit volume). Typically, 0.005 micrometer divisions will cause a change of 1 s for 13 mL of fuel consumption.

X2.3.3.4 Repeat the flow rate measurement procedure until the specified fuel flow rate is achieved.

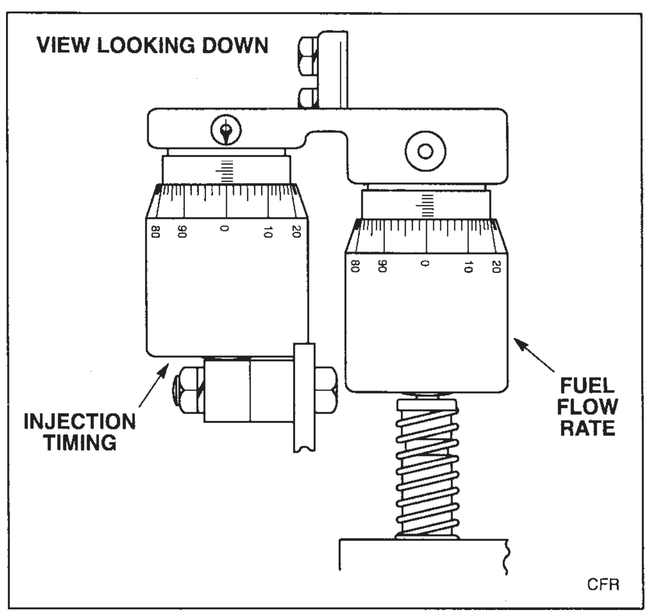


FIG. X2.2 Fuel Pump Flow Rate and Injection Timing Micrometers

X2.3.3.5 When the fuel level in the fuel tank lowers, the level in the flow-rate-buret may not be adequate to permit good flow rate measurement. In this case, use a suction bulb applied to the top vent hole of the buret and with the selector-valve positioned on the tank mark, pull fuel up from the pump gallery to the desired level. Before removing the suction bulb, quickly move the selector-valve to a position between the tank marks. Flow rate measurement must then be started almost immediately because the engine will be drawing fuel from the buret and the level in the buret will be falling.

X2.3.3.6 Determination of the proper flow rate is a trial and error procedure. Initial checks may be made using a 10 s time interval which should result in consumption of approximately 2 mL of fuel. The final flow rate measurement shall be made over a full 60 $\pm$ 1 s period.

X2.3.4 *Adjusting Fuel Injection Timing*—While operating the engine at the proper fuel flow rate and with the fuel-selector-valve positioned on the mark for the fuel being evaluated, observe the indicated injection timing (injection advance) value. Adjust the fuel injection timing micrometer to achieve the specified injection advance degrees (see Fig. X2.2). Turn the injection timing micrometer clockwise (as viewed from in front of the engine) to decrease the indicated number of degrees of advance.

X2.4 *Preparations Before Starting Engine:*

X2.4.1 Check the jacket coolant level in the condenser sight glass.

X2.4.2 Check the engine crankcase lubricating oil level in the crankcase oil sight glass.

X2.4.2.1 Check the crankcase breather assembly to insure that it is clean and operable.

X2.4.2.2 Turn on the crankcase oil heater or oil heat temperature controller.

X2.4.3 Check the fuel pump lubricating oil level using either the dip stick or by sighting through the plastic sump cover located on the side of the pump.

X2.4.4 Fill one of the fuel tanks with a diesel fuel oil suitable for engine warmup taking care to purge the tank line of any trapped air.

X2.4.4.1 Set the fuel-selector valve to the mark for the specific fuel tank so that fuel will flow to the fuel pump gallery and flow rate buret leg.

X2.4.4.2 Purge the fuel pump gallery of any entrained air by opening and closing the drain valve from the glass air trap three times.

X2.4.5 Open the cooling water valve or check that cooling water will be available for both the condenser and the injector coolant chamber when the engine is started.

X2.4.6 Using the hand crank, manually rotate the engine crankshaft three or four complete revolutions to ensure that all parts move freely. Complete the cranking so that the flywheel is positioned at top-dead-center on the compression stroke to minimize the load on the absorption motor when the engine is started.

X2.5 *Starting the Engine*—It is assumed that the engine has been commissioned and is in operable condition and that electrical circuits and cooling water are available on demand.

X2.5.1 Check that the injector by-pass valve (see Fig. X2.3) is open and the handwheel is set to about 1.000.

X2.5.2 Position the off-run-start switch to start and hold it in the start position for a few seconds to allow oil pressure to rise sufficiently to actuate the engine run circuitry so that the engine continues to operate when the start switch is released to the run position.

X2.5.3 Turn on the intake air heater.

X2.5.4 Allow the engine to motor (operate under non-firing conditions) for an additional few seconds to purge the fuel lines and injector.

X2.5.5 Initiate engine combustion by closing the injector by-pass valve and if necessary, by increasing the C.R. through clockwise rotation (as viewed from in front of the engine) of the unlocked handwheel. After firing commences, back off the handwheel toward the higher reading direction (counterclockwise) until the engine operates smoothly. (**Warning**—Sharp knocking sounds may occur and blowby smoke may appear from the mechanism as the handwheel is rotated in the counterclockwise direction which increases the handwheel reading. These are normal.)

X2.5.6 Energize the cetane or ignition delay meter instrumentation in accordance with manufacturer instructions.

X2.5.7 Set the fuel flow rate to approximately the specified value.

X2.5.8 Set the injection timing to approximately the specified value.

X2.5.9 Check that the ignition delay period is nominally at the specified value.

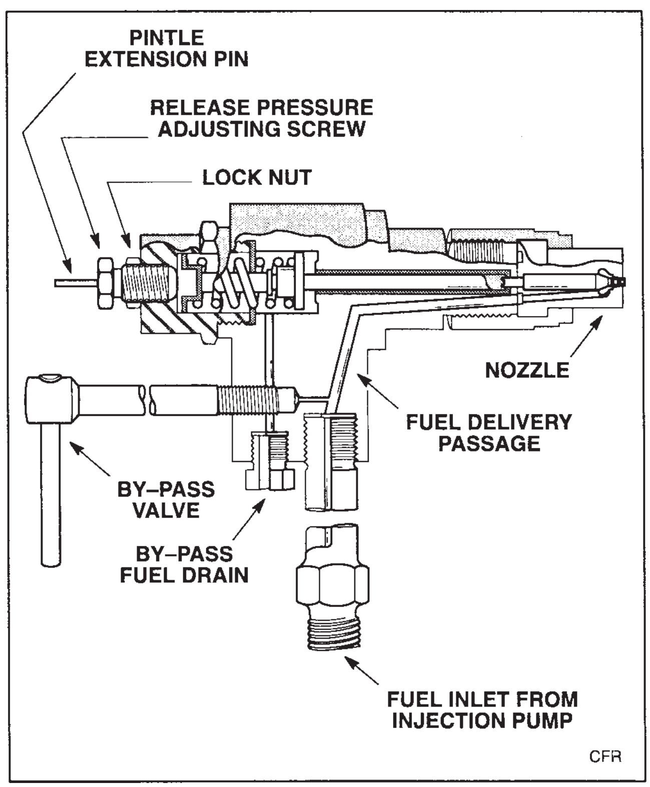


FIG. X2.3 Fuel Injector Assembly

X2.5.10 Continue engine warmup for approximately 1 h taking care to periodically observe and if necessary, readjust all critical operating conditions.

X2.6 *Stopping the Engine:*

X2.6.1 Turn off the cetane or ignition delay meter and the intake air heat switches.

X2.6.2 Open the injector by-pass valve to prevent further injection of fuel to the combustion chamber.

X2.6.3 Stop the engine by positioning the stop-run-start switch to the off position.

X2.6.4 Using the hand crank, manually rotate the engine to set it on top-dead-center on the compression stroke so that the intake and exhaust valves are closed. This will minimize possible valve warping or corrosion in the combustion chamber between operating periods.

X2.6.5 Drain all fuel tanks and fuel lines.

X2.6.6 Turn off the cooling water.

NOTE X2.2—Cooling water flow may be continued for a period of 20 to 30 min after engine shut down, especially to the injector coolant passage, to minimize the build-up of a hard coke deposit on the tip of the injector nozzle due to potential pintle drip.

X2.7 *Checking Ignition Delay vs. Cetane Number Sensitivity*—The sensitivity characteristic illustrated in Fig. X2.4 can provide a measure of confidence that the injector assembly and particularly the injector nozzle are performing in a satisfactory manner. It is a test that requires approximately 1 h to perform but it is useful to judge nozzle acceptance when engine instability has been experienced after cleaning and resetting.

X2.7.1 Using a secondary reference fuel blend of approximately 35 cetane number, adjust all engine variables to standard operating conditions with the ignition delay period carefully set to 13.0°.

X2.7.2 Prepare a series of at least four more reference fuel blends of higher cetane number so that there is a difference of about 4 cetane numbers between each successive pair of blends.

X2.7.3 Operate the engine on each successive blend without changing the handwheel reading established for the 35 cetane number blend but adjusting the fuel flow rate to 13 mL/min and the injection timing to 13°. Record the resulting ignition delay values for each of the reference fuel blends.

X2.7.4 Plot the data on a graph similar to that in Fig. X2.4 so that the sensitivity characteristic can be observed. If the points do not fit an easily defined smooth curve, the injector nozzle is probably suspect and may require further cleaning maintenance or replacement. If a nozzle is faulty, it is often easily noted by the erratic operation and data scatter of the results obtained during the early stages of this procedure.

X2.8 *Checking Exhaust and Crankcase Breather Systems for Resonance:*

X2.8.1 Resonance in the piping systems can occur when the configuration creates a critical length/volume relationship. A resonant condition affects the primary pressure within the system and can affect critical operating conditions.

X2.8.2 Exhaust system resonance may be checked by providing either a ¾ inch or larger gate or ball valve at the surge tank or close to the engine exhaust port. Opening the valve should drastically change the exhaust discharge configuration while the engine is operating at standard conditions to determine if there is an effect.

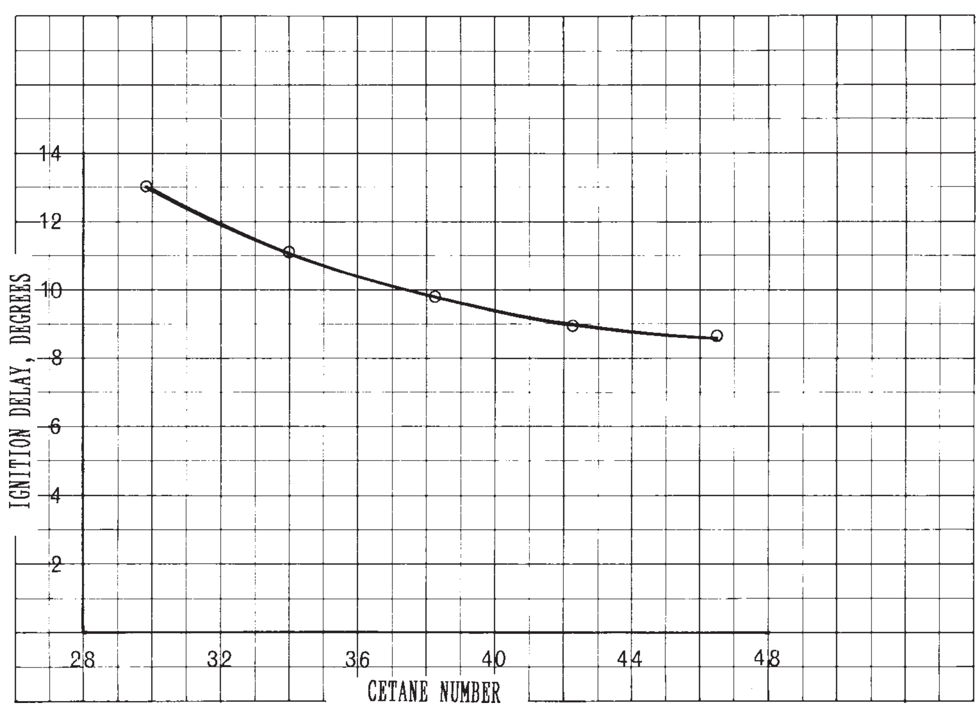


FIG. X2.4 Ignition Delay vs Cetane Number Characteristic

X2.8.2.1 Operate the engine at standard operating conditions on a typical diesel fuel oil and allow sufficient time for the ignition delay period to stabilize.

X2.8.2.2 Open the valve or effect the change in exhaust piping with the engine running.

X2.8.2.3 If the ignition delay is not affected, resonance does not occur and the piping system is satisfactory.

X2.8.2.4 If ignition delay is affected when the valve is opened, resonance may be a factor and typically a change in the length of the exhaust discharge pipe will correct the condition.

X2.8.3 Crankcase breather system resonance typically causes the crankcase pressure to be positive. Resonance in the discharge piping is not a problem as long as the operating engine creates a crankcase vacuum.

X3. MAINTENANCE TECHNIQUES

X3.1 *Importance of Maintenance:* The need for proper maintenance of the cetane engine unit cannot be overemphasized if reliable cetane number ratings of diesel fuel oils are to be obtained. The care used in the inspection, adjustment, and especially the overhaul of the combustion chamber components is a major factor in achieving these aims.

X3.2 *Types of Maintenance:*

X3.2.1 *Daily Checks*—Those checks associated with the preparations before starting the engine as detailed in Appendix X2.

X3.2.2 *Top Overhaul*—The generally accepted term used to describe valve reconditioning, the cleaning of the combustion chamber, piston, piston rings, variable expansion plug or handwheel assembly and the cleaning of the coolant jacket passages and the coolant condenser. Some other parts may also be given attention during a top overhaul, depending on need.

X3.2.2.1 Typically, a top overhaul is necessary every 100 to 300 h and the need is usually indicated by unstable or non-repeatable performance of the engine. The interval between top overhauls varies and depends primarily upon the severity of the conditions under which the unit is operated.

X3.2.3 *Injector Assembly Inspection*—The disassembly and cleaning of the nozzle, checking nozzle opening pressure and spray pattern.

X3.2.3.1 It is recommended that injector inspection and checking be performed at every top overhaul. However, depending on the severity of testing, the process may need to be performed more frequently and some testing facilities make it a practice to install a cleaned and checked injector prior to each unit startup.

X3.2.4 *Crankcase/Unit Inspection*—Encompasses crankcase cleaning, mechanical component wear checks, alarm function checks, power absorption motor inspection, belt tension adjustment, instrumentation checks, etc.

X3.2.4.1 The recommended interval between crankcase/unit inspections is every 2000 h of operation or biannually, whichever comes first. Model CFR-48 crankcases, which can be completely restored by the manufacturer, have been found to perform acceptably for periods of 40 000 h or more before such restoration is required. (**Warning**—Deactivate the engine unit before performing any maintenance. Shut off electrical power at the main disconnect, lock out, if possible. Place a WARNING notice on the unit panel indicating repairs are in process and that no attempt is to be made to start the engine. Shut off coolant water to the unit.)

X3.2.5 *Auxiliary Equipment Maintenance*—Volumetric glassware such as the engine fuel flow rate buret and the reference fuel blending burets should be chemically cleaned on a regular basis to insure accurate volumetric measurement.

X3.2.5.1 Quarterly cleaning of volumetric ware is recommended.

X3.3 *Top Overhaul Procedures:*

X3.3.1 Disassemble the complete combustion chamber and associated assemblies from the engine crankcase. Components to be removed include:

X3.3.1.1 Combustion and injector pickups.

X3.3.1.2 Thermometers and any temperature sensors.

X3.3.1.3 Intake air elbow, silencer and heater assemblies.

X3.3.1.4 Fuel injector tubing and injector assembly.

X3.3.1.5 Circulating cooling water piping at the coolant condenser, the condenser/water pipe assembly and the water inlet pipe to the cylinder.

X3.3.1.6 Exhaust pipe assembly.

X3.3.1.7 Handwheel assembly from the cylinder head using detailed instructions available from the manufacturer.

X3.3.1.8 Valve cover, rocker arm bracket assembly, rocker half-balls and push rods.

NOTE X3.1—Marking of push rods as intake and exhaust ensures they will be reassembled in the same positions.

X3.3.1.9 Cylinder head.

X3.3.1.10 Valve rotators, valve springs, and valves.

X3.3.1.11 Cylinder.

X3.3.1.12 Piston pin retainers, piston pin, and piston.

X3.3.2 *Component Cleaning*—All combustion deposits, gasket material, rust, etc. should be removed from components.

X3.3.2.1 Commercial chemical cleaning solutions may be used in accordance with the manufacturers instructions as long as they do not etch or affect the surface finish of the machined surfaces. Except for electromechanical pickups, use of ultrasonic bath equipment has been demonstrated to be effective and heating of some cleaning solutions can also be beneficial. (**Warning**—Chemical Cleaning Solutions—Poison. May be Harmful or Fatal if Inhaled or Swallowed. See Annex A1.)

X3.3.2.2 Scraping, brass wire brushes (manually or power driven), and fine steel wool have been found to be effective cleaning aids.

X3.3.2.3 Complete any cleaning sequence by rinsing of all parts with a solvent, such as kerosine. (**Warning**—Kerosine—Combustible. Vapor Harmful. See Annex A1.)

X3.3.3 *Cylinder Head:*

X3.3.3.1 *Combustion Chamber Surface*

Discard head if badly pitted or corroded.

X3.3.3.2 *Precombustion Chamber*

Discard head and handwheel housing if internal diameter of chamber exceeds 1.630 in.

X3.3.3.3 *Valve Guides*

Replace a guide when the internal diameter exceeds 0.3785 in. Replacement requires special tools.

X3.3.3.4 *Valves*

Discard if stem is badly scuffed or diameter is less than 0.3705 in. Reface to 45° using a valve refacing (grinding) machine so that face runout is within less than 0.0015 in. Discard valve if grinding has created a sharp edge at the outer diameter of the head indicating stellite coating has been removed.

X3.3.3.5 *Valve Seats*

Reface seats using a valve seat grinding machine or a valve seat cutter kit. Use a 45° seat angle and subsequently lap the valve to the seat. Alternatively, an interference angle approach may be utilized by refacing the seat at both 46° and 15° so that the intersecting line becomes the contact surface with a 45° faced valve. When an interference angle approach is utilized, lapping may be performed but extreme care must be taken to exert very light pressure to prevent creating a groove in the valve face.

X3.3.3.6 *Valve to Valve Seat Matchup*

Check the valve to seat contact. Lapped valve seat width must not exceed 0.070 in. as viewed on the valve. The top edge of the contact line or area shall be at least 0.030 in. from the top edge of the faced portion of the valve. The valve head shall be recessed at least 0.020 in. below the surface of the cylinder head, however, the recess shall not exceed 0.060 in.

X3.3.3.7 *Face of Nozzle Hole in Head*—Check that surface against which the nozzle seats is flat and not excessively corroded.

X3.3.3.8 *Valve Rotators*— Inspect the races which should rotate freely so that, when the engine is operating, the valve will rotate at approximately 1 to 2 rpm.

X3.3.3.9 Reassemble valves, felt lubrication washers, springs, spacers and rotators. Install valve springs with closely wound coils next to the cylinder head.

X3.3.4 *Cylinder*:

X3.3.4.1 Check the cylinder bore diameter at the top, middle, and bottom areas of ring travel in two planes which are 90° apart. Replace the cylinder if the internal diameter at the area of maximum wear is more than 0.006 in. larger than the unworn skirt internal diameter. Replace the cylinder if the bore is out of round in excess of 0.0025 in.

X3.3.4.2 Cylinders rebored to 0.010, 0.020, and 0.030 in. larger than the original 3.250 in. diameter are permitted and the same wear limits apply based on the unworn skirt diameter of the rebore.

X3.3.5 *Piston and Rings*:

X3.3.5.1 Replace the piston if there is evidence of scoring or a wear pattern.

X3.3.5.2 Replacement of all rings at the time of every overhaul is typical. If a chrome plated top compression ring is used, it may be reused for several overhaul periods.

X3.3.5.3 The ring gaps should be checked by feeler gauge with the ring inserted in the skirt end of the cylinder. The piston should be used to square the ring in the bore about 1 in. beyond the chamfer. Rings should be rejected if the gap is not within 0.007 to 0.030 in. for compression rings and 0.010 to 0.030 in. for oil rings.

X3.3.5.4 After assembly of the rings on the piston, the ring to land clearances, as measured using a feeler gage, should not exceed 0.004 in. for top compression ring or 0.0035 in. for all other rings.

X3.3.5.5 Piston pin replacement should be made when scoring or wear marks are observed.

X3.3.6 *Handwheel Assembly*—The handwheel assembly is an integral part of the cylinder head assembly and includes a variable compression plug that is a close fit in the precombustion chamber bore. It is screwed in and out of the head by the handwheel to effect changes in compression ratio. To prevent leakage of combustion gases, this plug, which has no seals or rings, is expanded by action of the locking wheel which is connected to a drawbolt that exerts pressure on a dished and split washer inserted in the plug causing it to expand and clamp the plug in the bore. The variable compression plug mechanism should be kept free-working, and easily adjusted. The locking wheel should be easily released and locked by hand without the use of an auxiliary wrench.

X3.3.6.1 Detailed instructions, available from the manufacturer, include specific inspection criteria, proper parts selection, as well as the proper order of reassembly and lubrication instructions.

X3.3.7 *Rocker-Arm Assembly*:

X3.3.7.1 Inspect each rocker for excessive bearing wear or wobble on the rocker shaft.

X3.3.7.2 Inspect the rocker adjusting screws for galled ball ends and also for damaged Phillips screwdriver slots.

X3.3.7.3 Inspect the rocker ball sockets for wear or galling.

X3.3.7.4 Replace any worn or out of specification parts.

NOTE X3.2—When installing the rocker arm shaft, the pipe plug end should face the intake side and the center feed hole should point downward to receive oil. The exhaust rocker bushing must have a hole to permit pressurized oil to reach the distribution channel on the top rocker surface.

X3.3.8 *Condenser and Cooling System*:

X3.3.8.1 Inspect the inner surfaces of the condenser and the baffle tube for rust or scale deposits, wipe out the cavity, and rinse with hot water prior to reassembly.

X3.3.8.2 Inspect the cooling coil, clean surface deposits, and observe that the coils are slightly separated from each other to maximize the cooling surface exposed to coolant steam.

X3.3.8.3 Chemical cleaning of coolant system surfaces should take place whenever significant deposits are observed or at least at every third top overhaul. One approach is to introduce a commercial cooling system cleaner in the cooling system after reassembly of the engine. By running the engine for intermittent periods, the solution can be heated to 80 to 90°C (180 to 200°F). The solution should be kept at this temperature for approximately 30 min and drained. The system should then be flushed with clean hot water before recharging with rust inhibited coolant water. (**Warning**—Chemical cleaning solutions are poisonous and may be harmful or fatal if inhaled or swallowed. See Annex A1.)

X3.3.9 *Reassembly Procedures*:

X3.3.9.1 Install the piston, piston pin and pin retainers on the connecting rod. Lubricate the rings with SAE 30 engine crankcase oil.

X3.3.9.2 Place a selection of cylinder base gaskets on the crankcase surface. Cylinder base gaskets of several thicknesses are available and the number and thicknesses must be selected by trial and error to obtain the proper piston overtravel of 0.014 to 0.016 in.

X3.3.9.3 Rigidly support the piston above the crankcase surface. Install the cylinder over the piston so that it is seated on the cylinder base gaskets. Care should be taken not to break any of the rings as they enter the chamfered bore. (Use of a ring compressor tool over the piston rings is advisable despite the cylinder chamfer). Manually rotate the crankshaft through several revolutions so that the cylinder is centered. Tighten and torque the cylinder stud nuts to 75 lbf-ft.

X3.3.9.4 Manually rotate the crankshaft so that the piston is at top-dead-center as indicated by the flywheel pointer.

X3.3.9.5 Place a true piece of metal flat stock on the piston so that it projects over the top cylinder surface. Using a feeler gage, measure the piston overtravel or separation of the flat stock above the cylinder surface. Make the same measurement in two directions, parallel to and at 90° to the crankshaft center line. The overtravel should be 0.014 to 0.016 in. or the cylinder must be removed and the number and thickness of the cylinder base gaskets changed to bring the overtravel within specification.

X3.3.9.6 Place the cylinder head gasket on the cylinder surface.

NOTE X3.3—Current cylinder head gaskets have a special non-stick/sealer coating and do not require additional sealer/lubricant.

X3.3.9.7 Install the cylinder head.

X3.3.9.8 Install the marked push rods, and manually rotate the crankshaft so that both rods are at their lowest point of travel (flywheel at top-dead-center, compression stroke).

X3.3.9.9 Install the rocker-arm assembly with the half-balls properly inserted.

X3.3.9.10 Install, tighten and torque the head nuts to 75 lbf-ft.

X3.3.9.11 Set the valve clearances to 0.004 in. for the intake valve and 0.014 in. for the exhaust valve.

X3.3.9.12 Install the handwheel assembly.

X3.3.9.13 Reassemble the condenser, the intake air elbow and silencer, the exhaust pipe, the cooling water lines to the condenser and injector cooling passage.

X3.3.9.14 Introduce coolant water through the condenser cover fill hole until coolant just appears in the condenser sight glass.

X3.3.9.15 Install a cleaned and inspected injector assembly using a new solid copper gasket. Install the associated fuel lines.

X3.3.9.16 Install the injector pickup and set the pickup gap to 0.040 in. using a non-magnetic feeler gage.

X3.3.9.17 Turn on the main cooling water and establish flow through the injector cooling passage. Observe the face of the injector nozzle through the pickup hole to be certain the injector assembly is tightened evenly and coolant is not leaking past the nozzle into the precombustion chamber.

X3.3.9.18 Index the handwheel assembly.

X3.3.10 *Crankcase Breather*:

X3.3.10.1 Disconnect the breather pipe and remove the breather assembly from the engine crankcase.

X3.3.10.2 Unscrew the cap from the body, remove the plastic cup, and clean the emulsion deposits from all of the pieces.

X3.3.10.3 Inspect the cup and if the surface of the open edge is rounded rather than square, replace the cup.

X3.3.10.4 Rinse the components using a petroleum based solvent or kerosine and reassemble them on the engine. (**Warning**—Petroleum Based Solvent—Flammable. Vapors Harmful if Inhaled. Vapors may Cause Flash Fire. See Appendix X1.) (**Warning**—Kerosine—Combustible Vapor Harmful. See Annex A1.)

X3.3.11 *Crankcase Oil Change*:

X3.3.11.1 Drain the used oil and add new SAE 30 Grade engine crankcase lubricating oil.

X3.3.11.2 It is recommended that the crankcase lubricating oil be changed at intervals of approximately 50 h of engine operation and at the time of each top overhaul.

X3.3.11.3 It is recommended that the oil filter cartridge be changed at the time of every other oil change.

X3.3.12 *Fuel Injection Pump*:

X3.3.12.1 Drain the used oil and add new SAE 30 Grade engine crankcase lubricating oil.

X3.3.12.2 The fuel pump assembly seldom needs maintenance or basic adjustment other than attention to regular and proper lubrication. If any disassembly is attempted in the field, it should be performed by a qualified fuel injection equipment specialist.

X3.3.12.3 If diesel fuel oils having high sulfur content are being tested on a fairly regular basis, inspection of the fuel pump delivery valve holder and delivery valve is recommended at approximately 500 h periods of operation. Typically this inspection could be part of a top overhaul. If pitting or corrosion of these components is observed, the parts should be replaced.

X3.3.13 *Engine Starting Preparations*—See Appendix X2.

X3.4 *Injector Assembly Inspection:*

X3.4.1 Disassembly.

X3.4.1.1 With the engine shut down, close the coolant water valves (supply and return) to the injector cooling passage, and drain the coolant from the injector cooling passage.

X3.4.1.2 Disconnect the fuel lines at the injector assembly.

X3.4.1.3 Remove the injector pickup and associated bracket.

X3.4.1.4 Remove the injector assembly.

X3.4.2 *Nozzle Cleaning*:

(**Warning—**Injector nozzles are precision devices which have finely finished fits and meticulously polished surfaces. Scrupulous cleanliness must be observed to prevent dirt or moisture from causing damage. As parts are removed, they should be placed in a clean container and submerged in diesel fuel oil or kerosine. Do not touch the critical lapped surfaces with bare fingers because body acids can cause undesirable etching.)

X3.4.2.1 Clamp the injector assembly in a vise so that the nozzle cap nut can be loosened and removed. Separate the nozzle from the cap nut.

X3.4.2.2 Clean the carbon from the nozzle, pintle and cap nut by immersion in a suitable cleaner for as long as necessary. Placing the parts container of cleaner solution in an ultrasonic bath hastens the cleaning process.

X3.4.2.3 Reassemble the nozzle components on the injector assembly and tighten the nozzle cap nut to a torque of 50 lbf-ft.

X3.4.2.4 Check the injector nozzle opening pressure and spray pattern.

X3.4.2.5 Reinstall the injector assembly with injector pickup on the engine and check for cooling water leakage past the nozzle into the precombustion chamber.

X3.4.2.6 Before installing the combustion pickup, motor the engine for a short time to blow out any water which may have entered the combustion chamber during the maintenance process. Restricting the pickup hole by pressing a cloth (not paper) wiper against the opening will aid in removing any entrained water.

X3.5 *Crankcase/Unit Inspection:*

X3.5.1 *Crankcase*—Inspect the crankcase annually as follows.

X3.5.1.1 Turn off the electrical power circuits to the engine and unit.

X3.5.1.2 Drain the crankcase lubricating oil and clean the crankcase sump using a petroleum based solvent.

X3.5.1.3 Disassemble the oil suction screen assembly and clean the components.

X3.5.1.4 Disassemble the crankcase breather body from the crankcase side door and clean the internal passage and baffles.

X3.5.1.5 Disassemble the connecting rod from the crankshaft. Inspect the big end bearing shells and replace if wear is indicated. Reassemble the connecting rod and torque the bearing cap bolts to 104 lbf-ft.

X3.5.1.6 Disassemble the valve lifters from the top of the crankcase, clean, inspect and, if necessary, replace worn assembly components.

X3.5.1.7 Approximate the rear main bearing clearance by dial indicator measurement of the movement of the crankcase edge of the flywheel outer surface. Measure with the flywheel at rest and then with the flywheel lifted using an appropriate lever, if the difference in the measurements exceeds 0.006 in., crankcase rebuilding is recommended.

X3.5.1.8 Disassemble the oil pressure control valve assembly, solvent clean, inspect for worn components and replace as required. (**Warning**—In addition to other precautions, avoid over tightening the four relief valve body fastening bolts to prevent valve body distortion and restriction of the plunger movement.)

X3.5.1.9 Inspect the outer crankcase surfaces for indications of oil seal leakage which may require extensive maintenance or crankcase rebuilding.

X3.5.2 *Power Absorption Motor*—Inspect the power absorption motor annually as follows:

X3.5.2.1 Turn off all the electrical power circuits to the engine and unit.

X3.5.2.2 Check the condition and tension of the drive belts. Replace belts as required and adjust the motor position to achieve proper belt tension.

X3.5.2.3 Inspect the motor bearing housings for evidence of wear or loss of lubricant. Flush lubricate the bearings if the unit is equipped with field lubrication fittings.

X3.5.2.4 Remove dust and dirt from the motor end bell openings using low pressure compressed air.

X3.5.3 *Safety Cutoff Checks*:

X3.5.3.1 *High Coolant Temperature Switch*—After shutting off the cooling water to the condenser coil, the engine should stop within one minute. Check and adjust the thermal switch set point as required.

X3.5.3.2 *Low Oil Pressure Switch*—When starting the engine, release of the momentary start switch before the oil pressure reaches approximately 20 psi (138 kPa), should result in unit shut down.

X3.5.3.3 *Electrical Interlock*—Disconnecting either the single phase or the three phase power at the appropriate supply switch should cause unit shut down.

X3.5.3.4 *Fuel Pump Safety Solenoid*—Disconnecting the single phase power should cause release of the fuel pump safety solenoid, closing of the fuel pump rack with the result that combustion ceases.

TABLE X3.1 Recommended Torque Values

Item	Torque, lbf-ft	Torque, N-m
Cylinder head stud nuts	75	101.7
Cylinder stud nuts	75	101.7
Crankshaft balancing weight bolts	100	135.6
Balancing shaft weight bolts	100	135.6
Balancing shaft weight bolt locknuts	75	101.7
Connecting rod big end bolts	104	141.0
Combustion pickup	30	40.7
Injector Cap Nut	50	67.8

X3.6 *Engine Torque Tightening Recommendations*—Recommended torque values are given in Table X3.1.

SUMMARY OF CHANGES

Subcommittee D02.01 has identified the location of selected changes to this standard since the last issue (D 613–03a) that may impact the use of this standard (approved June 10, 2003).

(1) Revised 7.3 to allow for gravimetric blending of reference fuels.

(2) Revised X1.4 for clarity and emphasis.

Subcommittee D02.01 has identified the location of selected changes to this standard since the last issue (D 613–03) that may impact the use of this standard (approved May 10, 2003).

(1) Added warning statement to 8.2.

(2) Clarified warning statements in Annex A1.

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