ASTM Designation: D02-XXM-XX

Standard Test Method for

EVALUATION OF ENGINE OILS IN A HIGH SPEED, SINGLE-CYLINDER DIESEL ENGINE – CATERPILLAR 1R TEST PROCEDURE[1]

This standard is issued under the fixed designation D02-XXXM-XXXX; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parenthesis indicates the year of last approval.

Introduction

[1] This test method is under the jurisdiction of ASTM Committee D-2 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.B0 on Automotive Lubricants.

Any properly equipped laboratory, without outside assistance, can use the test method described in this standard. The ASTM Test Monitoring Center (TMC)[2] provides calibration oils and an assessment of the test results obtained on those oils by the laboratory. By this means the laboratory will know whether their use of the test method gives results statistically similar to those obtained by other laboratories. Furthermore, various agencies require that a laboratory utilize the TMC services in seeking qualification of oils against specifications. For example, the U.S. Army has such a requirement in some of its engine oil specifications. Accordingly, this test method is written for those laboratories that use the TMC services. Laboratories that choose not to use these services should ignore those portions of the test method that refer to the TMC. Information Letters issued periodically by the TMC may modify this method.[3] In addition, the TMC may issue supplementary memoranda related to the method.

1. Scope

1.1 This test method that stresses an engine oil under modern high-speed diesel operating conditions and measures the oil's deposit control, lubrication ability, and resistance to oil consumption. It is performed in a laboratory using a standardized high-speed, single-cylinder diesel engine[4].

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[2] ASTM Test Monitoring Center, 6555 Penn Avenue, Pittsburgh, PA 15206-4489. (Telephone: (412) 365-1005)

[3] Users of this test method shall contact the ASTM Test Monitoring Center to obtain the most recent information letters.

[4] Available from Caterpillar Inc., Engine System Technology Development, P.O. Box 610, Mossville, IL 61552-0610.

1.2 The values stated in either SI units or in other units shall be regarded separately as the standard.

1.3 This standard does not purport to address all of the safety problems 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. Being an engine test method, this standard does have definite hazards that require safe practices (see Appendix X2 on Safety).

1.4 The following is the Table of Contents:

Annexes

Appendixes

2 Referenced Documents

2.1 ASTM Standards:

D 86 Test Method for Distillation of Petroleum Products at Atmospheric Pressure[5]

D 93 Test Methods for Flash Point by Pensky-Martens Closed Cup Tester[5]

D 97 Test Method for Pour Point of Petroleum Products[5]

D 130 Test Method for Detection of Copper Corrosion from Petroleum Products by the Copper Strip Tarnish Test[5]

D 235 Specification for Mineral Spirits (Petroleum Spirits) (Hydrocarbon Dry Cleaning Solvent)[6]

D 445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (the Calculation of Dynamic Viscosity)[5]

D 482 Test Method for Ash from Petroleum Products[5]

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[5] Annual Book of ASTM Standards, Vol. 05.01.

[6] Annual Book of ASTM Standards, Vol. 06.04.

D 524 Test Method for Ramsbottom Carbon Residue of Petroleum Products[5]

D 613 Test Method for Cetane Number of Diesel Fuel Oil[7]

D 664 Test Method for Acid Number of Petroleum Products by Potentiometric Titration[5]

D 976 XX

D 1298 XX

D 1319 Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Absorption[5]

D 2274 Oxidation Stability of Distillate Fuel Oil (Accelerated Method)[5]

D 2425 Test Method for Hydrocarbon Types in Middle Distillates by Mass Spectrometry[5]

D 2500 Test Method for Cloud Point of Petroleum Products[5]

D 2622 Test Method for Sulfur in Petroleum Products by Wavelength Dispersive X-ray Fluorescence Spectrometry[8]

D 2709 Test Method for Water and Sediment in Middle Distillate Fuels by Centrifuge[8]

D 3227 Mercaptan Sulfur in Gasoline, Kerosine, Aviation Turbine, and Distillate Fuels (Potentiometric Method)[8]

D 3524 Test Method for Diesel Fuel Diluent in Used Diesel Engine Oils by Gas Chromatography[8]

D 4175 Terminology Relating to Petroleum, Petroleum Products, and Lubricants[8]

D 4485 Specification for Performance of Engine Oils[8]

D 4739 Test Method for Base Number Determination by Potentiometric Titration[9]

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[7] Annual Book of ASTM Standards, Vol. 04.04.

[8] Annual Book of ASTM Standards, Vol. 05.02.

[9] Annual Book of ASTM Standards, Vol. 05.03.

D 4863 Test Method for Determination of Lubricity of Two-Stroke-Cycle Gasoline Engine Lubricants[9]

D 5185 Standard Test Method for Determination of Additive elements, Wear Metals, and Contaminants in Used Lubricating Oils and Determination of Selected Elements in Base Oils by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES)[9]

D 5302 Test Method for Evaluation of Automotive Engine Oils for Inhibition of Deposit Formation and Wear in a Spark-Ignition Internal Combustion Engine Fueled with Gasoline and Operated Under Low-Temperature, Light-Duty Conditions[9]

D 5844 Test Method for Evaluation of Automotive Engine Oils for Inhibition of Rusting (Sequence IID)[9]

D 5862 Test Method for Evaluation of Engine Oils in the Two-Stroke Cycle Turbo-Supercharged 6V92TA Diesel Engine[9]

D 5967 XX

D 6202 Test Method for Automotive Engine Oils on the Fuel Economy of Passenger Cars and Light-Duty Trucks in the Sequence VIA Spark-Ignition Engine[9]

D 6594 XX

E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications[10]

E 344 Terminology Relating to Thermometry and Hydrometry[11]

G 40 Terminology Relating to Wear and Erosion[12]

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[10] Annual Book of ASTM Standards, Vol. 14.02

[11] Annual Book of ASTM Standards, Vol. 14.03

2.2 Coordinating Research Council:

CRC Manual No. 20[13]

2.3 SAE Standard:

SAE J183 Engine Oil Performance and Engine Service Classification[14]

2.4 API Standard:

API 1509 Engine Service Classification and Guide to Crankcase Oil Selection[15]

3. Terminology

3.1 Definitions:

3.1.1 **additive**, *n* – a material added to another, usually in small amount, to impart or enhance desirable properties or to suppress undesirable properties. **(D 4175)**

3.1.2 **automotive**, *adj* – descriptive of equipment associated with self-propelled machinery, usually vehicles driven by internal combustion engines. **(D 4485)**

3.1.3 **blind reference oil**, *n* – a reference oil, the identity of which is unknown by the test facility.

Discussion: This is a coded reference oil, which is submitted by a source independent from the test facility. **(D 5844)**

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[12] Annual Book of ASTM Standards, Vol. 03.02

[13] Available from the Coordinating Research Council Inc., 3650 Mansell Road Suite 140, Atlanta, GA 30022-8246. (Telephone: 678-795-0506, Fax: 678-795-0509).

[14] Available from the Society of Automotive Engineers Inc., 400 Commonwealth Drive, Warrendale, PA 15096.

[15] Available from the American Petroleum Institute, 1220 L Street NW, Washington D.C., 20005

3.1.4 **blowby**, *n – in internal combustion engine*, the combustion products and unburned air-and-fuel mixture that enter the crankcase. **(D 5302)**

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

3.1.6 **calibrated test stand**, *n* – a test stand on which the testing of reference material(s), conducted as specified in the standard, provided acceptable test results.

Discussion: In several automotive lubricant standard test methods, the ASTM Test Monitoring Center provides testing guidance and determines acceptability. **(Sub. B Glossary)**[16]

3.1.7 **candidate oil**, *n* – an oil which is intended to have the performance characteristics necessary to satisfy a specification and is to be tested against that specification. **(D 5844)**

3.1.8 **debris**, *n – in internal combustion engines*, solid contaminant materials unintentionally introduced into the engine or resulting from wear. **(D 5862)**

3.1.9 **dispersant**, *n – in engine oil*, an additive that reduces deposits on oil-wetted surfaces primarily through suspension of particles. **(D 4175)**

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

[16] Available from ASTM Test Monitoring Center, 6555 Penn Avenue, Pittsburgh, PA 15206-4489. (Telephone: (412) 365-1005)

Discussion: It may contain additives to enhance certain properties. Inhibition of engine rusting, deposit formation, valve train wear, oil oxidation and foaming are examples. **(D 5862)**

3.1.11 **heavy-duty**, *adj – in internal combustion engine operation*, characterized by average speeds, power output and internal temperatures that are close to the potential maximums. **(D 4485)**

3.1.12 **lubricant**, *n* – any material interposed between two surfaces that reduces the friction or wear, or both, between them. **(D 5862)**

3.1.13 **lubricating oil**, *n* – a liquid lubricant, usually comprising several ingredients, including a major portion of base oil and minor portions of various additives. **(Sub. B Glossary)**

3.1.14 **oxidation**, *n – of engine oil*, the reaction of the oil with an electron acceptor, generally oxygen, that can produce deleterious acidic or resinous materials often manifested as sludge formation, varnish formation, viscosity increase, or corrosion, or combination thereof. **(D 5967)**

3.1.15 **non-reference oil**, *n* – any oil other than a reference oil; such as a research formulation, commercial oil or candidate oil. **(D 5844)**

3.1.16 **purchaser**, *n – of an ASTM test*, person or organization that pays for the conduct of an ASTM test method on a specified product. **(D 6202)**

3.1.17 **reference oil**, *n* – an oil of known performance characteristics, used as a basis for comparison.

Discussion: Reference oils are used to calibrate testing facilities, to compare the performance of other oils, or to evaluate other material (such as seals) that interact with oils. **(D 5844)**

3.1.18 **scoring**, *n – in tribology*, a severe form of wear characterized by the formation of extensive grooves and scratches in the direction of sliding. **(G 40)**

3.1.19 **scuff, scuffing**, *n – in lubrication*, damage caused by instantaneous localized welding between surfaces in relative motion that does not result in immobilization of the parts. **(D 4863)**

3.1.20 **sponsor**, *n – of an ASTM test method*, an organization that is responsible for ensuring supply of the apparatus used in the test procedure portion of the test method.

Discussion: In some instances, such as a test method for chemical analysis, an ASTM working group can be the sponsor of the test method. In other instances, a company with a self-interest may or may not be the developer of the test procedure used within the method, but is the sponsor of the test method. **(D 6594)**

3.1.21 **used oil**, *n* – any oil that has been in a piece of equipment (for example, an engine, gearbox, transformer, or turbine), whether operated or not. **(D 4175)**

3.1.22 **varnish**, *n – in internal combustion engines*, a hard, dry, generally lustrous deposit that can be removed by solvents but not by wiping with a cloth. **(D 5302)**

3.1.23 **wear**, *n* – the loss of material from, or relocation of material on, a surface.

Discussion: Wear generally occurs between two surfaces moving relative to each other, and is the result of mechanical or chemical action or by a combination of mechanical and chemical actions. **(D 5302)**

4. Summary of Test Method

4.1 Prior to each test, the power section of the engine is disassembled, solvent-cleaned, measured and rebuilt in strict accordance with the specifications. A new piston, ring assembly, and cylinder liner are measured and installed for each test. The engine crankcase is solvent-cleaned and worn or defective parts are replaced. The test stand is equipped with feedback control systems for fuel rate, engine speed and other engine operating conditions. A suitable system for filtering, compressing, humidifying and heating the inlet air shall be provided along with a system for controlling the engine exhaust pressure. Test operations involve the control of the single-cylinder diesel test engine for a total of 504 h at a specified speed and fuel rate input using the test oil as a lubricant. A defined break-in precedes each test. A prescribed warm-up is used when restarting the engine. At the end of the test, the piston deposits are rated; the piston, rings and liners are inspected, measured, and photographed; oil consumption is calculated and the oil is analyzed to determine the test results. Critical engine operating conditions are statistically analyzed to determine if the test was precisely operated. Test acceptability parameters, for each calibration test, are also statistically analyzed to determine if the engine/test stand produce the specified results.

5. Significance and Use

5.1 This is an accelerated engine oil test, performed in a standardized, calibrated, stationary single-cylinder diesel engine that give a measure of (1) piston and ring groove deposit forming tendency, (2) piston, ring and liner scuffing and (3) oil consumption. The test is used in the establishment of diesel engine oil specification requirements as cited in Specification D 4485 for appropriate API Performance Category C oils (API 1509). The test method can also be used in diesel engine oil development.

6. Apparatus and Installation

6.1 The test engine is an electronically controlled, direct injection, in-head camshaft, and single-cylinder diesel engine with a four-valve arrangement. The engine has a 137.2 mm bore and a 165.1 mm stroke resulting in a displacement of 2.4 L.

6.1.1 The Electronic Control Module (ECM) defines the desired engine fuel timing, monitors and limits maximum engine speed, maximum engine power, minimum oil pressure, and, optionally, maximum engine crankcase pressure. The ECM also controls the fuel injection duration that defines the engine fuel rate based on set conditions from the test cell feedback control systems. The oil pressure is also set by the ECM with signals to the 1Y3867 Engine Air Pressure Controller (Mamac) to modulate the facility air supply to the 1Y3898 Johnson Controls Relief Valve.

6.1.2 The 1Y3700 engine arrangement also consists of inlet air piping and hoses from the cylinder head to the air barrel and exhaust piping and bellows from the cylinder head to the exhaust barrel that are specifically designed for oil testing.[17]

6.2 Equip the engine test stand with the following accessories or equipment:

6.2.1 Intake Air System – The intake air system components from the cylinder head to the air barrel are a part of the basic 1Y3700 engine arrangement. These

[17] See the Caterpillar Service Manual. Available from Caterpillar Inc., Engine System Technology Development, P.O. Box 610, Mossville, IL 61552-0610.

components consisting of an adapter, elbow, hose, clamps, and flanged tube can be found in the 1Y3700 Parts Book.[18]

6.2.1.1 Purchase the 1Y3978 intake air barrel (which is almost identical to the exhaust barrel except for the top cover) from one of the three approved manufacturers.[19] Install the intake air barrel at the location shown in A2. Do not add insulation to the barrel.

6.2.1.2 Paint the inside of the intake air piping with Caterpillar yellow primer or red Glyptal prior to installation.[20]

6.2.1.3 Install the air heater elements in the intake air barrel as specified in A2 (even if they will not be supplied with electricity).[21]

6.2.1.4 Use an air filter capable of 10 µm (or smaller) filtration.

6.2.1.5 Use a Sierra Model 780 airflow meter with Feature 1 = F6, Feature 2 = CG and calibrated at the following conditions: temperature = 60 °C, humidity = 17.8 g/kg, pressure = 292 kPa(abs), approximate flow range = 425 kg/h to measure intake airflow for each calibration test.[22] A4 shows the piping requirements for the installation

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[18] Available from Caterpillar Inc., Engine System Technology Development, P.O. Box 610, Mossville, IL 61552-0610.

[19] Cimino Machinery Corp., 5958 South Central Ave, Chicago, IL 60638. Gaspar Inc., 4106 Mahoning Rd. N.E., Canton, OH 44705. M.L. Wyrick Welding, 2301 Zanderson Highway 16 N, Jourdanton, TX 78026.

[20] Crankcase Paint Primer: BASF Coating and Colorant Div., P.O. Box 1297, Morganton, NC 28655. Primer #A123590 & BASF Part #U27YD005. Yellow CAT Primer Part #IE2083A.

[21] Watlow Air Heaters, Chicago, IL 708-490-3900.

[22] Sierra Instruments, Inc. 5 Harris Court, Monterey, CA 93940 (800) 866-0200.

of the Sierra Model 780 airflow meter. For tests not using the airflow meter, maintain instrumentation configuration using a spool piece of equivalent dimensions.

6.2.1.6 Measure the inlet air temperature at the location shown in A2. Measure the inlet air pressure at the air barrel as shown in A2. The location of the 1Y3977 Humidity Probe is shown in A4. The sample line may require insulation to prevent dropping below dew point temperature and shall not be hygroscopic. Drain taps may be installed at the low points of the combustion air system.

6.2.1.7 Use feedback-equipped controls to maintain filtered, compressed, and humidified inlet air at the conditions specified in A10.

6.2.2 Exhaust System – The exhaust system components from the cylinder head to the exhaust barrel are part of the basic 1Y3700 engine arrangement. These components consisting of an adapter, elbow, bellows, flange, and clamps can be found in the 1Y3700 Parts Book.

6.2.2.1 Purchase the 1Y3976 exhaust barrel (which is almost identical to the intake barrel except for the top cover) from one of the three approved manufacturers.[19] Install the exhaust barrel at the location shown in A2. Do not add insulation to the barrel. Any of the approved suppliers may modify the exhaust barrel in order to meet appropriate ASME pressure vessel codes that accommodate the high temperature and pressure conditions of the 1R Test Method. Drawings of the permitted modifications are located with Gaspar Inc.[19]

6.2.2.2 Install a restriction valve downstream from the exhaust barrel. The distance between the valve and barrel is not specified. The location of the exhaust thermocouple is shown in A2. Measure the exhaust pressure at the exhaust barrel shown in A2.

6.2.2.3 Use feedback-equipped controls to maintain the exhaust gases at the pressure specified in A10.

6.2.3 Fuel System – The fuel system schematic is shown in A5. The engine control module (ECM) controls fuel injection timing at 6° BTC. Measure the fuel rate using a Micro Motion device scaled to the 1R operation range specified in A10.[23] Use the day tank specified in A5. Measure fuel temperature at the fuel filter base as shown in A2 and control it using the cell facility feedback system. Use the required fuel heat exchanger(s) and arrange them as specified in A5. Use the Fisher regulator specified in A5.

6.2.4 Oil Consumption System – Use an oil scale system to accurately measure oil consumption (see A6). The oil scale system shall have a resolution as listed in A2. Use flexible hoses similar to Aeroquip flexible hose, FC352-08, to-and-from the oil scale reservoir to eliminate measurement errors.[24] Use Number five Teflon, steel-braided hoses to and from the oil scale pumps. The hose length to-and-from the oil scale cart shall not exceed 2.7 m. Use the special oil pan adapter described in A6. The flow rates for the oil consumption oil scale pumps shall be 23.6-24.9 kg/h for the oil being pumped from the oil pan to the oil scale, and 16.3-17.7 kg/h for the oil being pumped from the oil scale to the oil pan. See A6 for the procedure to verify these flow rates.

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[23] Micro Motion, Inc. 7070 Winchester Circle, Boulder, CO 80301 (800) 322-5867.

[24] Aeroquip Industrial Div, 1225 W. Main Street, Van Wert, OH 45891 (419) 238-1190.

6.2.5 Engine Oil System – A schematic of the oil system is shown in A6. Measure oil pressure at the engine oil manifold (see A2). An engine oil pressure sensor transmits a signal to the ECM that maintains oil pressure at 415 kPa. The ECM transmits a signal to an engine-mounted Mamac air pressure controller. The Mamac modulates the facility air pressure of 280 kPa to levels that vary between 0 to 140 kPa and directs it to the normally closed Johnson Controls relief valve. Because the engine oil pressure sensor calibration may vary from the cell data acquisition transducer, vary the oil pressure adjust signal to the ECM to maintain the oil pressure at the test specifications. See the Electronic Installation and Operation manual for additional information. The ECM maintains the oil pressure regardless of engine speed. Measure the oil temperatures at locations shown in A2. Install 1Y4021 gaskets on each side of the 1Y3661 oil pump bypass lock nut to prevent oil aeration (see A6). When a new pump is installed, begin adjustment of pressure relief plug with 43.7 mm of thread exposed as shown in A6. Optional oil pressure sensor lines may be installed at the oil filter block as shown in Fig. A2.6 for measuring the differential pressure across the oil filter.

6.2.5.1 Oil Heating System – Use an external oil heating system provided by the test facility to maintain the engine oil manifold temperature specified in A10. An example system is shown in X1. A special 1Y3908 oil cooler bonnet has been designed to allow separate fluids to the engine coolant tower (seeA6). Plug the 1Y3660 oil cooler adapter and 1Y3908 heat exchanger bonnet as shown in A6. Use Paratherm NF for the heating fluid.[25] The temperature of the Paratherm NF is measured by the thermocouple

[25] Paratherm NF Oil, Conshohocken, PA 19428 800-222-3611.

shown in A2. An additional heat exchanger may be installed to provide cooling capability if necessary to maintain test conditions.

6.2.5.2 Oil Sample Valve – Refer to A2 for the installation location and component makeup of the oil sample valve. Use of alternate equivalent components for the sample valve is permitted.

6.2.6 Engine Coolant System – The coolant system schematic is shown in A3. Pressurize the coolant tower with compressed air as specified in A3 to ensure water does not boil out of the antifreeze mixture. Control the coolant temperature out of the engine using a cell facility feedback system. Use a 1Y3898 Johnson Controls valve or equivalent fail-open valve to regulate the coolant temperature out of the engine as shown by the schematic in A3. If the 1Y3898 Johnson valve is used, supply facility air pressure at 280 kPa to the controller that regulates air pressure to the valve at 0-140 kPa. Install a feedback-equipped control system to pneumatically adjust the valve. Remove the 1Y3832 hose originally supplied with the engine and install a sight glass using the components shown in A3. Use Caterpillar part number 9X2378 replacement bulk hose for coolant hoses in the Caterpillar 1Y3700 engine.

6.2.7 Engine Instrumentation – Use feedback-equipped systems to control the engine operating temperatures, pressures, and flow rates. Measure the engine operating conditions at the locations shown in A2. For temperature measurements, use thermocouples 1Y468 (intake air), 1Y467 (engine exhaust) and 1Y466 (fluids-water, oil and fuel) or equivalent thermocouples as specified in A2. Install thermocouples with its tip at midstream. The thermocouple insertion depths listed in A2 are approximate depending on the mountings or fittings used. Instrument measurement and reporting resolutions are shown in A2.

6.2.8 Use a dynamometer with feedback control to maintain engine load and speed. Use a starting system capable of at least 136 N•m breakaway torque and 102 N•m sustained torque at 200 r/min.

6.2.9 Blowby – Measure engine blowby down stream of the engine breather housing by measuring the delta pressure across an orifice or an equivalent device.

6.2.10 Crankcase Pressure – Measure crankcase pressure at the location shown in A2.

Note 1: The crankcase pressure is above atmospheric pressure with this engine.

6.3 Obtain information concerning the test engine, engine electronics system, new engine parts, replacement parts and permissible substitution or replacement parts from Caterpillar, Inc.

6.4 Engine and parts warranty information can be found in A1. Use the form listed in A12 for returning defective parts.

7. Reagents and Materials

7.1 Purity of Reagents – Use reagent grade chemicals in all tests. Unless otherwise indicated, it is intended that all reagents conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society where such specifications are available.[26] Other grades may be used, provided it is first ascertained

[26] *Reagent Chemicals, American Chemical Society Specifications*, American Chemical Society, Washington, DC. For suggestions on the testing of reagents not listed by the American Chemical Society,

that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

7.2 Diesel Piston Rating Booth – as described by CRC Manual 20.

7.3 Diesel Piston Rating Lamp – as described by CRC Manual 20.

7.4 Engine Coolant – Use a mixture of 50% mineral-free water and 50% Caterpillar brand coolant (P/N 8C684 for 1 gal concentrated or 1012845 for 55 gal drum already pre-mixed) for engine coolant. Mineral-free water is defined as water having a mineral content no higher than 34.2 ppm total dissolved solids. The coolant mixture may be reused for 3 test starts or up to 1600 h. Keep the mixture at a 50-50 ratio as determined by using either Caterpillar testers 5P3514 or 5PO957 or an equivalent tester. Keep the coolant mixture contamination free. Total solids shall remain below 5000 ppm. Keep the additive level correct using Caterpillar test kit P/N 8T5296.

7.5 Lead Shot – commercial grade, approximately 5 mm in diameter.

7.6 Light Grease.

7.7 Mobil EF-411 – to be obtained for engine assembly and calibration of the oil scale pump flow rates.[27]

7.8 Paratherm NF – to be obtained from Paratherm and used as the fluid to heat the engine oil.[18]

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see *Analar Standards for Laboratory Chemicals*, BDH Ltd., Poole, Dorset, U.K., and the *United States Pharmacopia and National Formulary*, U.S. Pharmaceutical Convention, Inc. (USPC), Rockville, MD.

[27] Mobil EF-411 may be purchased from Golden West Oil Co., 3010 Aniol St, San Antonio, TX 78219 (210) 222-0866.

7.9 Pentane (Solvent) – 99 + %, high-performance liquid chromatography grade.

7.10 Reference Oil – to be obtained from the TMC for calibration of the test stand.

7.11 Sodium Bisulfate ($NaHSO_4$) – commercial grade.

7.12 Stoddard Solvent – Specification D 235 with a flash point greater than 100ºF and an aromatic content less than 22%.

7.13 Test Fuel – The specified test fuel is ChevronPhillips PC-9 Diesel Test Fuel. The specifications are shown in A7.

7.14 Test Oil – The total amount of oil needed for each test is approximately 42 L.

7.15 Trisodium Phosphate (Na_3PO_4) – commercial grade.

7.16 5.4000 in. Ring Bore Standard Class Z Master.[28]

8. Oil Samples and Oil Additions

8.1 Take a 60 mL purge sample and a 120 mL sample at 36, 144, 252, 360, 432 and 504 h. Take a 60 mL purge sample and a 30 mL sample at 72, 108, 180, 216, 288, 324, 396 and 468 h. Analyze the 36, 144, 252, 360, 432 and 504 h samples for 100 and 40 °C viscosity by Test Method D445, TBN by Test Method D4739, TAN by Test Method D664, wear metals Al, Cr, Cu, Fe, Pb, Si by Test Method D5185, and differential IR O_2 using the peak-area method 5. Analyze the 36, 360 and 504 h samples for fuel dilution by Test Method D3524. Analyze the 360, 432 and 504 h samples for TGA soot

[28] Available from Morse-Hemco, 457 Douglas Ave., Holland, MI 49423, 616-396-4604.

by Annex A4 of Test Method D5967. The 72, 108, 180, 216, 288, 324, 396 and 468 h samples are for optional analysis such as wear metals for mechanical problems.

8.2 Add new oil as computed in the worksheet shown in A6.

9. Preparation of Apparatus

9.1 General Engine Assembly Practices – As a part of good laboratory practice, inspect all components and assemblies that are exposed when the engine is disassembled and record the information for future reference. Inspect valve train components, bearings, journals, housings, seals and gaskets, and so forth and replace as needed. Assemble the engine with components and bolt torques as specified in the 1Y3700 engine Service Manual (see A8 for a partial list). It is the intent of this procedure for all engine assemblies and adjustments to be targeted to the mean of the specified values. Clean and lubricate the components in keeping with good assembly practices. Keep airborne dirt and debris to a minimum in the assembly area. Maintain standard engine assembly techniques and practices (such as staggering piston ring gap positions, and so forth.).

9.2 Complete Engine Inspection – Perform a complete engine inspection prior to the first calibration test scheduled after 15,000 h of test time. Ensure that wearing surfaces such as main bearings and journals, rod bearings and journals, camshaft bearings, valve train components, fuel system components, and so forth all are within manufacturer's specifications. Refer to the 1Y3700 Service Manual for disassembly, assembly, inspections and specifications. Paint crankcases as necessary with either Caterpillar yellow primer or red Glyptal[20].

9.3 Copper Components – It is recommended that anytime a copper part is replaced, run an engine test until two consecutive 12-h periods show a stable copper level in the used oil. Do not use rocker arms with a package date earlier than January 2000.

9.4 Engine Lubricant System Flush – Flush the engine of used oil before every test. A9 shows the Engine Flush Procedure and Apparatus. A flushing instruction sheet shown in Table A9.1 gives the step-by-step process required for flushing. The 1Y3700 engine includes five flushing nozzles in the crankcase and front cover (see A9). These nozzles are piped in parallel with the 1Y3935 filter flushing adapter (or equivalent) from a lab provided manifold that pressurizes fluids supplied by a flush cart (see X1). To increase flushing pressure, the oil pan may be plumbed as shown in X1. Seal the gear train housing during flush with a 1Y3917 round plug with a 117-8801 o-ring as shown in A9. Seal the crankcase using a 1Y3979 block flush cover with an internal bleed passage for the cam oil supply. Bolt a 1Y3980 plastic jet aiming fixture to the flush cover that is also used for flushing (see A9). Modify the crankcase side covers as shown in A9 to accommodate the flushing wand for a thorough flushing of the crankcase. If the test oil is not available at engine assembly, Mobil EF411 oil may be substituted.

9.5 Engine Piston Cooling Jet – Use cooling jet part number 1Y4011 and bolt 1Y4010. The piston cooling jets are flow-checked at the supplier and serialized to assure proper performance, but the rod clearances are minimal which may result in jet movement during assembly. Verify proper jet flow positioning using test oil or EF-411 before each test with the 1Y3980 plastic jet aiming fixture and 415 kPa oil pressure to the manifold. Record the cooling jet serial number.

9.6 Engine Measurements and Inspections – Measure and inspect the engine components prior to each test. Refer to the 1Y3700 Service Manual for information concerning component reusability and assembly not found in this procedure. The part numbers of components that need replacing are found in the 1Y3700 Parts Manual. Record the crankshaft angles at the specified maximum injector lift, exhaust and intake maximum lift before each test using the reference listed in A8. Record component part numbers and serial numbers and other required measurements as shown in the test report. Inspect and reuse the rocker arm roller followers and camshaft lobe surfaces based on Caterpillar Service Publication SEBF8256.[29]

9.7 Cylinder Head – A reconditioned head is required for each test. Measurements after reconditioning shall be within specifications as shown in the 1Y3700 Service Manual. Do not swap the cylinder head/jug assembly from test stand-to-test stand. Use the head/jug assembly used to calibrate the stand for all non-reference oil testing in that stand. In the event of a cylinder head/jug failure during the calibration period, a cylinder head/jug used on a successful 1R calibration attempt within the past 2 years may be used without re-calibration. A8 shows the cylinder head nut torque sequence. Use Caterpillar part number 175-7523-J for the inner spring, 175-7526-J for the outer spring and 186-2001 for the rotocoil.

9.8 Valve Guide Bushings – Clean the valve guide bushings with a solvent and bristle brush prior to assembly. Lubricate the bushings and valve stems with Mobil

[29] Available from Caterpillar Inc., Engine System Technology Development, P.O. Box 610, Mossville, IL 61552-0610.

EF-411 prior to assembly. See the 1Y3700 Service Manual for guide reusability specifications. Install new valve guide seals for each test.

9.9 Fuel Injector – Remove the fuel injector from the cylinder head before reconditioning commences. Refer to the 1Y3700 Service Manual for removal and assembly. Return defective fuel injectors to Caterpillar for warranty and failure-mode testing using the form listed in A12.

9.10 Piston and Rings – Use a new piston (1Y4016 iron crown, 1Y4015 aluminum skirt) and new rings (1Y4014, 1Y4013, 1Y4012) for each test. Clean all three rings with pentane and a lint-free cotton towel. Measure the ring side clearances and ring end gaps for all three rings (see A8). Keystone ring side clearance measurements require the ring to be confined in a dedicated slotted liner (see X1) or a 137.16 mm ring gage.[28] Measure the side clearances using four feeler gages of equal width and 0.01mm graduations at 90° intervals around the piston. Measure the rectangular ring side clearance this way as well. Measure the minimum side clearance as specified in CRC Manual 22. Record the measurements for these parts before and after each test. Compare the measurements before the test and after the test to determine the amount of wear. Assemble the piston with the part number toward the camshaft.

9.11 Cylinder Liner – Use a new 1Y3805 cylinder liner for each test. After removing the protective oil/grease with Stoddard solvent, clean the liner bore with a hot tap water and soap solution, then rinse with hot tap water. Measure and record the liner surface finish. Oil the liner bore with only Mobil EF-411. Assemble the cylinder liner, block and head with the torque specification shown in the 1Y3700 Service Manual or A8. Measure the liner with a dial bore gage to insure that the out-of-round and taper conditions are within specified tolerances measured at seven intervals as shown in A8. Measure the cylinder liner projection using the modified indicator shown in A8. Torque the cylinder liner support ring using the procedure shown in A8.

9.12 Compression Ratio – Before starting each test, measure the piston-to-head clearance to assure the proper compression ratio is used. Determine this dimension by using approximately 3.5 mm diameter lead balls. Locate four lead balls on the top of the piston at 90° intervals on the major and minor piston diameters. Hold them in place with light grease. With the piston near the top of the stroke, install the head and block assembly and torque to specifications. Turn the engine over top center by hand to compress the lead balls then remove the head and block assembly and measure the thickness of the lead balls to obtain the average piston-to-head clearance. The piston-to-head clearance specification is 1.62 mm ± 0.07 mm. Use multiple 1Y3817 block gaskets to adjust the clearance. If the piston-to-head measurement exceeds the tolerance specification, check the crankshaft main and rod journals, connecting rod and main bearings, and piston pin and rod bushing for excessive wear. The specified compression ratio for the 1Y3700 engine is 16.2 to 1.

9.13 Engine Timing – Use ECM EPROM part number 169-5028 with a date code of 10/98. The engine ECM sets desired fuel injection timing to 6° BTC. Record this timing using the Engine Technician Service Tool. Mechanically time the actual engine components as shown in A8. Install the electronic sensors as shown in the Electronic Installation and Operation manual. Both the mechanical and electrical systems shall be correctly assembled to produce the desired fuel timing.

9.14 Engine Coolant System Cleaning Procedure – Clean the coolant system when visual inspections show the presence of any oil, grease, mineral deposits, or rust following the procedure listed in A3.

9.15 After the engine components have been prepared and assembled, perform the following:

9.16.1 Fill the crankcase with 5800 ± 50 g of test oil.

9.16.2 Install a new 1R0713 oil filter.

9.16.3 Fill the coolant system with coolant specified in Section 7.

9.16.4 Assure the facility coolant to the engine heat exchanger is operational.

9.16.5 Pressurize the fuel system to remove air, then return the system to a non-pressurized state before starting engine.

9.16.6 Ensure all other systems and facilities are operational before starting the engine break-in.

10. Calibration and Standardization

10.1 Test Cell Instrumentation – Calibrate all facility read-out instrumentation used for the test immediately prior to stand calibration. Instrumentation calibration following a failed or invalid test is at the discretion of the test lab, or as directed by the TMC. Refer to A2 for calibration tolerances and allowable ***system*** time constants.

10.2 Instrumentation Standards – Calibrate all temperature, pressure, flow and speed measurement ***standards*** on a yearly basis. The calibration of all standards shall be traceable to a national bureau of standards. Maintain all calibration records for a minimum of two years.

10.3 Coolant Flow – Calibrate the coolant flow rate as follows: (1) calibrate the differential pressure transducer as outlined in 10.1 and 10.2, and (2) replace the Barco venturi every two years or calibrate the Barco venturi to a standard.[30] Use the following relationships as conversion factors from the differential pressure across the Barco venturi to L/min: 0.75 kPa = 24.3 L/min, 1.76 kPa = 37.8 L/min and 7 kPa = 75.7 L/min or use the equation

$$L/min = \sqrt{\Delta P}\, 28.848 - 0.5927 \quad \text{Eq. 1}$$

where ΔP is measured in kPa.

10.4 Fuel Injectors – The fuel injectors are calibrated during the manufacturing process. These fuel injectors can not be re-calibrated in the usual manner and require special test equipment to ensure proper flow, timing response and spray patterns. Therefore, replace the fuel injector at the start of a calibration test or calibration series. If the fuel injector is replaced on a calibrated stand, re-calibration is not required.

10.5 Air Flow – Install the Sierra Model 780 airflow meter to measure intake airflow. See Section 6.2.1.5 for calibration information specific to this Test Method. Measure the intake airflow during the break-in of every calibration test. Record the last value recorded during step five of the break-in as shown in A10.

10.6 Intake Air Barrel – Prior to each stand calibration test, inspect the intake air barrel for rust or debris. This may be done through either of the pipe flanges using a bore scope or some other optical means.

10.7 Fuel Filter – Change the fuel filter before every calibration test.

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[30] Available from Hyspan Precision Products, Inc., 1685 Brandywine Avenue, Chula Vista, CA 91911, 619-421-1355.

10.8 Oil Scale Flow Rates – Verify the oil scale flow rates before the start of every calibration test using the procedure listed in A6.

10.9 Test Stand Calibration – Calibrate a test stand before starting a non-reference oil test. Use a calibration oil assigned by the TMC to calibrate the engine stand. A test stand is considered calibrated when the test results are within the acceptability limits as published in the LTMS manual and the test is operationally valid. The TMC may request stand checks on calibration tests that fail statistically. Obtain a laboratory and Referee rating for all operationally valid calibration tests. The lab rating will be the primary measurement for results to determine test acceptability. The referee rating will be used as a secondary measurement. Electronically transmit the test data to the TMC within seven days from end-of-test (EOT) date. The TMC will issue the testing laboratory a control chart analysis for each calibration test (see A7). The calibration period is one year from the end-of-test date of the last acceptable calibration test. A non-calibration test can be started any time within the calibration period.

10.9.1 Re-calibration Requirements – The calibration status is void if one or more of the following occur:

10.9.1.1 The engine crankcase requires replacing,

10.9.1.2 The engine crankshaft requires replacing or regrinding,

10.9.1.3 The crankshaft is removed for any other purpose besides bearing replacement,

10.9.1.4 The cylinder head or jug suffer a failure for any reason during the calibration period and a cylinder head/jug not meeting the requirements under Section 9.7 is used.

All other engine components can be replaced at the discretion of the laboratory.

10.9.2 Extending Test Stand Calibration Period – There may be occasions when laboratories conduct a large portion of calibration tests in a short period of time. This may result in an unacceptably large time frame when very few calibration tests are conducted. To ensure proper severity and precision monitoring, conduct calibration tests throughout the year. The TMC is permitted to move up or extend calibration tests to enhance calibration test program design and test severity monitoring. An extensive test stand check will be required for any engines having extended test stand calibration periods.

10.10 Test Run Numbering – Number each test to identify the test stand number and the test run number. Number all runs sequentially. Append repeat calibration runs with a letter that is also sequential (i.e. number the first re-run of test 45 as 46A, the second as 47B, and so forth.). Maintain the letter suffix sequencing for each calibration test until the calibration has been accepted. Increment the run number for any test start.

10.11 Humidity Calibration Requirements – The accuracy of the laboratory's primary humidity measurement system shall be within ± 0.6 g of the humidity measuring chilled mirror dew point hygrometer. Calibrate the primary laboratory humidity measurement system during the first 48 h of each calibration test at each stand using a chilled mirror dew point hygrometer with an accuracy of at least ± 0.55 °C at a 24 °C dew point. The calibration consists of a series of paired comparison measurements between the primary system and the chilled mirror dew point hygrometer. The comparison period lasts from 20 min to 2 h with measurements taken at 1 min to 6 min intervals, for a total of twenty paired measurements. The measurement interval should be appropriate for the time constant of the humidity measuring instruments. Ensure that the flow rate is within the equipment manufacturer's specification. Take all measurements made with the dew point hygrometer at atmospheric pressure and correct them to standard pressure conditions (101.12 kPa). Compute the difference between each pair of measurements and calculate the mean and standard deviation of the differences. The absolute value of the mean difference shall not exceed 0.6 g and the standard deviation shall be less than or equal to 0.3 g. The primary humidity measurement system is deemed calibrated only if both of these requirements are met. If either of these requirements is not met, investigate the cause, make repairs, and recalibrate. Maintain the calibration data for a minimum of two years.

10.12 Calibration of Piston Deposit Raters – Train each piston deposit rater by the TMC Rating Task Force and each rater shall maintain rating expertise by attending at least one of the rating seminars annually. Each rater shall rate a minimum of six diesel pistons. If this schedule is not suitable to a particular rater or test lab, then make alternative arrangements by contacting the TMC as soon as possible to have the rater calibrated.

10.12.1 *Failure to attend a rating seminar will result in the loss of calibration status for that rater.*

11. Procedure

11.1 Engine Break-in Procedure – Open any drain taps at the low points of the combustion air system (if they are installed) during the start of the break-in and warm-ups, and following any shutdowns. The engine break-in and operational conditions are specified in A10. The total break-in time is 85 min. During the break-in, fix all leaks and make adjustments to assure proper engine operation. Record the ECM eprom module part number and release date. After the break-in period and while the engine is hot, drain the oil from the crankcase, oil cooler, engine oil filter and weigh scale for 30 min. Then weigh 5800 ± 50 g of new test oil into the engine. Start the engine, warm it up, and operate it for 504 h at the test conditions specified in step five of A10 with no oil changes. Turn on the oil scale pumps once the engine has reached the beginning of step five of the warm-up sequence. Record the oil weight in the oil scale as the full mark at test hour 4. Throughout the test, record the oil scale reading at least once every 6 min. Count test time from the moment the warm-up time is completed. The oil sample frequency is described in section eight. Do not remove the cylinder head, piston, or power assembly from the engine during a test.

11.1.1 Reinitialize engine timing calibration after the cam shaft/gear or cylinder head has been removed. See the electronic installation and operation manual. Complete this during the first step of the break-in.

11.2 Cool-down Procedure – Except for emergency (uncontrolled) stops, shut the engine down by operating it at conditions shown in steps four, three, two, and then one in A10.

11.3 Warm-up Procedure – Use the same procedure used for engine break-in to warm-up the engine for all subsequent starts throughout the test.

11.4 Shutdowns and Lost Time – Record the test hour, date and length of off test conditions for all occurrences. Record when the engine has early inspections or early test termination with the reasons for the occurrences. If the cool down procedure is not used, identify the shutdown as an *Emergency Shutdown*. A maximum of 125 h of off test conditions are allowed. If the engine shuts down, immediately stop the oil scale pumps. In the event of an emergency shutdown, leave the engine shut down for 2 h (or more) to allow complete engine cool down before restarting. In order to limit foreign matter entering the combustion chamber and to protect piston deposits, rotate the engine to top dead center of the compression stroke during downtime.

11.5 Periodic Measurements – Record all engine conditions listed in step 5 of A10 as a snapshot at least once every 6 min. Record humidity readings using the laboratory's primary humidity measurement system. Correct the recorded humidity values to standard pressure conditions of 101.12 kPa. Record the fuel position as indicated by the Electronic Technician at test hours 36, 360 and 504.

11.6 Engine Control Systems:

11.6.1 Engine Coolant – Pressurize the coolant system to 35.0 ± 7 kPa as shown in A3 to ensure the water does not boil out of the antifreeze. Manually adjust the coolant flow rate by turning the valve on top of the coolant tower to maintain the conditions specified in A10.

11.6.2 Engine Fuel System – Control the fuel rate by modifying the fuel limit adjusting the ECM using a facility controller that compares the actual fuel rate to the specified fuel rate listed in A10. See the Electronic Installation and Operation manual for more details. Manually adjust the Fisher regulator to control fuel pressure. Maintain the fuel pressure and temperature as specified in A10.

11.6.3 Engine Oil Temperature – Maintain the oil manifold temperature to test specifications as shown in A10. Do not allow the temperature of the Paratherm NF to exceed 165 °C at any time during break-in, warm-up or testing. Shut off the external oil heater (but not its circulating pump) the moment the engine goes to cool-down.

11.6.4 Exhaust Pressure – Control the exhaust pressure to the conditions shown in A10.

11.6.5 Intake Air – Filter, compress and humidify the inlet air to the conditions specified in A10. Heat (or cool, if necessary) the inlet air to the conditions in A10.

11.7 Post-Test Procedures – Remove the piston and ring assembly from the engine. Mark the location of the ring gaps on top of the piston.

11.7.1 Piston Ring Side Clearances – Measure the piston ring side clearances prior to removal of the rings to determine the level of deposit formation (see A8). Align ring gaps to the EOT ring gap marks on the top of the piston. Do not force the feeler gages between the ring and groove to disturb or remove the deposits.

11.7.2 Piston Ratings – Immerse the piston assembly in Stoddard solvent and air-dry it prior to any rating. Process and measure the piston deposits according to the Modified CRC Diesel Piston Rating Method described in CRC Manual No. 20 and modified by the directions listed in A11. Rate only two levels of carbon (heavy and light) on the second groove and all lands, and only one level of carbon (light) for the under-crown and cooling groove. Use a combined varnish rating method for the third groove, third land, fourth land, under-crown and cooling groove (see A11). An example rating worksheet is shown in X1. Another heavy-duty engine deposit rater shall verify all piston deposit ratings done by the testing laboratory. In special cases where another rater is not available, the rating may be verified by other qualified lab personnel. Record the initials of both the rater and the verifying rater.

11.7.2.1 Referee Ratings – The referee laboratory rates the entire piston. Wrap all pistons to be referee-rated in paper with CRC desiccant chips. Then place them in plastic and seal before shipping to the referee lab. Report referee ratings to the TMC within ten days of EOT for calibration tests. Referee-rate piston deposits for all non-reference tests reviewed by Caterpillar.

11.7.3 Ring End Gap Increase – Remove all carbon from the rings. If scraping of the rings is necessary, use only a wooden instrument or equivalent. Measure and record the ring end gaps.

11.7.4 Cylinder Liner Wear – Measure the wear at the front, rear, thrust and anti-thrust positions (4 equally spaced positions) as described in the Mack T-10 Test Method.[31]

11.7.5 Cylinder Liner Bore Polish – Section the cylinder liner through the front and rear axis and measure the cylinder liner to determine the amount of bore polishing. Use the liner rating method listed in A11.

11.7.6 Photographs – Photograph the piston and rings showing the thrust, anti-thrust, front, rear and under-crown positions (see X1). Place the rings on top of the piston to show ring gaps (thrust view) and 180° from gaps (anti-thrust view). Show the piston from the crown down to at least the bottom of the pin bore. Photograph the piston crown and skirt as one assembly. Photograph the bore ID of the sectioned liner (see X1).

12. Calculation and Interpretation of Results

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[31] Available from ASTM Test Monitoring Center, 6555 Penn Avenue, Pittsburgh, PA 15206-4489 (412) 365-1000.

12.1 Test Validity – If a test was run for 504 h according to this test method declare the test valid. If a test was not run as specified by this test method, then the test is operationally invalid. Some examples of an invalid test are:

12.1.1 Use of non-specified hardware,

12.1.2 Use of non-specified assembly methods,

12.1.3 A test run whose downtime is greater than 125 h,

12.1.4 Potentially a test that has a Quality Index (QI) value for a controlled parameter below the threshold of zero (see DACA II Report[32]),

12.1.5 If a test has greater than four consecutive hours without data acquisition on any controlled parameter.

12.2 A test with any control parameter QI value less than zero requires an engineering review to determine operational validity.

12.2.1 Engineering Review – Conduct an engineering review when a control parameter QI value is below zero. A typical engineering review involves investigation of the test data to determine the cause of the below zero QI. Other effected parameters may also be included in the engineering review. This can be helpful in determining if a real control problem existed and the possible extent to which it may have impacted the test. For example, a test runs with a low QI for fuel flow. An examination of the fuel flow data may show that the fuel flow data contains several over range values. At this point,

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[32] Available from ASTM Test Monitoring Center, 6555 Penn Avenue, Pittsburgh, PA 15206-4489 (412) 365-1000.

an examination of the exhaust temperatures may help determine whether the instrumentation problem effected real fuel flow versus effecting only data acquisition.

12.2.1.1 For calibration tests, the engineering review shall be conducted jointly with the TMC. For non-calibration tests, consultation with the TMC is available, but not required.

12.2.1.2 Determine operational validity based upon the engineering review, and summarize the decision in the comment section. It may be helpful to include any supporting documentation at the end of the test report. The final decision regarding operational validity rests with the laboratory.

12.3 Some examples of non-interpretable tests are:

12.3.1 If a test completes 504 h and the piston, rings, or liner exhibit distress,

12.3.2 If the test is terminated *prior* to completing 504 h for reasons including purchaser request, excessive oil consumption, or piston, ring, or liner distress then consider the test non-interpretable.

12.4 Calculations – Use the same set of data for all calculations and graphs in the test report.

12.4.1 Quality Index – Calculate and plot the Quality Index according to the instructions inA2.

12.4.2 Oil Consumption – Calculate oil consumption in g/h over 36-h intervals. Delete the first 4 h of readings after an oil add or shutdown from the linear regression. The linear regression technique is shown in A6. Calculate the overall average oil consumption, the initial average oil consumption and end-of-test (EOT) average oil consumption. The beginning of test oil consumption is the average of the 36-h periods from test hours 0-252 (36, 72, 108, 144, 180, 216, 252). The EOT average oil consumption is the average of the 468th and 504th hour data points for a full-length test or for a short-term test it is the average of the last two data points from the oil consumption graph. Calculate the difference between the end-of-test and beginning of test oil consumption.

12.4.2.1 For a 36-h period including a shutdown, calculate the oil consumption as follows:

12.4.2.2 Do not include the first 4-h oil weight readings after a shutdown in the linear regression.

12.4.2.3 Calculate the linear regression for the period before the shutdown.

12.4.2.4 Calculate the linear regression for the period after the shutdown.

12.4.2.5 Calculate a time-weighted average from both regressions to obtain the oil consumption for that 36-h period. For example, a test experiences a 7-h shutdown at test hour twenty. The slope for the first 16-h period (hour 4 to 20) is 10.7 g/h, and the slope for the second 12-h period (hour 24 to 36) is 2.1 g/h. The weighted average is calculated as follows:

$$Weighted\,Average = \frac{(10.7g/h)(16h)+(2.1g/h)(12h)}{16h+12h} \qquad \text{Eq. 2}$$

13. Report

13.1 Report Forms and Data Dictionary – For reference oil tests, the standardized report form set and data dictionary for reporting test results and for summarizing the operational data are required. The test report forms and data dictionary are available at the TMC Website and not included in this Test Method. All changes to the report forms and data dictionary are under the control of the Surveillance Panel for the Test Method. Test report forms should closely resemble those located at the TMC. Report values for all the field names listed in the report forms. Some fields may be blank for short-term tests. Report all deposits, wear, and engine operational data as shown in the test report. The data dictionary defines the field lengths, decimal size, data type, units and format for the field names listed in the test report forms.

13.2 Test Validity – Document on the first sheet of the test report whether the test is Valid, Invalid, or Non-interpretable. For a *valid stand calibration run*, report the test data to TMC who will include the test data in the operationally valid database and determine statistical validity using the LTMS method.[33] For an *invalid or non-interpretable stand calibration run*, report the test data to TMC with comments describing why the test is considered invalid or non-interpretable. TMC will not include the test data in the operationally valid database. All operationally invalid and non-interpretable calibration tests are reported by the TMC to the ASTM Single Cylinder Diesel Surveillance Panel in periodic testing summaries.

Note 2: For a *valid ACC Registered Oil Test*, report the data to Registration Systems, Inc. (RSI).[34] For an *invalid or non-interpretable ACC Registered Oil Test*,

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[33] The LTMS method tracks the severity and precision of stand and laboratory test results. For a complete definition, refer to the LTMS manual available from ASTM Test Monitoring Center, 6555 Penn Avenue, Pittsburgh, PA 15206-4489 (412) 365-1000.

[34] Registration Systems, Inc., ACC Monitoring Agency, 4139 Gardendale, Suite 205, San Antonio, TX 78229 (210) 341-2680, FAX (210) 341-4038.

report the test data to RSI with supporting comments describing why the test is considered invalid or non-interpretable.

Note 3: When non-calibration oil tests are presented to Caterpillar for review, include the data from all tests that were registered with RSI as part of the program.

13.3 Report Specifics

13.3.1 If more than one fuel batch is used, report the fuel batch analysis that is most representative of the fuel in the tank

13.3.2 Report any causes for any missing or bad test data in the comment section of Form 8. If any alternative data acquisition method is used, document it in the comment section of Form 8.

13.3.3 If a calibration period is extended beyond the normal one year period, make a note in the comment section of Form 8 and attach a written confirmation from the TMC to the test report.

13.3.4 For calibration tests, list the outcome of previous failed or invalid calibration runs in the comment section of Form 8.

13.3.4 Include the fuel analysis provided by the fuel supplier as Form 15. For calibration tests, include a copy of the TMC control chart analysis as Form 18.

Note 4: It is recommended that test purchasers include the form shown in Fig. X1.8 as Form 18 when presenting the test results against specification limits, such as those in Specification D4485 or Military Specifications.

14. Precision and Bias

14.1 *Precision* – Test precision is established on the basis of operationally valid reference oil test results monitored by the ASTM Test Monitoring Center. Table 1 summarizes reference oil precision and reproducibility of the test as of February 1, 2002.

Table 1 – Reference Oil Test Precision

Test Parameter	$S_{i.p.}$	i.p.	S_R	R
WDP (weighted demerits for the 1R Test Method)	25.79	72.21	26.31	73.67
TGC (top groove carbon piston deposits)	8.52	23.86	8.95	25.06
TLC (top land carbon piston deposits)	6.93	19.40	7.40	20.72
BTOC (beginning test oil consumption)	1.10	3.08	1.35	3.78
ETOC (final oil consumption)	1.17	3.28	1.51	4.23

$S_{i.p.}$ = Standard deviation for intermediate precision
i.p. = Intermediate precision
S_R = Standard deviation for reproducibility
R = Reproducibility

14.1.2 *Intermediate Precision (formerly called repeatability) Conditions* – Conditions where test results are obtained with the same test method using the same test oil, with changing conditions such as operators, measuring equipment, test stands, test engines, and time.

14.1.2.1 *Intermediate Precision Limit (i.p.)* – The difference between two results obtained under intermediate precision conditions that would in the long run, in the normal and correct conduct of the test method, exceed the values shown in Table 1 in only one case in twenty.

14.1.3 *Reproducibility Conditions* – Conditions where test results are obtained with the same test method using the same test oil in different laboratories with different operators using different equipment.

14.1.3.1 Reproducibility (R) - The difference between results obtained under reproducibility conditions that would, in the long run, in the normal and correct conduct of the test method, exceed the values in Table 1 in only one case in twenty.

14.2 *Bias* – Bias is determined by applying an accepted statistical technique to reference oil test results, and when a significant bias is determined, a severity adjustment is permitted for non-reference oil test results. Currently, there are two types of severity adjustments – Industry and Laboratory. There are no test stand severity adjustments. Industry severity adjustments are determined by the Single Cylinder Surveillance Panel under ASTM Committee D-2, Subcommittee B. Laboratory severity adjustments are determined by the instructions listed in the Lubricant Test Monitoring System (LTMS) document.[35]

15. Keywords

15.1 Caterpillar 1R Test Procedure; Piston Deposits; Oil Consumption; Single Cylinder Diesel Oil Test.

[35] Available from ASTM Test Monitoring Center, 6555 Penn Avenue, Pittsburgh, PA 15206-4489 (412) 365-1000.

ANNEXES

Mandatory Information

A1. Engine and Parts Warranty

A1.1 Engine Warranty – Caterpillar Inc. warrants single cylinder test engines sold by it to be free from defects in material and workmanship for a period of twelve months starting from the date of delivery to the first user. If a defect in material or workmanship is found during the warranty period, Caterpillar will provide the replacement parts to be installed by the user. There will be no charge to the user for parts furnished by Caterpillar. User at its own expense, shall return all defective parts to Caterpillar at Caterpillar's request. User will be responsible for giving Caterpillar timely notice of a warranty failure. User will also be responsible for labor costs and any applicable local taxes. Caterpillar is not responsible for failures resulting from abuse, neglect and/or improper repair. THIS WARRANTY IS EXPRESSLY IN LIEU OF ANY OTHER WARRANTIES, EXPRESSED OR IMPLIED, INCLUDING ANY WARRANTY OF MERCHANTABILITY OR FITNESS FOR PARTICULAR PURPOSE. REMEDIES UNDER THIS WARRANTY ARE LIMITED TO THE PROVISION OF PARTS AS SPECIFIED HEREIN. CATERPILLAR IS NOT RESPONSIBLE FOR INCIDENTAL OR CONSEQUENTIAL DAMAGES.

A1.2 Engine Parts Warranty – All parts for the 1Y3700 engine which are nonconforming by reason of faulty manufacture should be discussed with Engine System Technology Development (ESTD).

A. The Test Labs should contact ESTD when they believe a part is nonconforming:

R.A. Riviere

Telephone: 309-636-5247

Fax: 309-675-1598

B. ESTD will determine if they want the part returned, or provide warranty without viewing the part.

C. If ESTD determines that the part is nonconforming without viewing the part, the test labs will be asked to return the part to their Caterpillar Dealer. ESTD will contact the Dealer and let them know the part is coming and to provide warranty for it.

D. If ESTD wants to view the part, they will issue a Return Goods Authorization Number (RGA) to the test lab. The lab will fill out the Form shown in A9 and send the part and the form to:

Caterpillar Inc.

Tech Center TC-L

Wing 4 - Rm 406

14009 Old Galena Rd.

Mossville, IL 61552

Attn: Dwayne Tharp

The test labs should fax a copy of the RGA Claim Form to:

Caterpillar Inc.

Tech Services Div.

Tech Center Bldg L

Fax: 309-578-4232

Attn: Dwayne Tharp

E. If ESTD determines that the part is nonconforming, they will contact the Dealer for the test lab and have the Dealer provide warranty.

F. A sample of the RGA Claim Form is shown in A9 and should include: return goods authorization number, part name, hours on the part, part number, quantity, engine serial number, date purchased, test lab that purchased the part and contact person's name, phone, fax, and address, Dealer's name that sold the part, measurements and/or photos to document the nonconformance.

A2. INSTRUMENT LOCATIONS, MEASUREMENTS AND CALCULATIONS

Table A2.1 Instrument Locations

PARAMETER	DATA ACQUISITION AND CONTROL	ENGINE COMPUTER SENSORS
Cam Speed & Timing Sensor		A
Crankshaft Speed & Timing Sensor[A]		B[A]
Coolant Pressure to Jug	1	
Coolant Temperature to Jug	2	
Oil Temperature to Cooler	3	
Atmospheric Pressure		C[B]
Crankcase Pressure	4	D[B]
Facility Air Pressure to Cooling Tower	5	
Oil Manifold Temperature	6	E[B]
Oil Sampling Valve	7	
Oil Manifold Pressure	8	F
Coolant Temperature from Engine	9	H[B]
Coolant Pressure from Engine		G[B]
Coolant Flow Barco Delta Pressure	10	
Air Inlet Manifold Pressure	Fig. A2.8	I[B]
Air Inlet Manifold Temperature	11	
Fuel Temperature from Filter	Fig. A2.4 – Z	
Fuel Pressure from Head	Fig. A2.4 – 13	
Fuel Flow Rate	(At Micro Motion)	
Exhaust Manifold Temperature	Fig. A2.3 – 14	Fig. A2.3 – J[B]
Exhaust Manifold Pressure	Fig. A2.7	
Humidity	Fig. A4.1	
Air Flow Rate	Fig. A4.1	
External Heating Oil Temperature	Fig. A2.5	
Oil Filter Inlet Pressure	Fig. A2.6[B]	
Oil Filter Outlet Pressure	Fig. A2.6[B]	

[A] Connect for timing calibration only [B] Optional

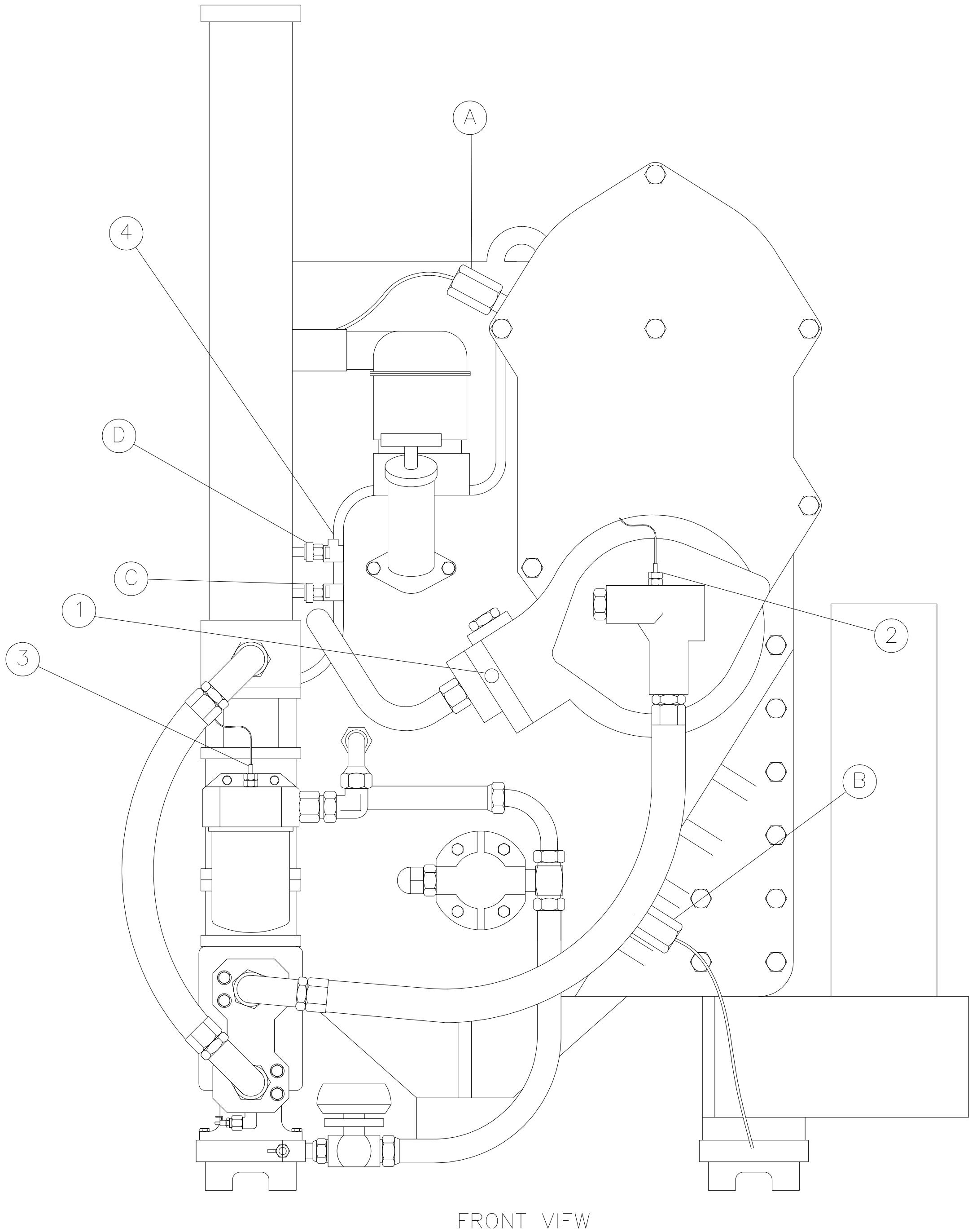


Fig. A2. 1 Instrument Locations - Engine Front View

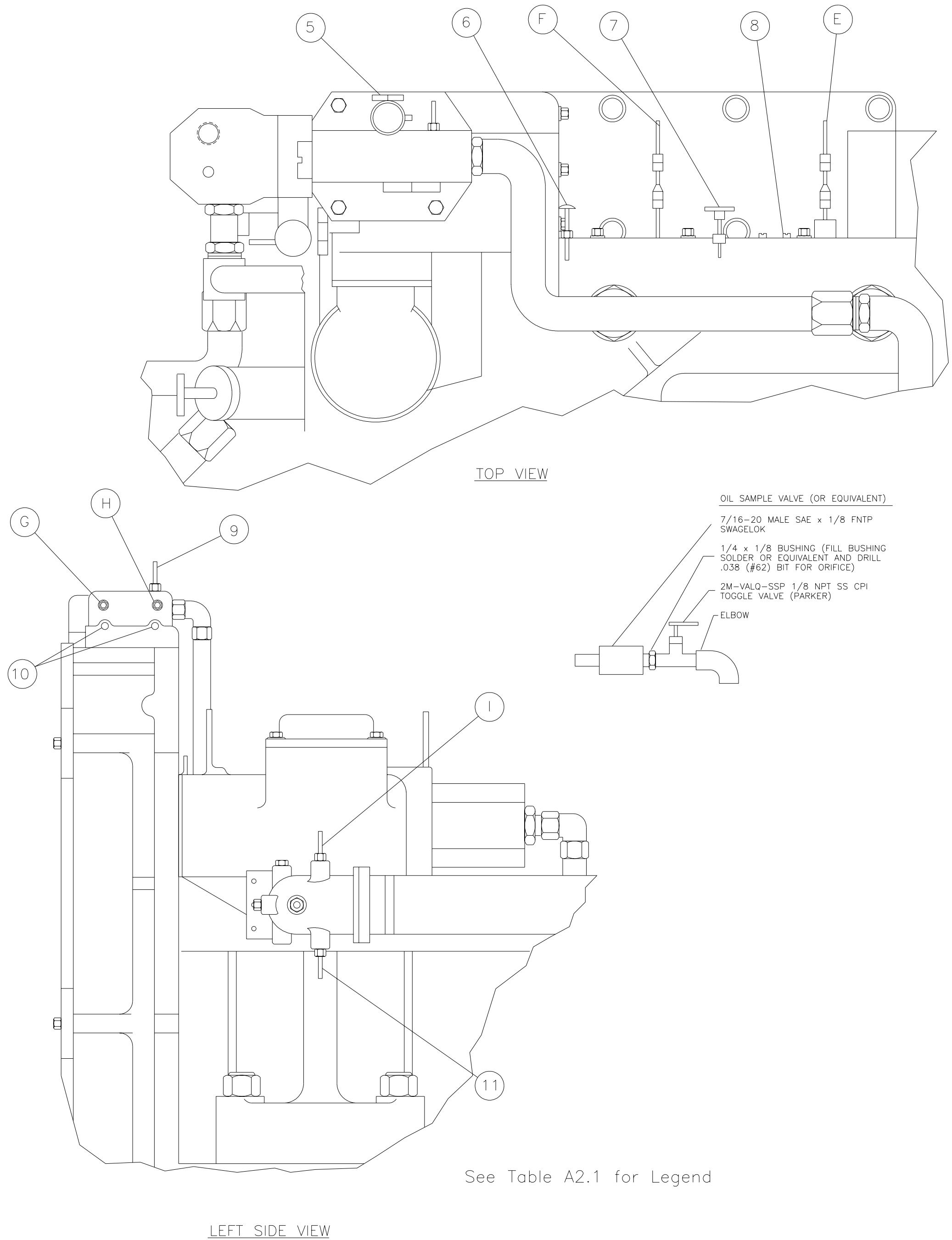


Fig. A2. 2 Instrument Locations - Top and Left Engine Views

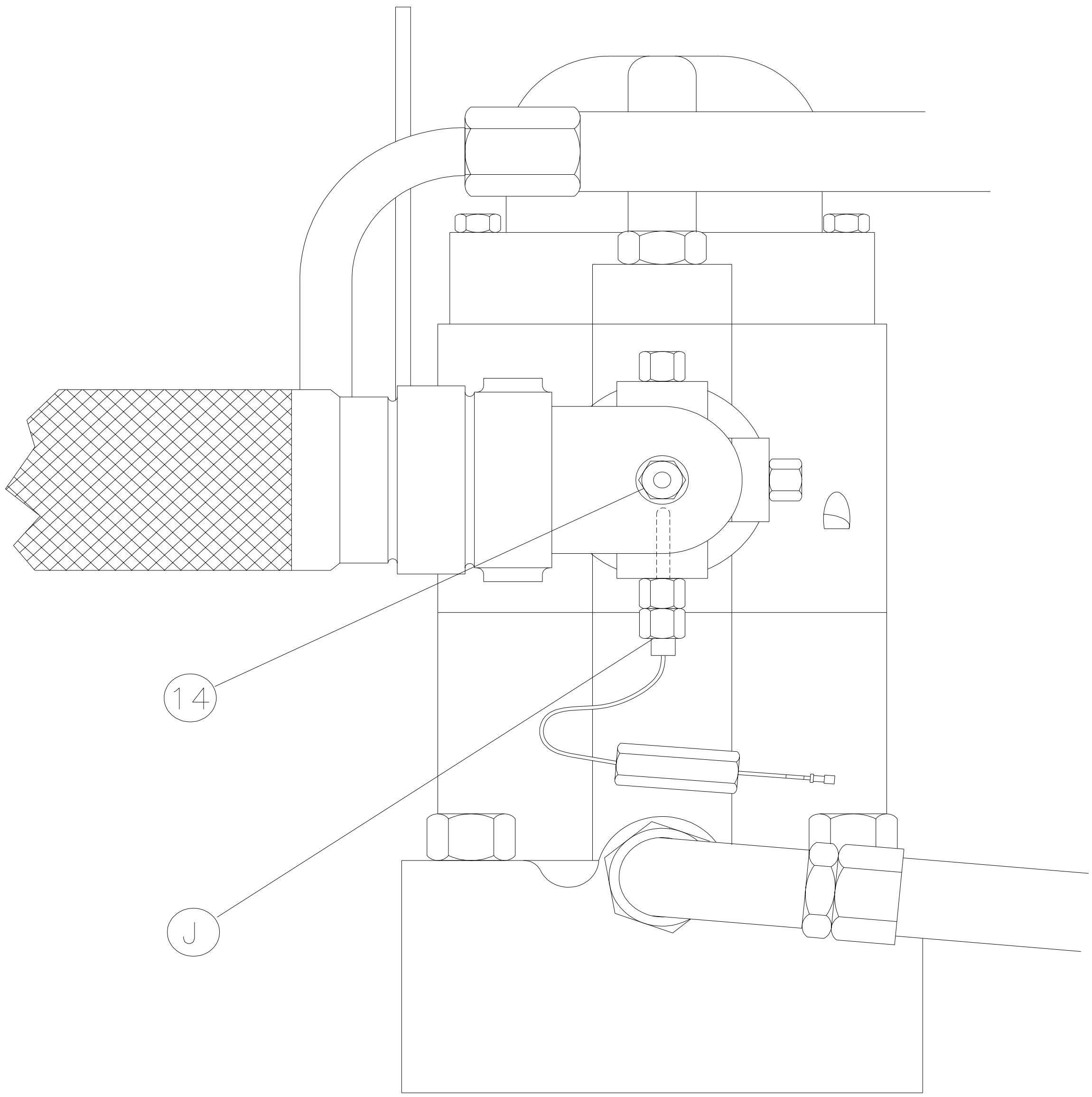
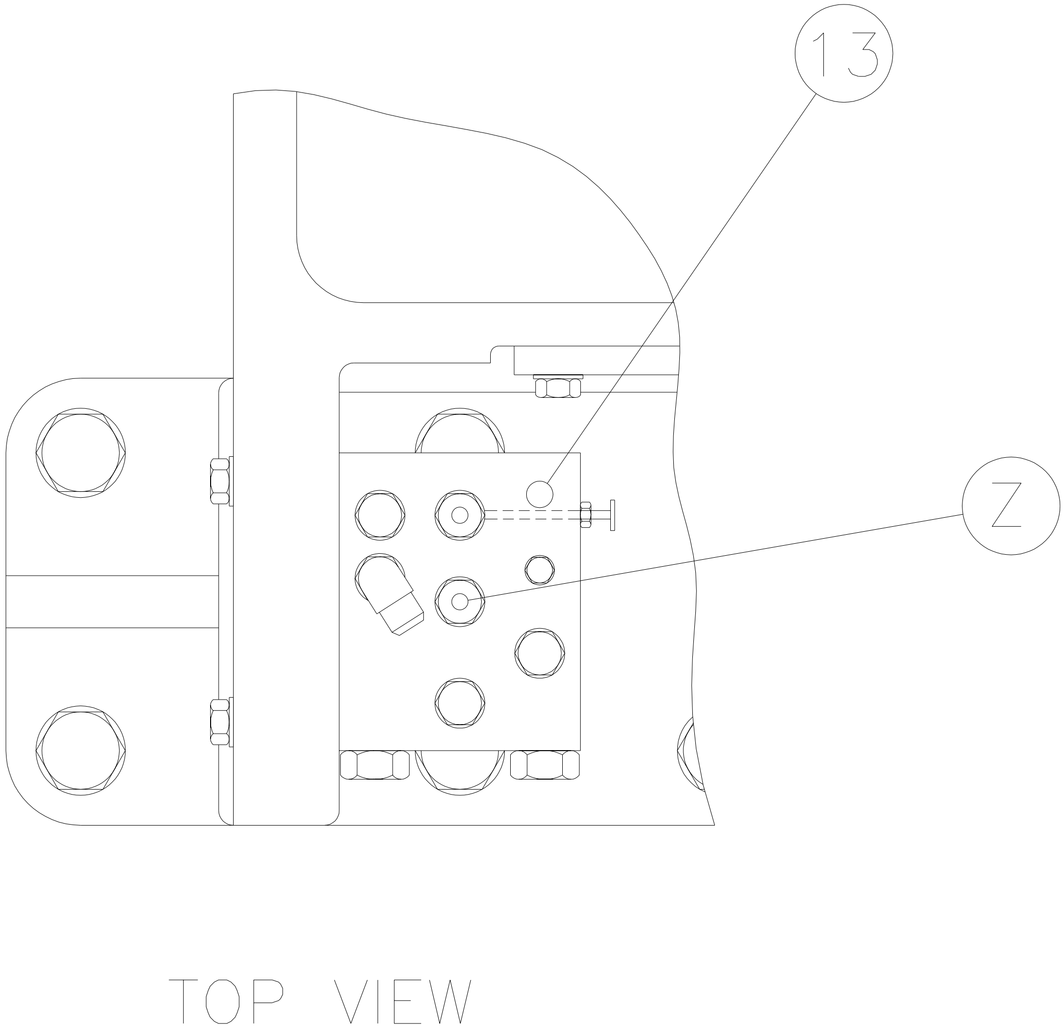


Fig. A2. 3 Instrument Locations - Right Engine View



See Table A2.1 for Legend

Fig. A2. 4 Instrument Locations - Top Engine View

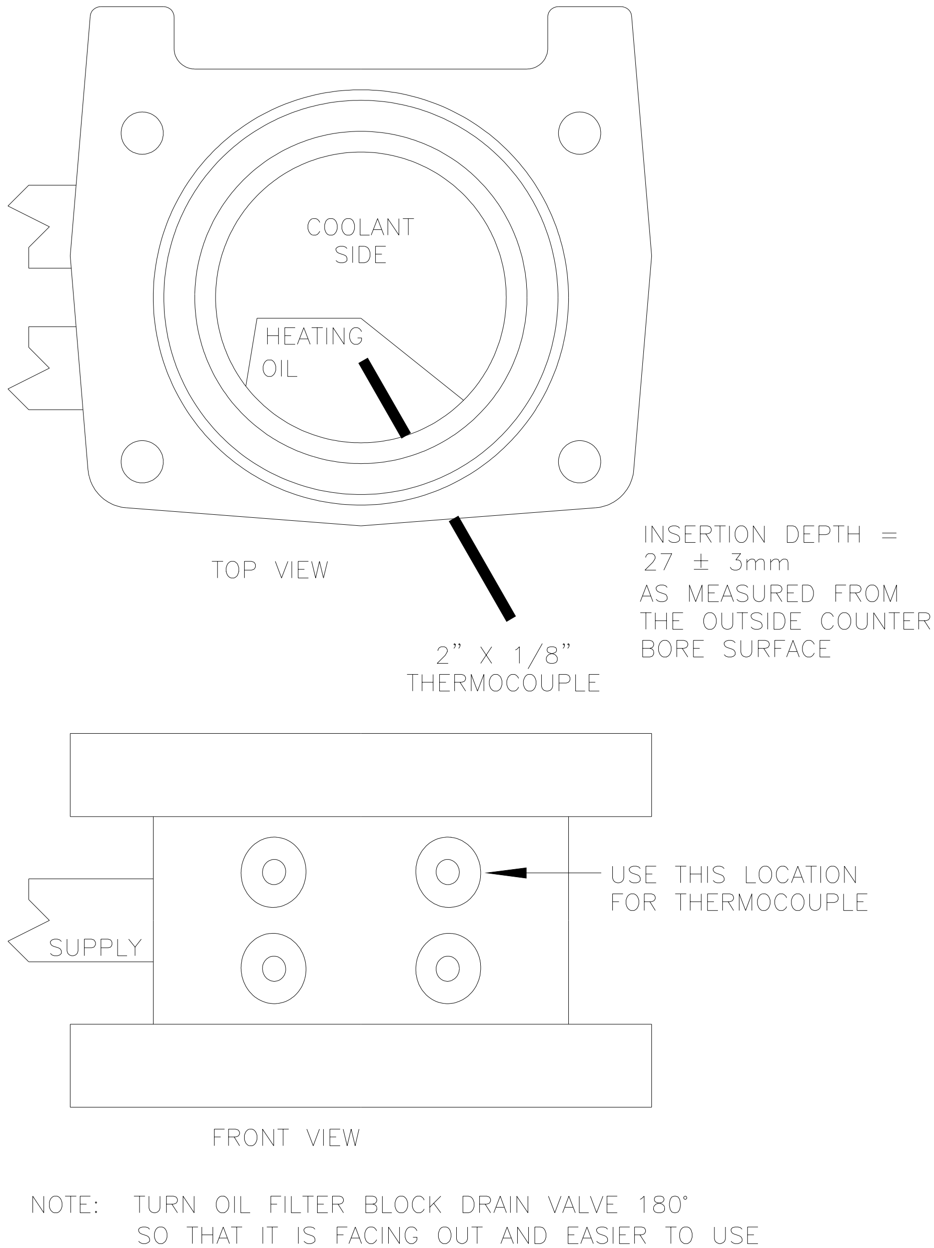


Fig. A2. 5 Engine Heating Oil Thermocouple Location

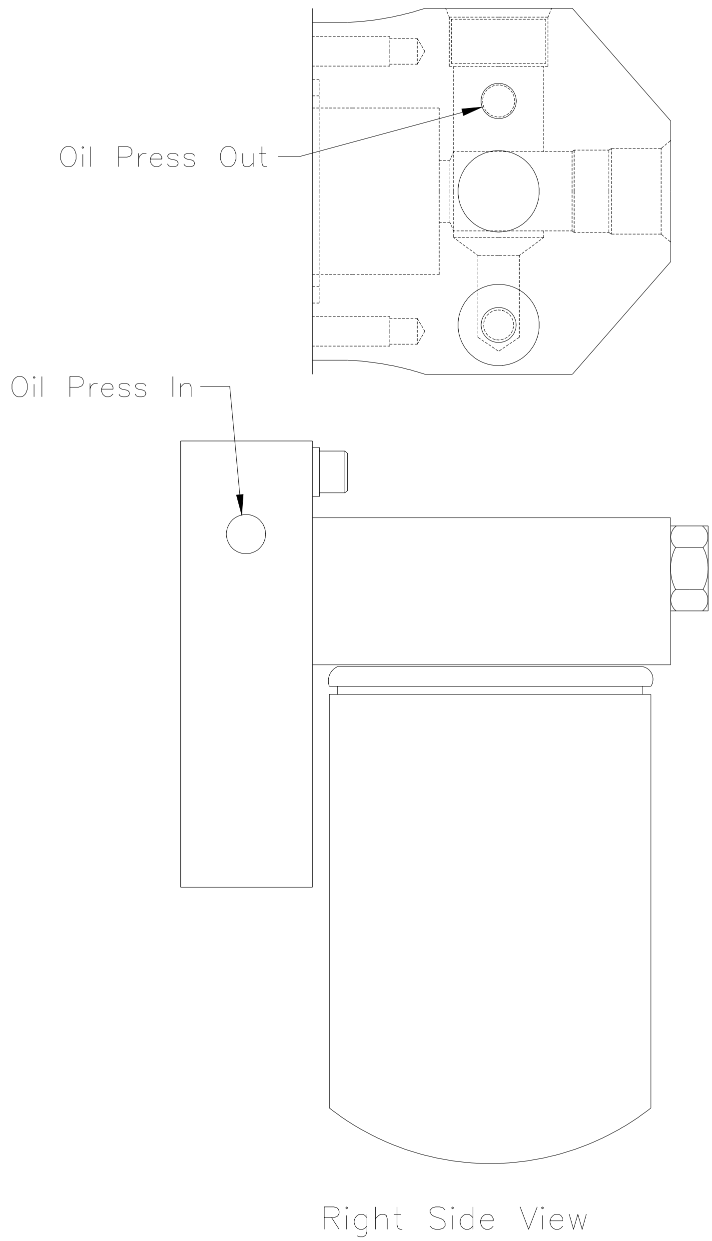


Fig. A2.6 Oil Filter Delta Pressure Locations

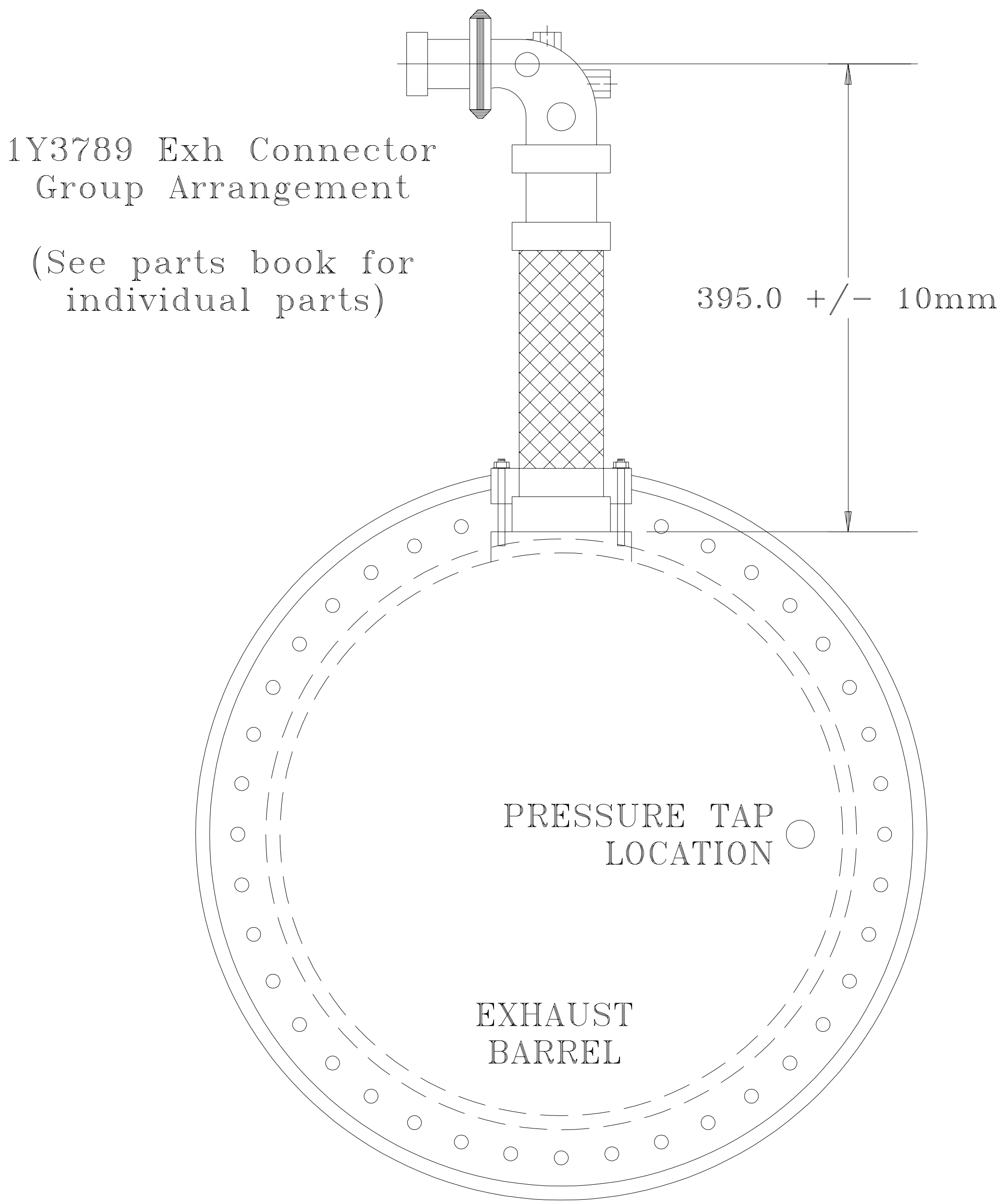
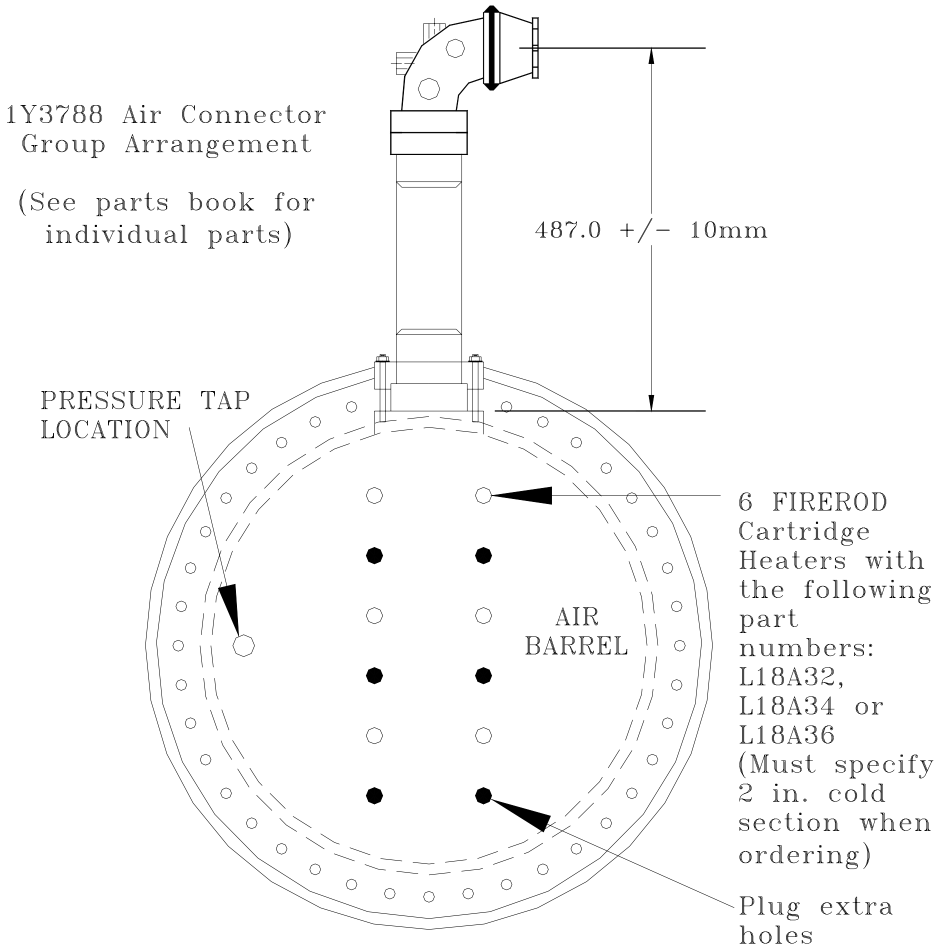


Fig. A2.7 1Y3978 Exhaust Barrel Piping and Pressure Locations



NOTE X: Dummy heater elements may be substituted for the FIREROD Cartridge Heaters[36] as long as they are the same dimension of 21 in. x 5/8 in. diameter. The 21 in. is from end-to-end. Length tolerance is 3 in. and the diameter tolerance is 1/64 in.

Fig. A2.8 1Y3976 Intake Air Barrel Piping and Pressure Locations

[36] FIREROD Cartridge Heaters may be purchased from Southwest Heater & Controls, 12052 Forestgate Dr., Dallas, TX 75243, (512) 451-9003.

Table A2.2 Recommended Thermocouple Diameters, Lengths and Immersion Depths[A]

LOCATION	*DIAMETER inches*	*LENGTH inches*	*DEPTH ± 3 mm*
Oil to Manifold	1/8	6 max	22
Oil to Cooler	1/8	6 max	27
External Heating Oil	1/8	6 max	27
Coolant In	¼	6 max	40
Coolant Out	¼	6 max	26
Inlet Air	¼	6 max	57
Exhaust	¼	6 max	67
Fuel	¼	6 max	34

[A] Chosen thermocouples shall meet the system time response shown in Table A2.4

Table A2.3 Calibration Tolerances

PARAMETERS	TOLERANCE
Torque	10 Nm
Fuel Flow Rate	0.4 g/min
Air Flow Rate	± 2% of reading from 10-100 % of calibrated range; ±0.5% of FS below 10% of calibrated range
Humidity	Listed in this Test Method
TEMPERATURES	**°C**
Fuel at Filter	0.5
Coolant to Jug	0.5
Coolant from Head	0.5
Oil to Cooler	0.5
Oil Manifold	0.5
External Heating Oil	0.5
Inlet Air at Manifold	0.5
Exhaust at Manifold	1.0
PRESSURES	**kPa**
Fuel from Head	0.7
Coolant to Jug	0.7
Oil Manifold	0.7
Inlet Air Barrel	0.3
Exhaust Barrel	0.3
Crankcase	0.02

Table A2.4 Maximum Allowable System Time Constants

Measurements	Time – Seconds
Speed	3.0
Fuel Flow Rate	20.0
Air Flow Rate	3.0
Oil Weight	See Note Below[A]
Temperatures	
Fuel at Filter	3.0
Coolant to Jug	3.0
Coolant from Head	3.0
Oil to Cooler	3.0
Oil Manifold	3.0
External Heating Oil	3.0
Inlet Air at Manifold	3.0
Exhaust at Manifold	3.0
Pressures	
Fuel from Head	3.0
Oil Manifold	3.0
Inlet Air Barrel	3.0
Exhaust Barrel	3.0
Crankcase	3.0

[A]Oil Weight shall have a time constant between 20 and 30 s

Table A2.5 Measurement and Reporting Resolutions

Parameter	Units	Tol.	Spec.	Minimum Measurement Resolution	Round Values to the Nearest Whole Number
Speed	RPM	± 3	1800	1	Whole Number
Power	kW	Approx.	66	0.1	Tenth
Torque	N·m	Approx.	352	0.1	Tenth
Fuel Rate	g/min	± 1	240	0.1	Tenth
Fuel Timing	BTC		6		
Humidity	g/kg	± 1.7	17.8	0.1	Tenth
Oil Weight	g			2	Whole Number
Temperatures					
Fuel at Filter	°C	± 3	42	0.1	Tenth
Coolant to Jug	°C	Approx.	101	0.1	Tenth
Coolant from Head	°C	± 3	105	0.1	Tenth
Oil to Cooler	°C	Approx.	124	0.1	Tenth
Oil Manifold	°C	± 3	120	0.1	Tenth
External Heating Oil	°C	Approx.	110	0.1	Tenth
Inlet Air at Manifold	°C	± 3	60	0.1	Tenth
Exhaust at Manifold	°C	Approx.	600	1	Whole Number
Pressures					
Fuel from Head	kPa	± 20	275	1	Whole Number
Coolant to Jug	kPa	Approx.	80	1	Whole Number
Oil Manifold	kPa	± 20	415	1	Whole Number
Inlet Air Barrel (abs)	kPa(abs)	± 1	292	0.1	Tenth
Exhaust Barrel (abs)	kPa(abs)	± 1	252	0.1	Tenth
Crankcase	kPa	Approx.	0.20	0.01	Hundreth
Flows					
Coolant	L/min	± 2	75	0.1	Tenth
Blowby	L/min	Approx.	35	1	Whole Number
Air	kg/h	Approx.	400	0.1	Tenth

A2.1 Requirements for the Quality Index Calculation:

A4.1.1 Round the recorded values in accordance with the specifications listed in Table A2.5.

A4.1.2 Use the values listed in Table A2.6 for all calculations.

A4.1.3 Use 6-min data to calculate the Quality Index.

A4.1.4 Reset data that is greater than the high values listed in Table A2.6 from the Over & Under Range Values column to the high value for that particular parameter.

A4.1.5 Reset data that is less than the low values listed in Table A2.6 from the Over & Under Range Values column to the low value for that particular parameter.

A4.1.6 Round the Quality Index values to the nearest 0.001.

A4.1.7 Report Quality Index values on Form 3 of the test report.

NOTE 1: Refer to the DACA II Final Report for calculating the Quality Index involving the loss of test data or bad quality test data.

A2.2 Formula to calculate the Quality Index

$$QI = 1 - \frac{1}{n}\sum\left(\frac{\alpha + \beta - 2X_i}{\beta - \alpha}\right)^2 \qquad \text{Eq. A2.1}$$

X_i = Recorded test measurement parameter

α = Lower specification for that parameter

β = Upper specification for that parameter

n = Total number of data points taken as determined from test length and procedural specified sampling rate

Table A2.6 Quality Index Calculation Values and Plotting Axis Scale Definitions

		Quality Index α & β Values[A]		Over & Under Range Values[B]		Plot Axes Ranges[C]		
Controlled Parameters	Units	α	β	Low	High	Min	Max	Increment
Speed	r/min	1798.53	1801.47	1710	1890	1770	1830	10
Fuel Flow	g/min	238.97	241.03	125	245	230	255	5
Humidity	g/kg	16.78	18.82	5	21	5	40	5
Coolant Flow through Engine	L/min	73.06	76.94	0	82	60	90	5
Coolant from Head Temp.	°C	104.378	105.622	55	125	90	120	5
Oil to Manifold Temp.	°C	118.798	121.202	60	200	105	135	5
Inlet Air at Manifold Temp.	°C	59.36	60.64	20	100	50	70	5
Fuel into Head Temp.	°C	40.885	43.116	0	75	30	60	5
Oil to Manifold Press.	kPa	404.384	425.616	0	690	380	450	10
Inlet Air Press. at Barrel	kPa(abs)	291.449	292.551	242	302	285	300	5
Exhaust Press. at Barrel	kPa(abs)	251.15	252.85	215	315	235	265	5
Fuel Press.	kPa	271.471	278.529	125	425	230	300	10
Uncontrolled Parameters								
Power	kW					62	72	1
Torque	N·m					335	375	10
Blowby	L/min					5	65	5
Coolant In Temperature	°C					75	100	5
Coolant Delta	°C					0	10	1
Oil to Cooler Temp.	°C					110	140	5
External Heater Oil Temp.	°C					100	165	5
Exhaust at Manifold Temp.	°C					620	670	10
Crankcase Press.	KPa					0.0	1.5	0.1
Coolant Press. from Engine Pump	KPa					60	95	5

[A]The threshold for operational validity is 0.00.

[B]Only to be used in the calculation of Quality Index & Average and does not effect how process is graphed.

[C]Quality Index Scales are to range from -0.3 to 1.0 with increments of 0.1. The axis for Test Time is 0 to 504 h in 30-h increments. X-axis length should be at least 8.0 in. Y-axis length should be at least 5.5 in.

A3. COOLING SYSTEM ARRANGEMENT

A3.1 Install a sight glass as shown using the following components listed in Table A3.1.

Table A3.1 Coolant Sight Glass Components

Item	Qty	Part Number	Source	Description	Location
1	1	2061-20-20S	Aeroquip	45° SAE O-ring port to 37° flare	Inlet to top of coolant tower
2	1	190265-20S	Aeroquip	45° Elbow – SAE O-ring to 37° flore swivel	Head outlet
3	2	412-16-20S	Aeroquip	Male pipe re-usable fitting	Inlet & outlet of sight glass
4	1	4288 1 in. NPT Female	Gits[A]	Style OL Flow Gage (Sight Glass)	Locate in middle of hose assembly
5	1	FC350-20	Aeroquip	Hose ~ 5 ½ in.	Head side of assembly
6	1	FC350-20	Aeroquip	Hose ~ 6 ½ in.	Tower side of assembly

[A]Gits Manufacturing Company (515) 782-2105.

A3.1.1 Reuse one of the straight 37° flare swivel hose fittings on the existing hose for the tower side of assembly. The 90° fitting in the cylinder head is also still used. Installation angle will be slightly different.

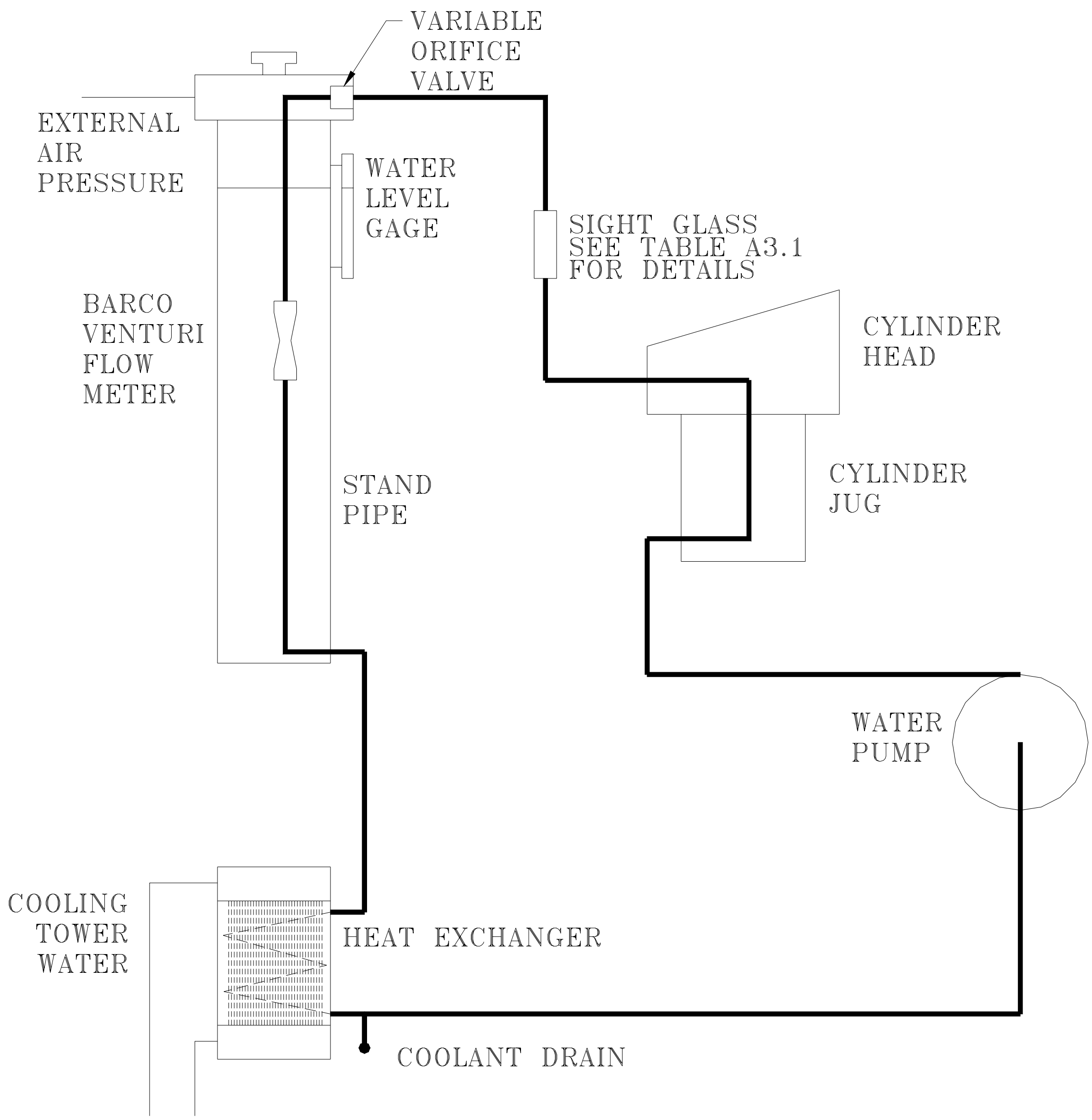


Fig. A3.1 Engine Cooling System Arrangement

A3.2 Cleaning Procedure for the Engine Coolant System - Clean the coolant system when visual inspections show the presence of any oil, grease, mineral deposits, or rust.

A3.2.1 To remove oil and grease from the cooling system:

A3.2.1.1 Operate the engine until oil and water operating temperatures are attained; shutdown the engine and drain the cooling system.

A3.2.1.2 Fill the cooling system with a solution of 454 g of trisodium phosphate (Na_3PO_4) to 38 L of water; operate the engine for 5 min to assure complete mixing of the solution with any material remaining from the previous fill.

A3.2.1.3 Shutdown the engine and drain and flush the engine with fresh water and drain the water from the system.

A3.2.2 To remove mineral deposits from the cooling system:

A3.2.2.1 Operate the engine until oil and water operating temperatures are attained; shutdown the engine and drain the cooling system.

A3.2.2.2 Fill the cooling system with a solution of 454 g of commercial sodium bisulfate ($NaHSO_4$) to 19 L of water; then run the engine at operating temperatures for 30 min.

A3.2.2.3 Shutdown the engine, drain and flush the engine with fresh water and drain the water from the system.

A3.2.2.4 Fill the cooling system with a solution of 454 g of trisodium phosphate (Na_3PO_4) to 38 L of water; operate the engine for 5 min to ensure complete mixing of the solution with any material remaining from the previous flush.

A3.2.2.5 Shutdown the engine and drain the engine, flush with clear water and drain after flushing.

A3.2.2.6 Disassemble the engine and prepare for the next test.

A3.2.3 If the cooling system is contaminated by oil and mineral deposits, remove the oil from the system, then remove the mineral deposits. Alternatively, the cylinder head coolant passages may be cleaned after the head is removed.

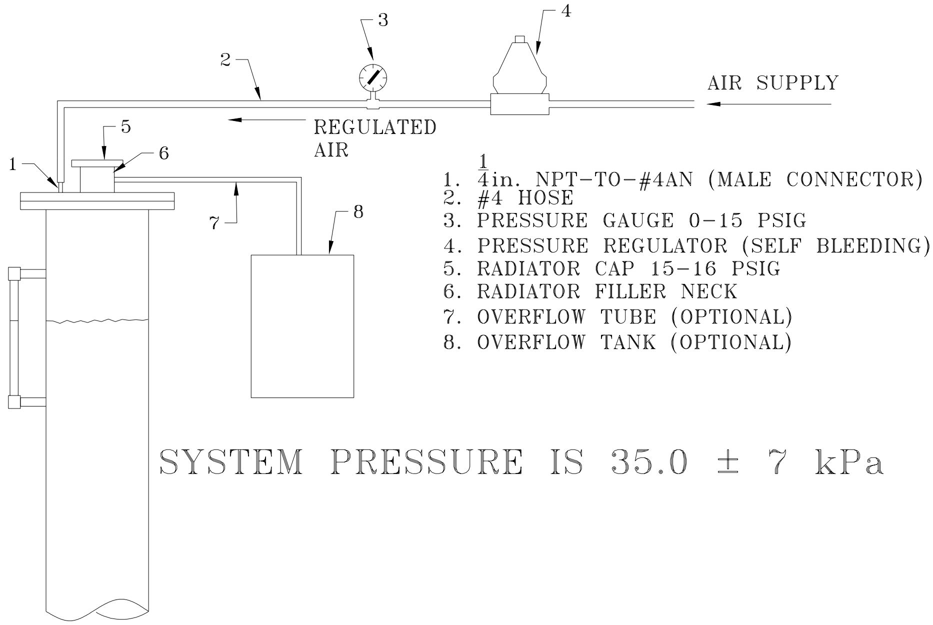


Fig. A3.2 Coolant Pressurization System

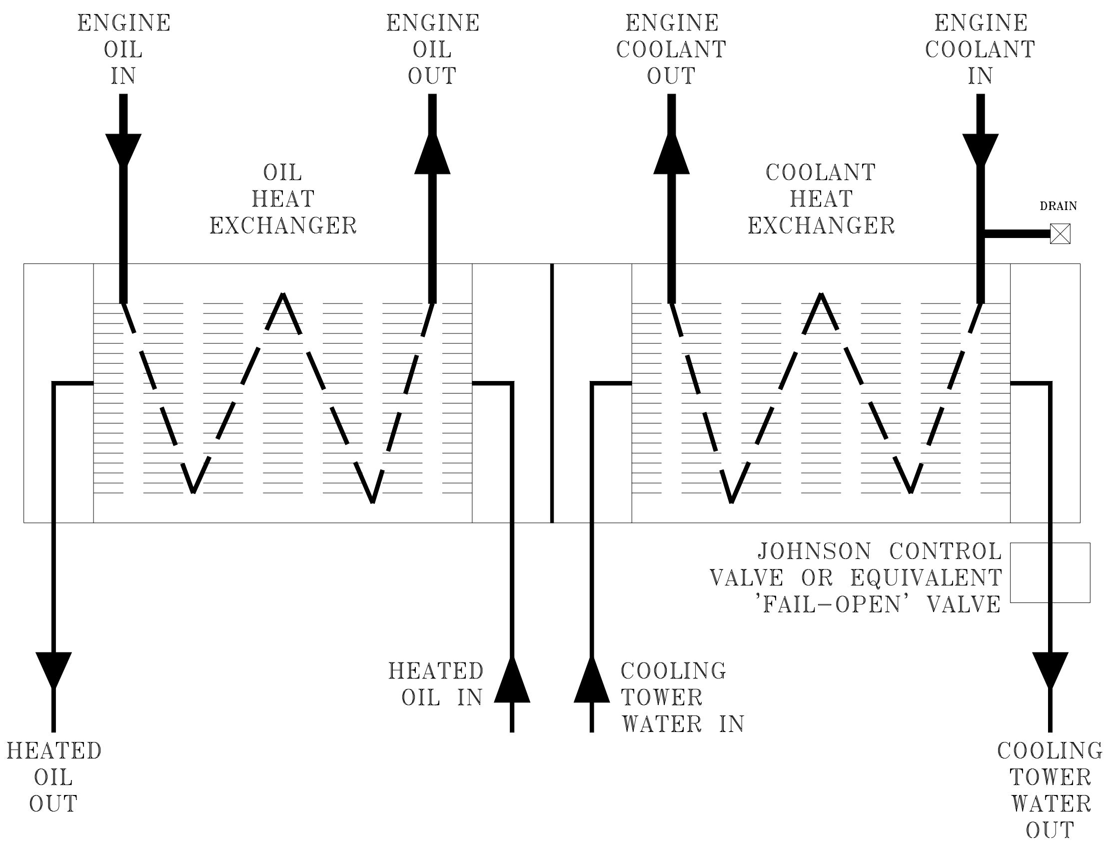


Fig. A3.3 Cooling Tower Water Circuit

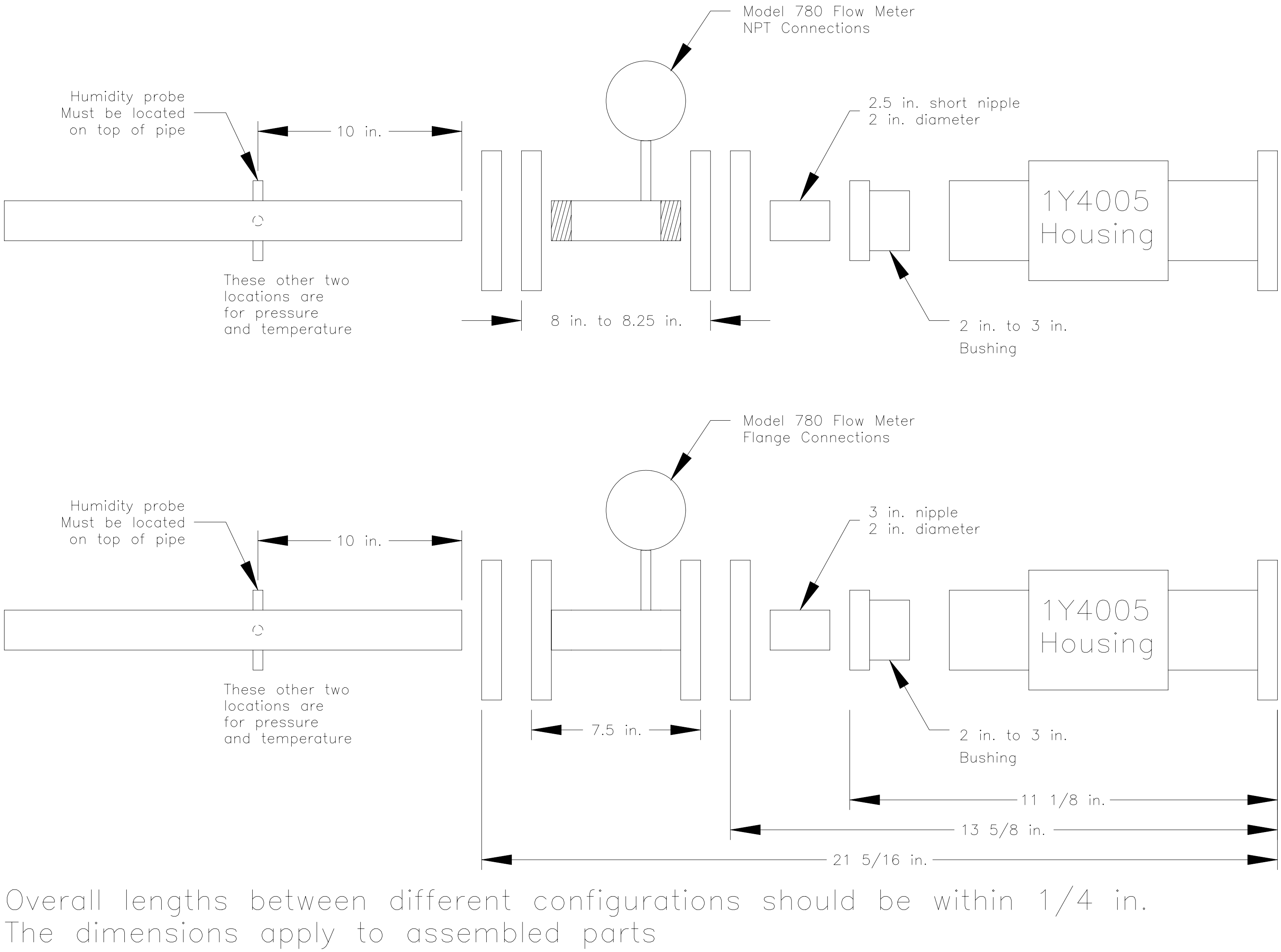


Fig. A4.1 Intake Air Sensor Installation

A5 Fuel System

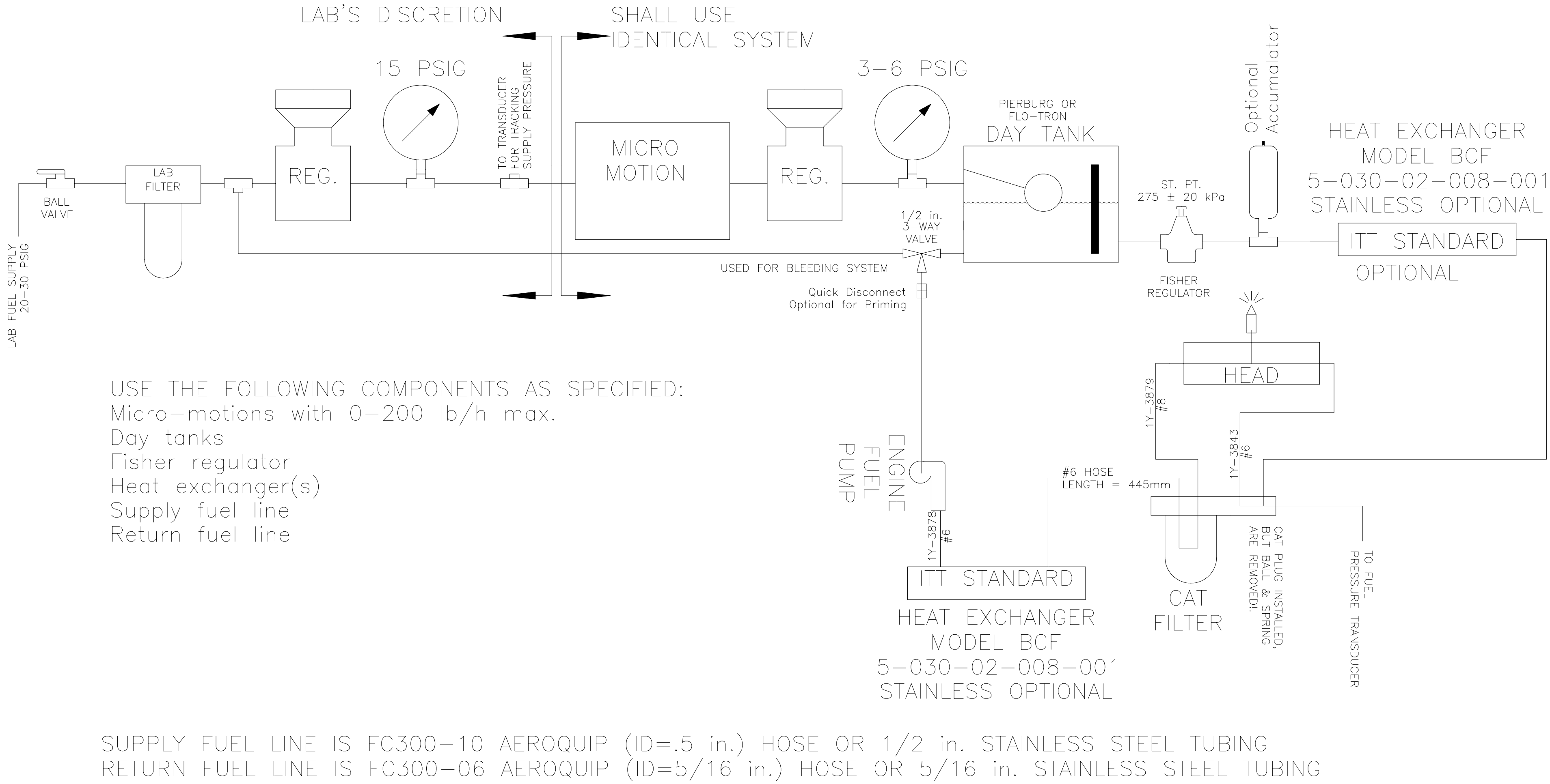


Fig. A5.1 Fuel System Design and Required Components

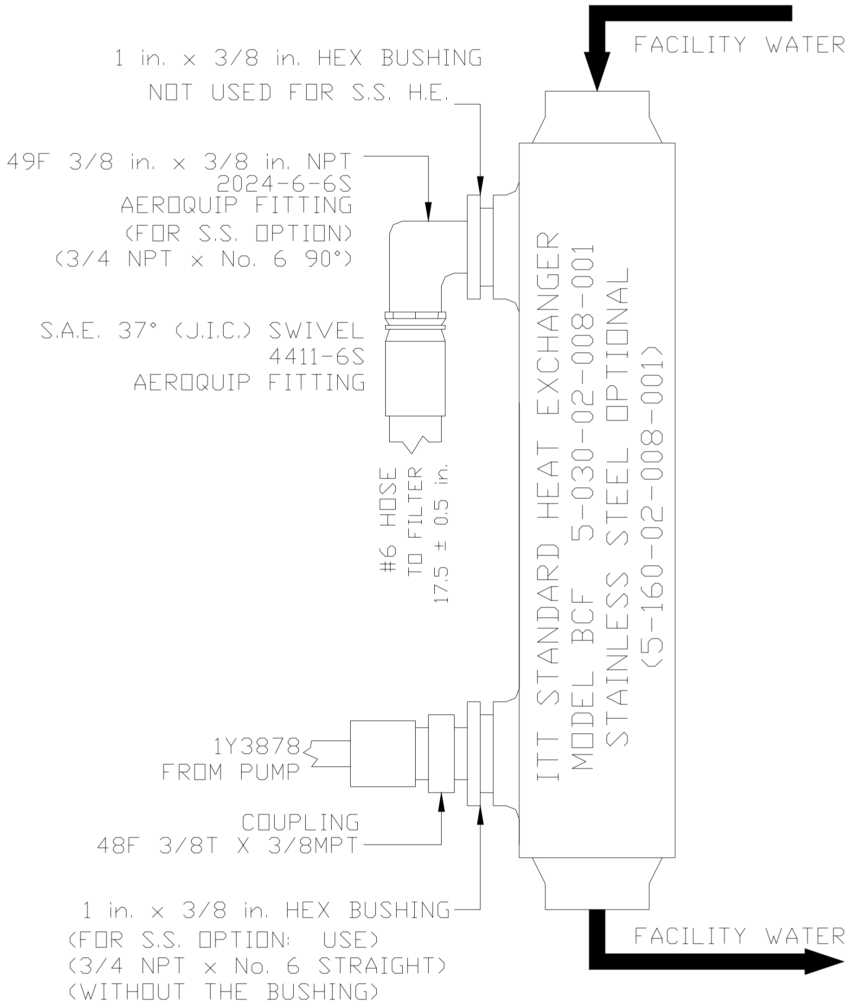


Fig. A5.2 Fuel Heat Exchanger Plumbing Connections

Table A5.1 Fisher Regulator Information

Information as it appears on regulator tag

TYPE 98	PRESS. UNITS	MAX INLET	SPRING RANGE	TRIM MATERIAL	MAX ALLOWABLE INLET PRESS
H-17	PSIG	75	25-75	SST	250

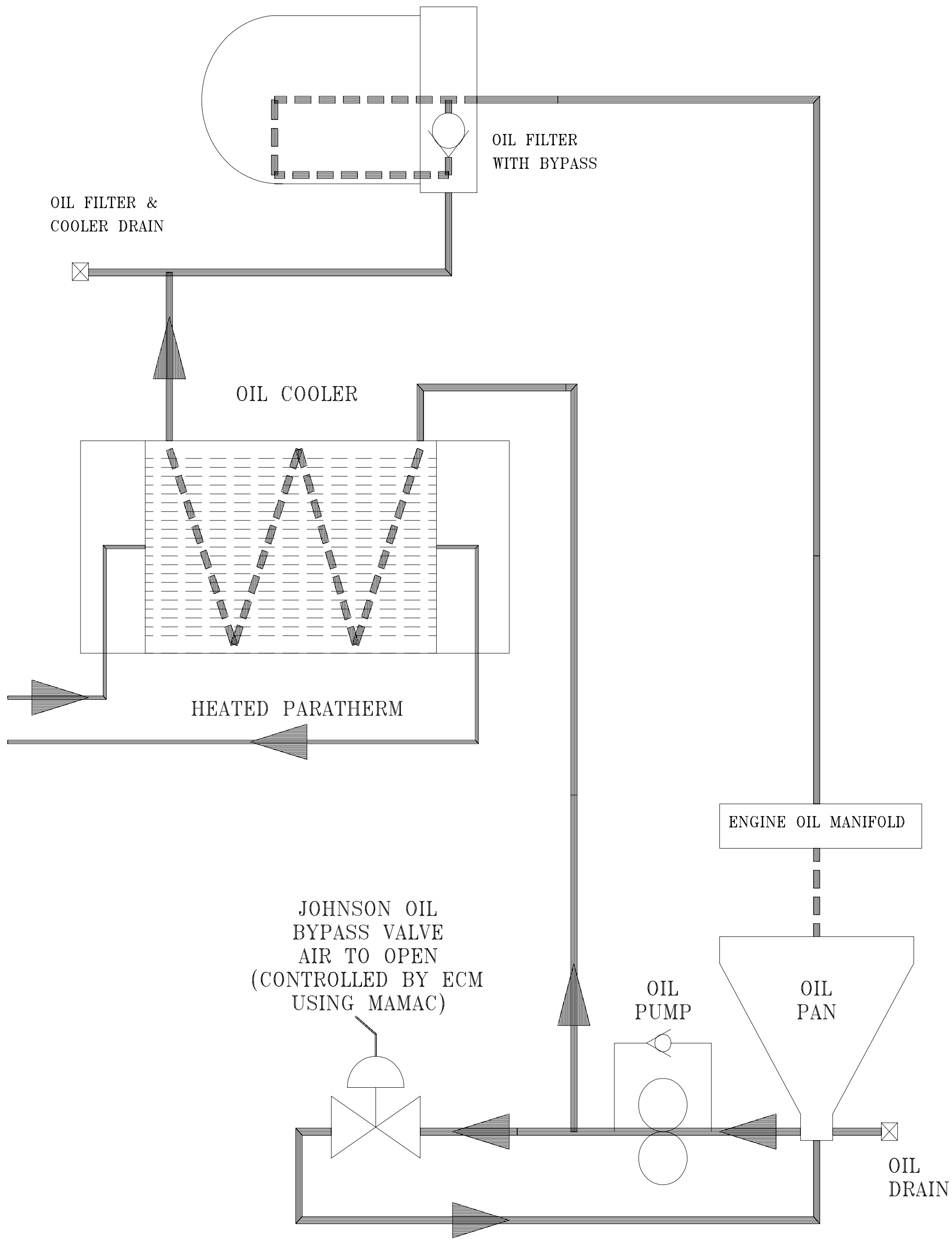


Fig. A6.1 Details of Oil System

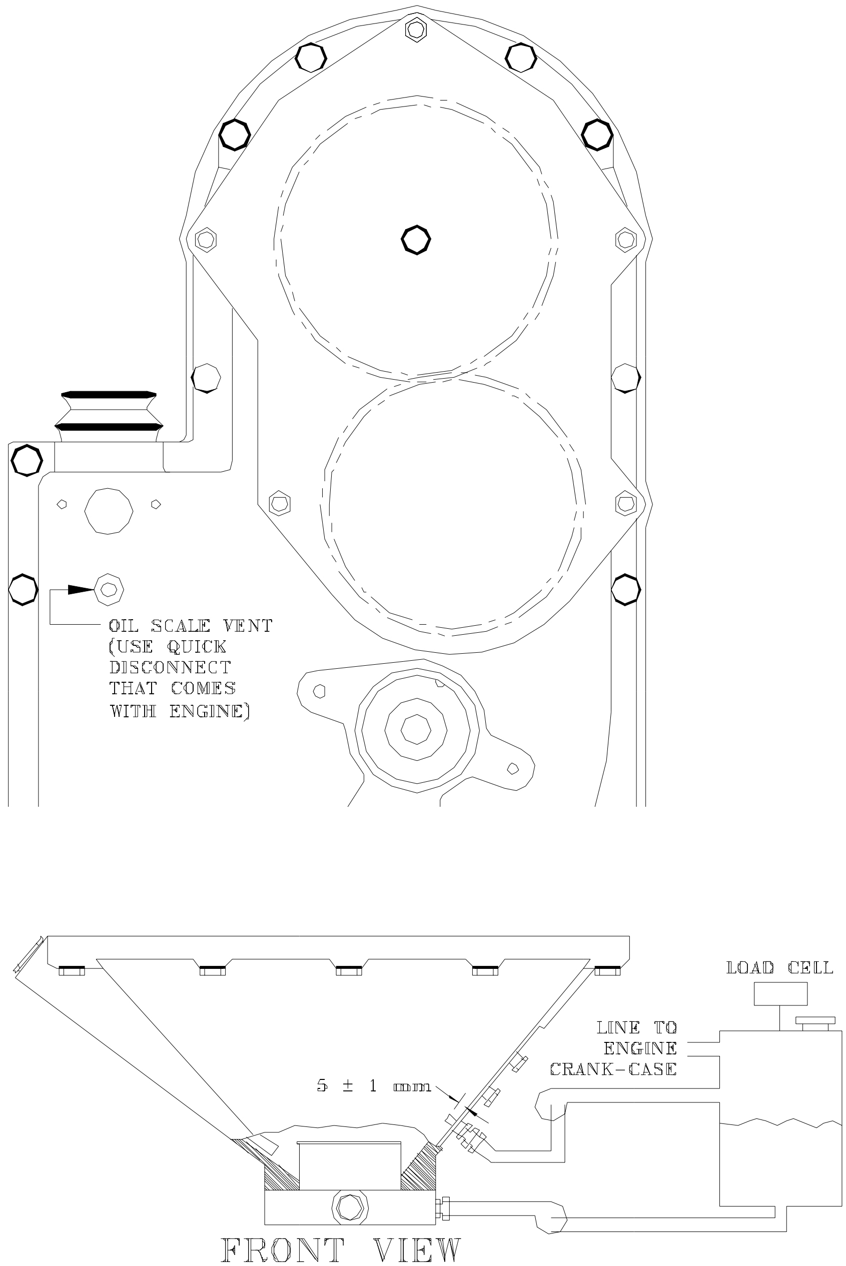


Fig. A6.2 Oil Scale Measurement System

[A] SUCTION PUMP AND HOSE
Type: Viking C-90 Pump
Flow: 6 ± 1.5 g/h
Speed: 285 r/min
Hose: 0.25 in. ID Teflon Steel braided
2.7 m max. length

[A] RETURN PUMP AND HOSE
Type: Viking C-92 Pump
Flow Differential: 3 ± 1 g/h
Speed: 163 r/min
Hose: 0.25 in. ID Teflon Steel braided
2.7 m max. length

VENT LINE: 0.25 in. ID Hose
OIL IN RESERVOIR: 1,000 g (approx)
SCALE PRECISION: See Procedure
[A]FLEXIBLE HOSE (to and from fixed external sump support):
Aeroquip FC352-08

[A] Or Equivalent

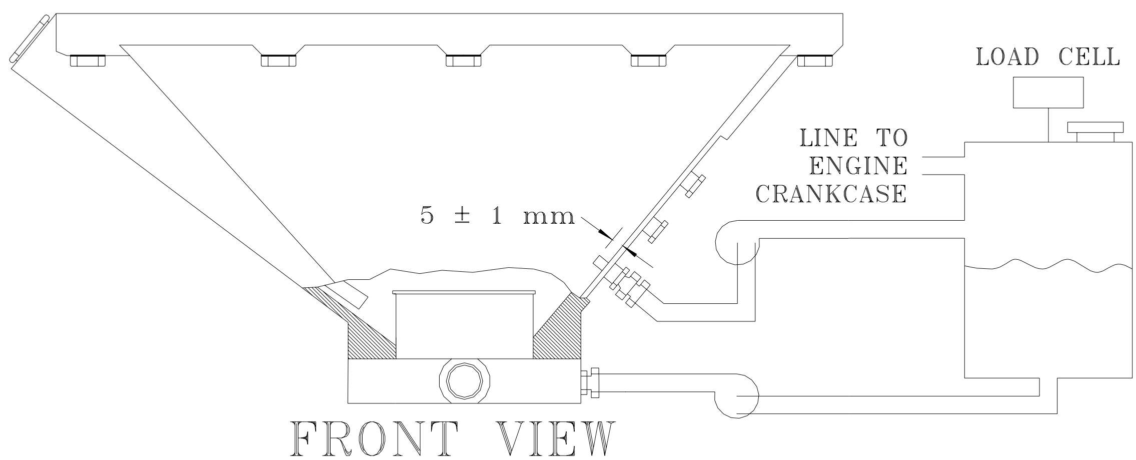


Fig. A6.3 Low Flow Oil Scale System

A6.1 Verification of Oil Scale Pump Flows - Verify the oil scale pump flow rates with EF-411 at 26.5 ± 5.5 °C as the test fluid using the following procedure:

A6.1.1 EQUIPMENT NEEDED:

A6.1.1.1 1 stopwatch

A6.1.1.2 1-2 gal of EF411 oil at 26.5 ± 5.5 °C

A6.1.1.3 1 temporary reservoir pan

A6.1.1.4 1 temporary discharge pan

A6.1.2 FLOW FROM OIL PAN TO OIL SCALE:

A6.1.2.1 Disconnect the line from the oil pan and place in temporary reservoir pan.

A6.1.2.2 Disconnect the line from the oil scale and place in the temporary discharge pan.

A6.1.2.3 The height of the pump relative to the reservoir and discharge pans shall be within 3 ft to reduce any head pressure differences, which may effect the flow rates.

A6.1.2.4 Prime the system (both hoses and pump), then shutdown.

A6.1.2.5 Empty the discharge pan and record the weight of it.

A6.1.2.6 Turn the system on and start the stop watch at the same time.

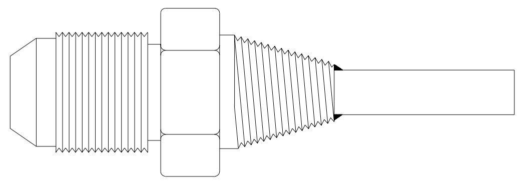
A6.1.2.7 Let the system run for 4 min and the stop it.

A6.1.2.8 Weigh the oil in the discharge pan, subtracting the empty weight.

A6.1.2.9 Determine the flow rate.

A6.1.3 FLOW FROM THE OIL SCALE TO THE OIL PAN:

A6.1.3.1 Repeat the above procedure by disconnecting the line from the oil scale and placing it in the temporary reservoir pan and disconnecting the line at the oil pan and placing it in the temporary discharge pan.

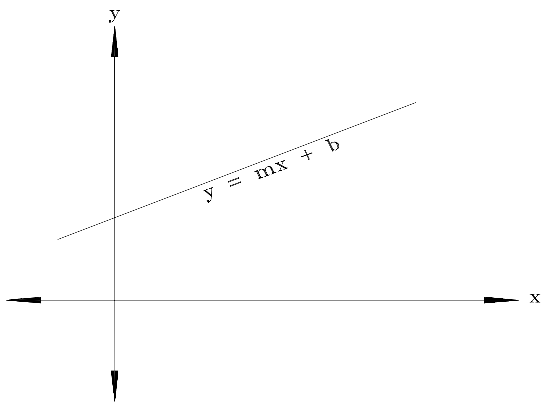


Materials:
1. Steel Tubing: ¼ in. OD, 3/16 in. ID, Approximately 1 in. long
2. Adapter Fitting: ¼ in. NPT to desired connection type
   (Drawing shows an Aeroquip No. 2000-4-4B for a #4, 45° Flare)
3. Silver Solder

Procedure:
1. Drill adapter fitting on pipe thread end to ¼ in. nominal diameter, 3/8 in. minimum depth
2. Insert tube into fitting until bottomed out in the ¼ in. hole
3. Silver solder the tube-to-fitting joint
4. Remove oil pan from engine and install the fitting in location specified
5. Mark the tube location to achieve 5 ± 1 mm protrusion into the oil pan
6. Remove the fitting and cut to length
7. Re-install fitting in pan, check protrusion, and re-install oil pan on engine

Fig. A6.4 Oil Pan Suction Fitting to Oil Scale

A6.2 Oil Consumption Linear Regression Method - If there is good reason to assume that a variable Y is dependent upon another variable X and that the relationship is linear, the best-fit line describing this relationship can be plotted using the following formula:



$$m = \frac{\sum x_i y_i - \frac{\sum x_i \sum y_i}{n}}{\sum x_i^2 - \frac{(\sum x_i)^2}{n}} \quad \text{Eq. A6.1}$$

$$b = \left[\frac{\sum y_i}{n} - m\frac{\sum x_i}{n}\right] \quad \text{Eq. A6.2}$$

$$r^2 = \frac{\left[\sum x_i y_i - \frac{\sum x_i \sum y_i}{n}\right]^2}{\left[\sum (x_i)^2 - \frac{(\sum x_i)^2}{n}\right]\left[\sum (y_i)^2 - \frac{(\sum y_i)^2}{n}\right]} \quad \text{Eq. A6.3}$$

In the case in which we are interested:

1. Y_i points = Oil weights taken at time X
2. X_i points = Times at which oil weight observation X are made
3. m = Slope of best-fit line = Oil Consumption
4. b = Y intercept
5. r^2 = Goodness of fit (1 if perfect, 0 if not fit at all)

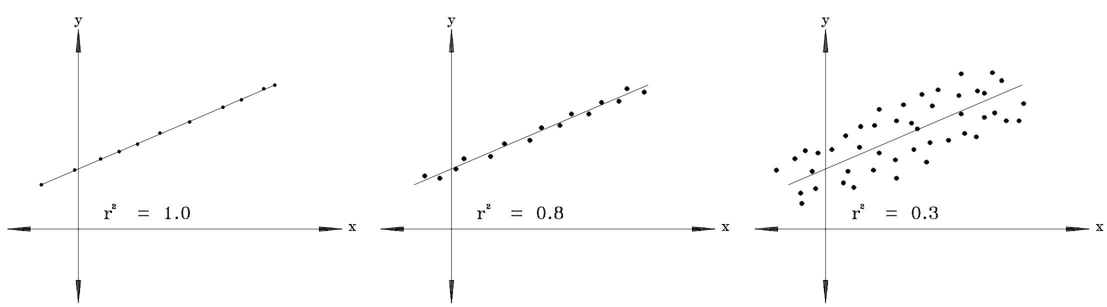


Fig. A6.5 Examples of the Goodness of Fit

A6.3 Oil Sampling Procedure

A6.3.1 Record oil scale reading at test hour four _______g. This is the ***Full Mark***

A6.3.2 Record the ***oil weight*** from the 36th hourly reading ______g

A6.3.3 For **test hours 72, 108, 180, 216, 288, 324, 396, and 468** first remove a ***60mL purge sample, then a separate 30mL sample*** from the sample valve on the oil manifold.

__________ - ________ = ________g
sample + container — container — sample

A6.3.3.1 Return all the purge sample directly back to the oil weigh scale.

A6.3.3.2 Add the amount of new oil using the following equation:

_______ - ___________ + ________ = ______________ g
Full Mark — 36th hourly reading — Sample Weight — Amount of new oil to add

Again, the oil scale reading will generally not return to its full mark. This is normal, and you must not add any additional oil other than what is calculated using the above equation.

A6.3.4 For **test hours 36, 144, 252, 360, 432 and 504** first remove a ***60mL purge sample, then a separate 120mL sample*** from the sample valve on the oil manifold

__________ - ________ = ________g
sample + container — container — sample

A6.3.4.1 Return all the purge sample directly back to the oil weigh scale

A6.3.4.2 Add the amount of new oil using the following equation:

_______ - ___________ + ________ = ______________ g
Full Mark — 36th hourly reading — Sample Weight — Amount of new oil to add

Again, the oil scale reading will generally not return to its full mark. This is normal, and you must not add any additional oil other than what is calculated using the above equation.

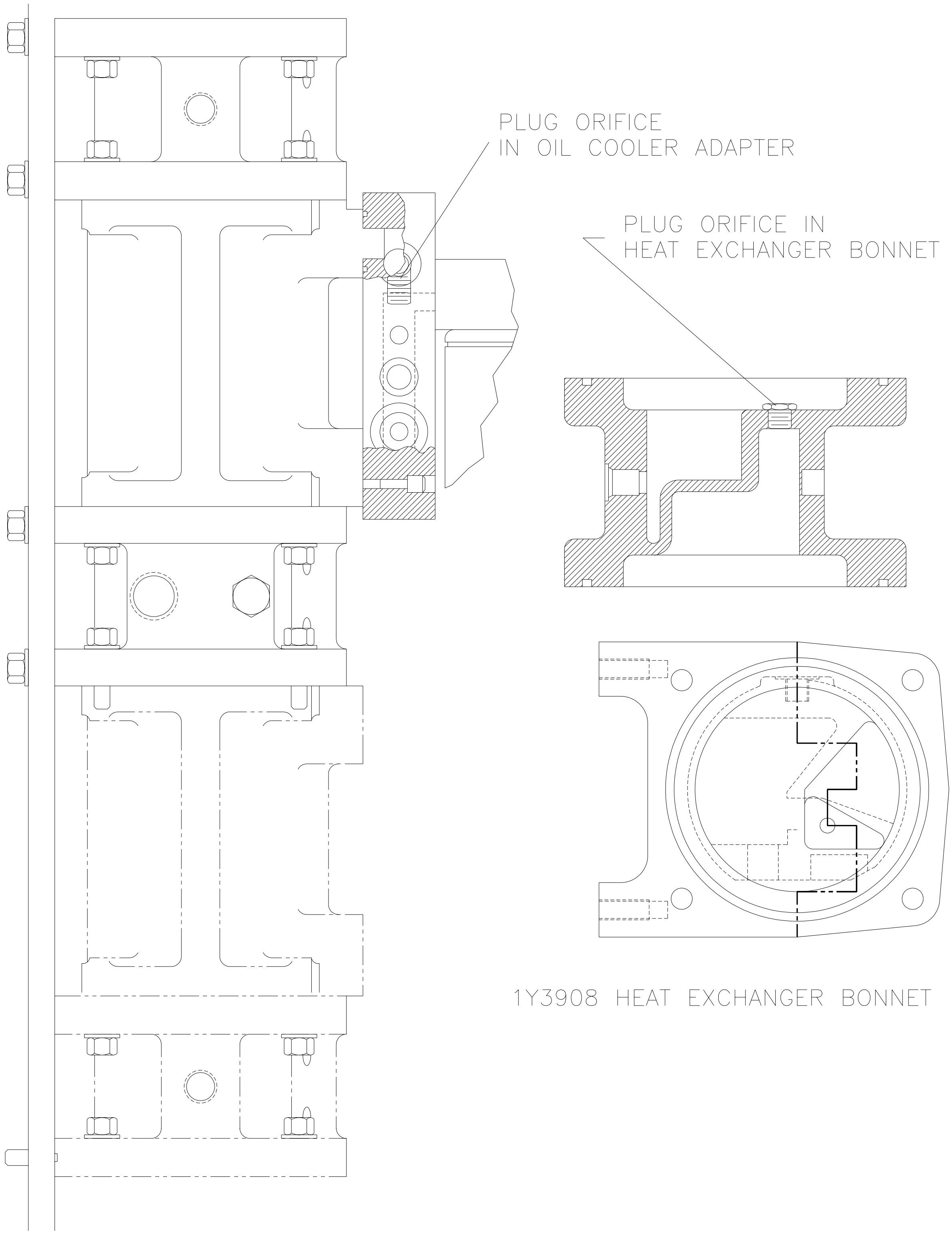


Fig. A6.6 Engine Oil Heating Hardware

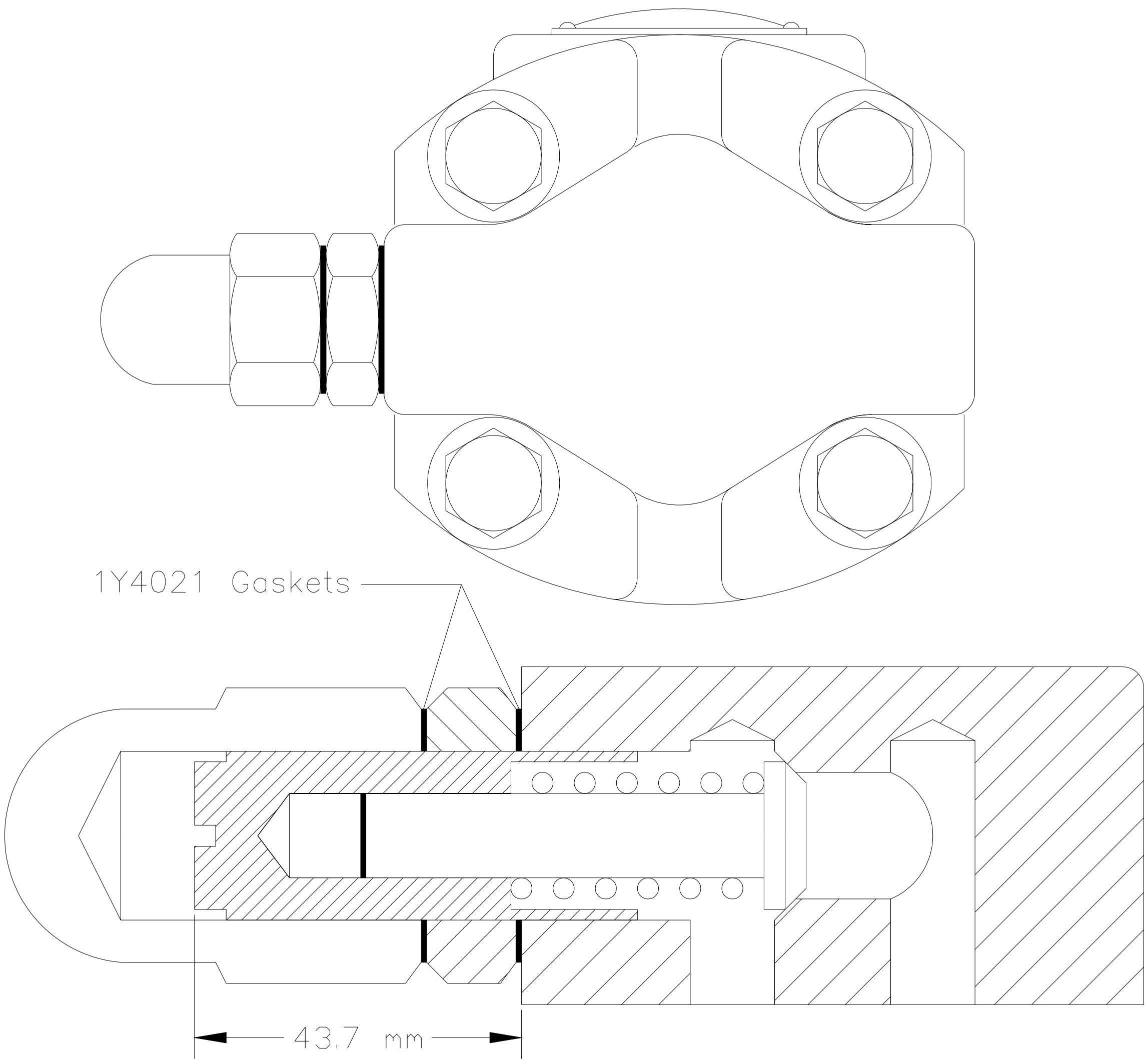


Fig. A6.7 1Y3661 Oil Pump and 1Y4021 Gaskets

A7. ADDITIONAL REPORT FORMS

A7.1 Fuel Batch Analysis Example

Include a copy of the Suppliers Fuel Sheet in the Test Report

Date of Shipment: 12/11/2000 Customer Order No. 1RO9030
Inv./Reqn. No. 5305779 Trailer No. 310
MFG 11/20/2000

PC-9
DIESEL TEST FUEL
OKPPC901

TESTS	RESULTS	SPECIFICATIONS	METHOD
Specific Gravity	0.8520	0.845 – 0.8524	ASTM D4052
API Gravity	34.58	34.5 – 36.0	ASTM D1298
Corrosion, 50˚C, 3h	1A	1 max	ASTM D130
Sulfur, wt%	0.0414	0.04 – 0.05	ASTM D2662
Flash Point ˚F, PM	152	130 min	ASTM D93
Pour Point ˚F	0	0 max	ASTM D97
Cloud Point ˚F	+9	Report	ASTM D2500
Viscosity, Cs 40˚C	2.69	2.4 – 3.0	ASTM D445
Carbon Residue on 10% Bottoms	0.0	0.35 max	ASTM D524
Net Heat of Combustion	18416	Report	ASTM D3338
Water & Sediment, vol%	0.0	0.05 max	ASTM D2709
Accelerated Stability (mg/100mL)	0.4	0.5 max	(PAD)
Total Acid No.	0.003	0.05 max	
Strong Acid No.	0	0 max	
Cetane Index	46.55	Report	ASTM D976
Cetane Number	45.8	42 – 46	ASTM D613
DISTILLATION, ˚F		Report	ASTM D86
IBP	350.4		
5%	401.3		
10%	417.3		
20%	448.2		
30%	471.6		
40%	493.2		
50%	512.1		
60%	530.7		
70%	550.6		
80%	574.3		
90%	607.8	540 – 640	
95%	668.6		
EP	668.6		
Loss	0.5		
Residue	1.0		
HYDROCARBON TYPE, VOL%		ASTM D1319	
Aromatics	32.6	28 – 33	
Olefins	1.2	Report	
Saturates	66.2	Report	

BJS:teh 12/11/00 1033803

A7.2 EXAMPLE OF FAX COPY OF TMC CONTROL CHART ANALYSIS FOR CALIBRATION TESTS

Fax To:
Company:
Fax Number:

**** ASTM Test Monitoring Center *****
*** 1R Control Charts Analysis ***

Start	=	Lab	=	CMIR	=
EOT date	=	Stand	=	IND	=
EOT time	=	Run	=		
LTMS date	=	Reported	=	Analysis Compiled:	
LTMS time	=				

Parameter	Reported Value	Transformed Value	Targets Effective 19970219 to *** Mean	s
-------------	------------	----------------	-------	----
WDR				
TGC				
TLC				
AOC				
EOTOC				

Note: When two Limits given, the upper is the Warning Limit and the lower is the Action Limit.

Keys: A = Action alarm
W = Warning alarm

Stand Analysis

	EWMA							SHEWHART					
	N	Z(i)	Severity Limit	Al	Q(i)	Precision Limit	Al	Y(i)	Severity Limit	Al	R(i)	Precision Limit	Al
	----	------	----------	-----	-----	------	---	-----	-------	----	-----	-------	-----
WDP													
TGC													
TLC													
AOC													
EOTOC													

Laboratory Analysis

	EWMA							SHEWHART					
	N	Z(i)	Severity Limit	Al	Q(i)	Precision Limit	Al	Y(i)	Severity Limit	Al	R(i)	Precision Limit	Al
	----	------	----------	-----	-----	------	---	-----	-------	----	-----	-------	-----
WDR													
TGC													
TLC													
AOC													
EOTOC													

**** Laboratory Level Severity Adjustments ****
WDR SA = TGC SA = TLC SA =
AOC SA = EOTOC SA =

STAND is Calibrated: YES NO (Circle Required)

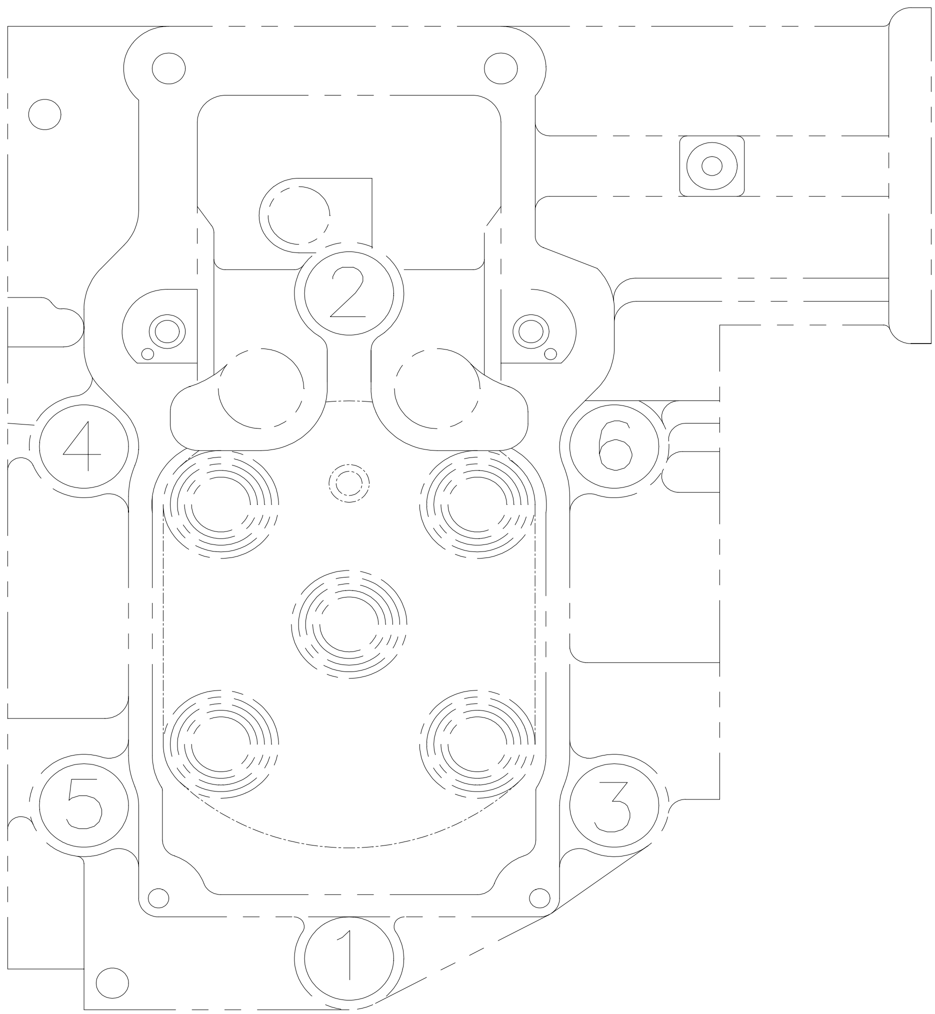
Calibration Expiration Date: _________________

[A] TMC Validity Code:________ AC = Acceptable Calibration.
OC = Oper. Valid, Failed Acceptance Criteria.

_____ STAND PULLED FROM LTMS SYSTEM (Check required) Reviewer Initials:________

[A] Based on review of call-in report of operational data and control chart analysis shown above.

A8. Engine Assembly and Inspection Information



1) Coat valve stems with Mobil EF411 engine oil immediately prior to installation
2) Lubricate stud threads and both washer faces with Mobil EF411 engine oil
3) Tighten cylinder head nuts with hand torque wrench:
   a) Tighten nuts 1 through 6 in numerical sequence to 100 ± 15 N·m
   b) Tighten nuts 1 through 6 in numerical sequence to 200 ± 15 N·m
   c) Tighten nuts 1 through 6 in numerical sequence to 400 ± 15 N·m

Fig. A8.1 CYLINDER HEAD TIGHTENING PROCEDURE

Piston part numbers: Skirt 1Y4015, Crown 1Y4016
Rings part numbers: Top 1Y4014, Intermediate 1Y4013, Oil 1Y4012

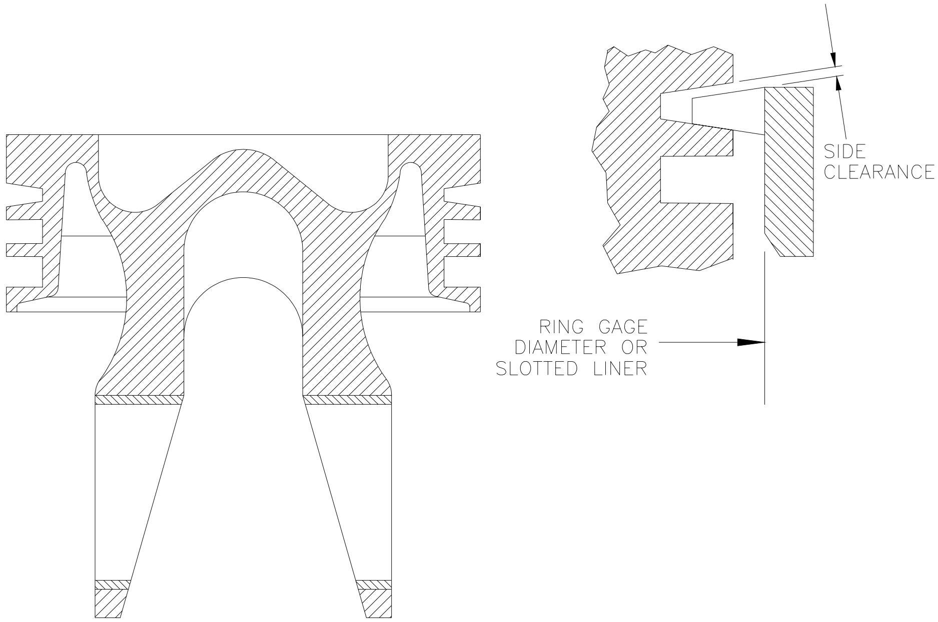


Fig. A8.2 Piston and Ring Specifications

Table A8.1 Piston and Ring Specifications

	TOP RING	INTERMEDIATE RING	OIL CONTROL RING
Width of groove in piston for piston ring (new)		3.07 ± 0.01mm	4.03 ± 0.01mm
Thickness of piston ring (new)		2.985 ± 0.015mm	3.975 ± 0.015mm
Side Clearance between groove and piston ring (new)[A]	0.090 – 0.127mm	0.060 – 0.110mm	0.030 – 0.080mm
End gap clearance between end of ring (new) installed in 137.160mm diameter gage	0.350 – 0.550mm	0.754 – 0.906mm	0.400 – 0.750mm

[A]This engine uses a keystone style piston ring and groove for the top ring and groove in the piston. The piston ring lands are also elliptically ground; therefore, measure ring side clearance as follows:

1. Assemble piston ring on the piston with UP side toward the top of the piston.
2. Install piston and ring in a 137.60mm diameter ring gage or modified slotted liner (see X1).
3. Push piston and ring until ring to be measured is at the top of the gage. Keep the piston in the center of the gage.
4. Measure the side clearance with a feeler gage at both major (90° from the centerline of the pin bore) and minor diameters. Each measurement should be within specification shown.
5. Install the oil control ring with gap in the spring 180° away from the gap in the ring.

<u>Liner Bore Surface Finish</u>
0.4 – 0.8 μm (Ra)

<u>Negative Liner Projection</u>
(Measure with O-rings removed from liner)
- Measure from jug top surface to bottom of liner seal surface with modified 8T0455 indicator
- Specification is 1.02 +/- 0.06 mm

<u>Unassembled Liner Bore I.D.</u>
137.185 +/- 0.025 mm

<u>Liner Assembled in Jug and Head Torqued</u>
- Liner bore out-of-round is 0.038 mm max. (difference of transverse and longitudinal dia. at each vertical height level)

- Liner bore taper is 0.050 mm max. (difference of all vertical height dia. in either the transverse or longitudinal direction)

- Minimum assembled liner bore dia. is 137.154 mm

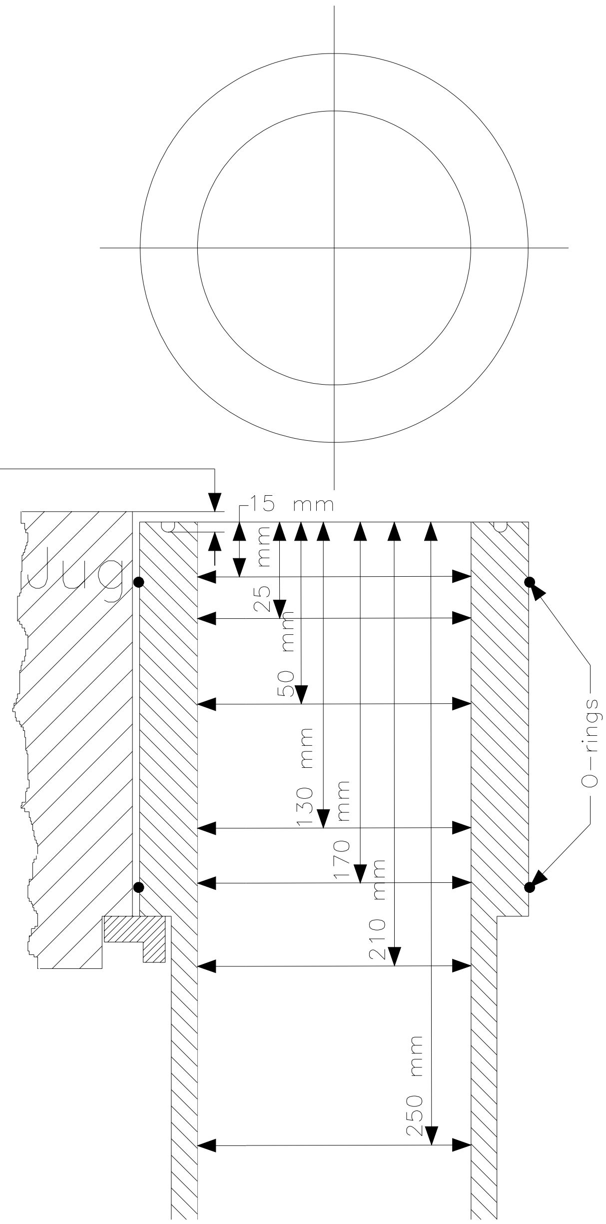
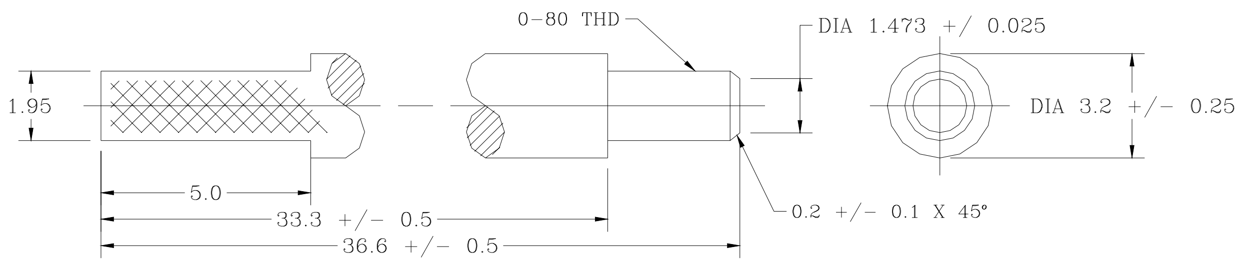


Fig. A8.3 Cylinder Liner Measurements and Specifications

8T0455 INDICATOR MODIFICATIONS[A]

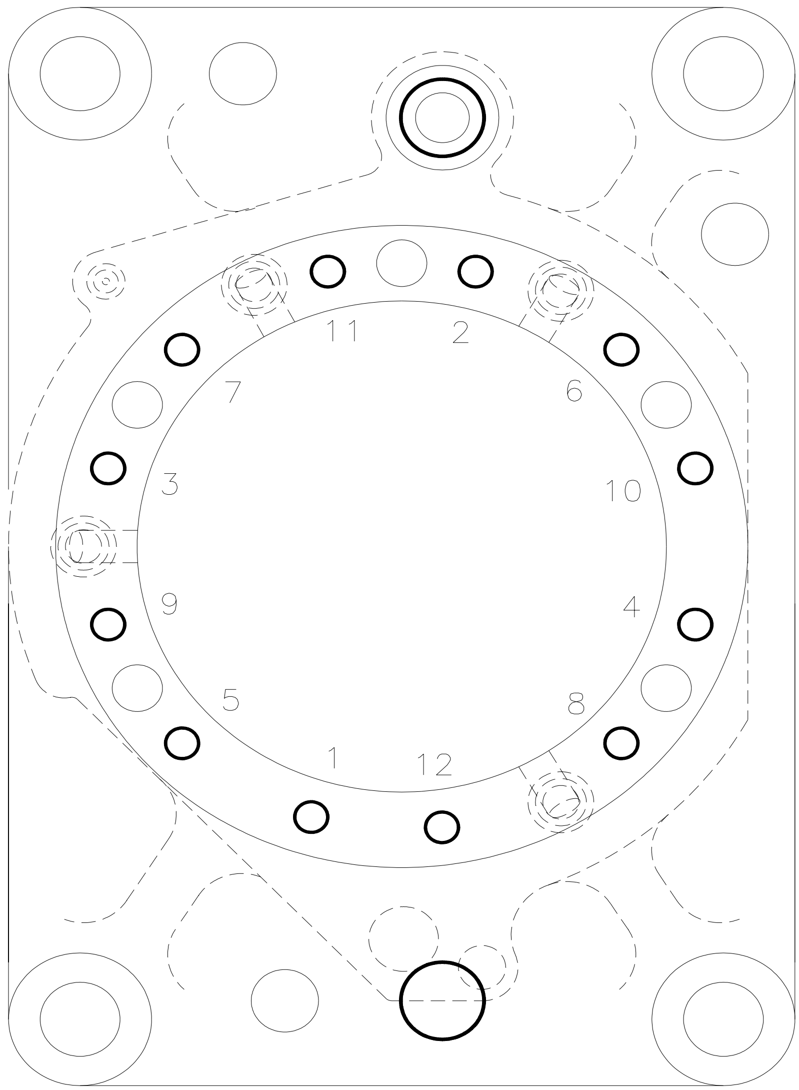
[A] Indicator measures liner recession from the jug deck surface to the bottom of the liner combustion seal groove. The tip of the 8T0455 indicator rod requires modifications as shown below.



(Grind the tip to 1.95 ± 0.02 mm diameter for 5.0 ± 0.5 mm long from spherical end)
(All dimensions are in mm)

Fig. A8.4 Cylinder Liner Projection Measurement Indicator Modifications

(1) Center the support ring I.D. to the cylinder liner with four feeler gages of equal thickness, hand tighten the stud nuts, but remove feeler gages before tightening stud nuts
(2) Tighten the stud nuts in numerical order as shown with a sequence level of 15, 55 and 105 ± 10 N·m.



NOTE 5: The cylinder liner support ring torque sequence may be used after the cylinder head torque sequence as an alternate method if the liner bore distortion is out of test specifications.

Fig. A8.5 Cylinder Liner Support Ring Tightening Procedure

A8.1 1Y3700 Engine Mechanical Timing – Remove the camshaft gear to replace cylinder head components after test and re-time as follows:

A8.1.1 Rotate the engine to position the piston at TDC.

(The TDC mark on the flywheel will align with the timing pointer)

(The 6.28 mm diameter 1Y3919 timing pin will insert in the crank gear key-way slot through the timing hole in the front housing near the oil pump flange)

A8.1.2 Pin the camshaft with a second 6.28 mm diameter 1Y3919 timing pin.

A8.1.3 Mesh the camshaft gear with the adjustable idler gear and with the UP mark on the front face of the camshaft gear in the 12:00 o'clock position. Assemble the camshaft gear to the camshaft.

A8.1.4 Set lash between the adjustable idler gear and the camshaft gear and torque the six socket head bolts at the stub-shaft flange.

A8.1.5 Remove both 6.28 mm diameter timing pins.

A8.2 1Y3700 Engine Mechanical Timing – General Information

NOTE 6: This is not part of the normal engine timing procedure.

A8.2.1 Follow this procedure only on new engine assembly or in the event that a new timing disk, or crankshaft, or flywheel or front housing is assembled on an old engine.

A8.2.2 With the crankshaft connecting rod journal at top dead center (TDC), the tooth valley V mark on the crankshaft gear is 35.38° clockwise from the vertical and the key-way is 68.48° clockwise from vertical. With the crankshaft gear fixed, assembly of the cluster idler gear on its stub-shaft causes the cluster idler gear to rotate 2.87° clockwise, so that its dash marked tooth is 145.73° counterclockwise from vertical. The V and dash marks line up valley-to-tooth.

A8.2.3 Assembly of the adjustable idler gear with its UP mark at the top orients the three kidney-shaped openings in the gear web to allow access to the socket head bolts that attach the adjustable idler gear stub-shaft to the front housing plate.

A8.2.4 Assembly of the camshaft gear with its V mark and UP mark at the top and with the camshaft pinned to the cylinder head, by design, results with the 0.50 in. bolts on-center of the 17 mm diameter clearance holes in the camshaft gear. Additive tolerances for all the involved parts can cause the bolts to be off-center in either direction. The purpose of the oversize holes is to ensure that the gears will mesh at all off-nominal, but in tolerance dimensions of the parts.

A8.2.5 With the camshaft and the crankshaft pinned, the engine is necessarily at top dead center on the firing stroke. The flywheel pointer is at 0° (TDC). The leading edge of a 3° timing notch on the camshaft gear is on the centerline of the cam sensor hole in the front housing. The leading edge of a 6° notch on the crankshaft timing disk is on the centerline of the crankshaft sensor hole in the front housing.

A8.2.6 With the flywheel pointer at 3° after top dead center, a 1Y3918 pin inserted in the crank timing sensor hole in the front housing shall also slide into a 6° wide notch of the crankshaft timing disk. This verifies that the leading edge of a notch on the timing disk is on the centerline of the crankshaft sensor which sets TDC for the electronic control module (ECM).

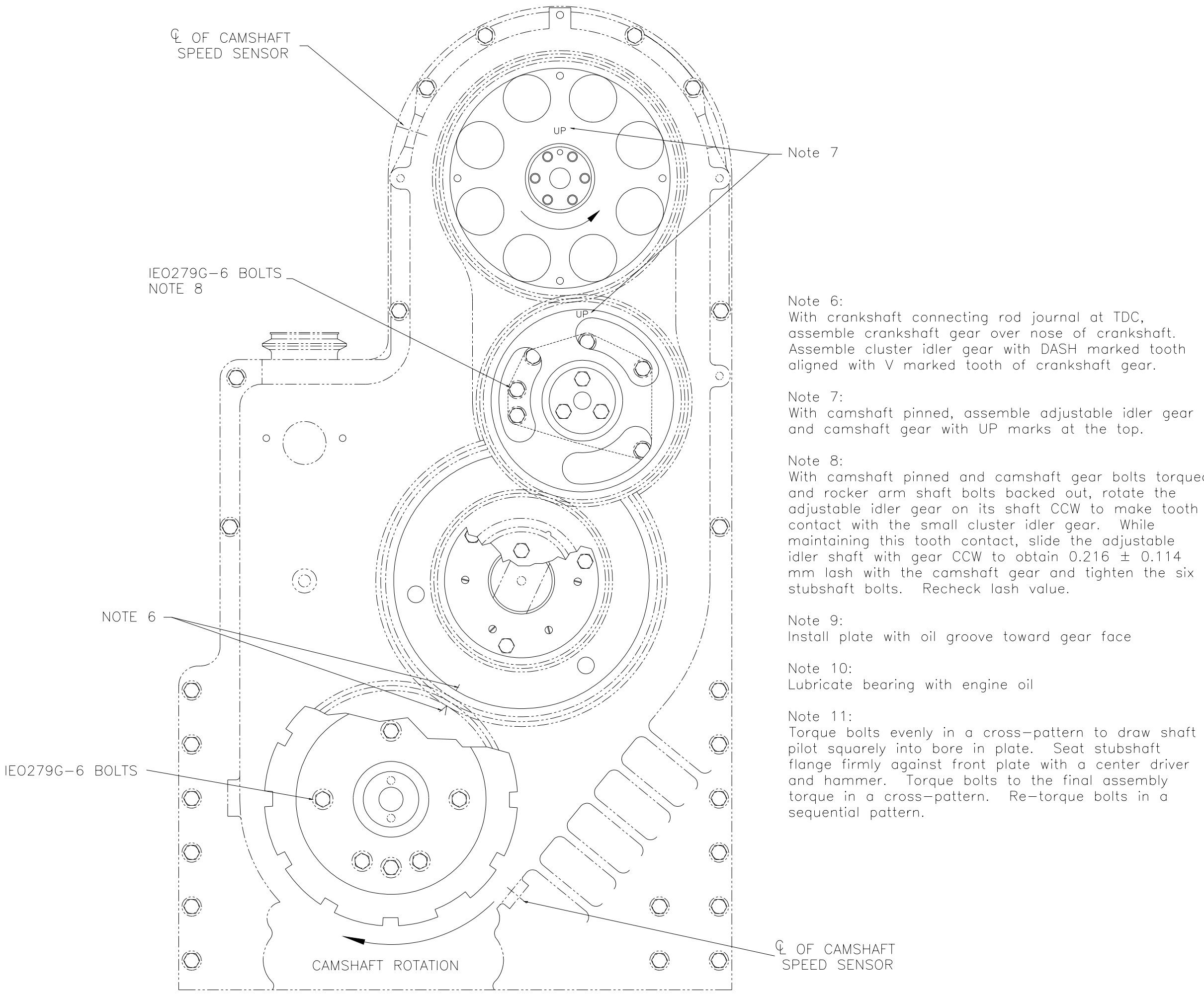


Fig. A8.6 1Y3700 Engine Timing

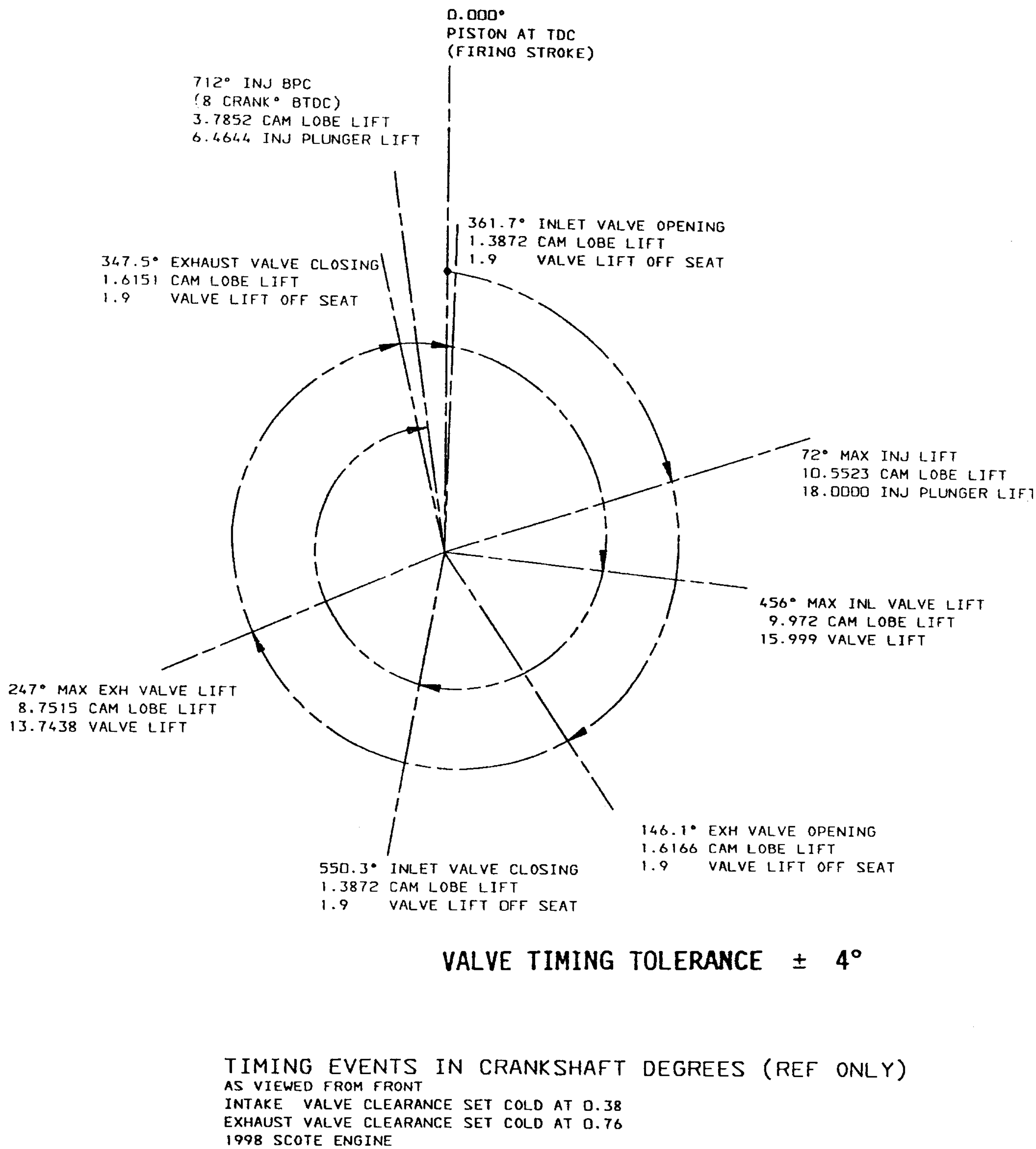


Fig. A8.7 Timing Events in Crankshaft Degrees (for reference purpose only)

Table A8.2 Engine Assembly Measurements, mm

Items to be Checked	Specifications			Actual
	Min.	Mean	Max.	
Crankshaft end play	0.11	0.34	0.57	
Camshaft end play	0.175	0.25	0.325	
Main bearing clearance (No.1) (front)	0.089	0.138	0.187	
Main bearing clearance (No.2)	0.089	0.138	0.187	
Main bearing clearance (No.3)	0.089	0.138	0.187	
Main bearing clearance (No.4)	0.089	0.138	0.187	
Nozzle tip projection	1	1.3	1.6	
Cam gear backlash	0.102	0.216	0.33	
Piston-to-head clearance	1.55	1.62	1.69	
Int valve (1) recess (closest to manifold)	2.2	2.5	2.8	
Int valve (2) recess	2.2	2.5	2.8	
Exh valve (1) recess (closest to manifold)	1.2	1.5	1.8	
Exh valve (2) recess	1.2	1.5	1.8	
Initial intake valve lash (cold)		0.38		
Initial exhaust valve lash (cold)		0.76		
Initial injector setting[A]		78[A]		
After test intake valve lash (cold)	0.3	0.38	0.46	
After test exhaust valve lash (cold)	0.68	0.76	0.84	
After test injector setting[A]	77.8[A]	78[A]	78.2[A]	
Flywheel adapter runout (Bore TIR)			0.15	
Flywheel adapter runout (Face TIR)(at R95)			0.15	
Timing sensor location in front housing	2° ATDC	3° ATDC	4° ATDC	
Liner recession	1.12	1.17	1.22	
Liner ID taper			0.051	
Liner ID out of roundness			0.038	
Liner ID smallest anywhere			137.154	
Align pointer with TDC mark on flywheel. Verify top of liner is below jug surface. Flow cooling jet to verify aim.				
Injector and valve max lifts, mm				
Injector plunger lift at 72° crank angle	17.3	18.0	18.7	
Exhaust valve lift at 247° crank angle	13.0	13.7	14.4	
Intake valve lift at 456° crank angle	15.3	16.0	16.7	

[A]Measured using a Go/No-go gage

A9. FLUSHING INSTRUCTIONS AND APPARATUS

Table A9.1 Flushing Instruction Sheet

Step	Procedure	Flushing Fluid	Relief Valve[A]
1	Flushing is easier when the engine is warm Drain used oil from sump, cooler, oil scale and remove oil filter Install 1Y3916 plug in front plate (in place of fuel cam/cylinder head) Install 1Y3979 cover on top of block Install 1Y3980 piston jet aim fixture on top of 1Y3979 cover Connect flush cart outlet to filter flush adapter 1Y3935 and 5 spray nozzles		Open
2	Connect flush cart pump inlet to solvent tank Install new oil filter on the oil flush cart Open engine sump drain. Then pump solvent into engine to flush used oil	7.6 L Stoddard Solvent No recirculation	Closed
3	Connect flush cart pump inlet to engine oil sump Close engine sump drain Circulate fluid with flush cart and oil scale pumps turned on	- 7.6 L Stoddard Solvent	Closed 5 min Open 5 min
4	Drain mixture from sump, cooler, oil scale, flush cart and filters		Open
5	Circulate fluid with flush cart and oil scale pumps turned on Use flush wand through side covers to clean crankcase	7.6 L Stoddard Solvent	Open 5 min Closed 5 min
6	Drain fluid from sump, cooler, oil scale, flush cart and filters		Open
7	Repeat steps 5 and 6 two times or as needed until solvent remains clean		
8	Circulate EF-411 to flush Stoddard solvent	5.6 L EF-411	Open 5 min Closed 5 min
9	Drain oil from sump, cooler, oil scale, flush cart and filters		Open
10	Circulate EF-411 at 415 kPa manifold pressure and align piston jets	5.6 L EF-411	Open 5 min
11	Drain oil from sump, cooler and oil scale. Rebuild engine for test		Open
12	After engine is rebuilt, motor engine at a minimum of 200 r/min	5.6L EF-411	Reconnect for normal operation
13	Drain oil from sump, cooler and oil scale		Open

[A]Supply 50 kPa air pressure to open the Johnson Controls oil relief valve

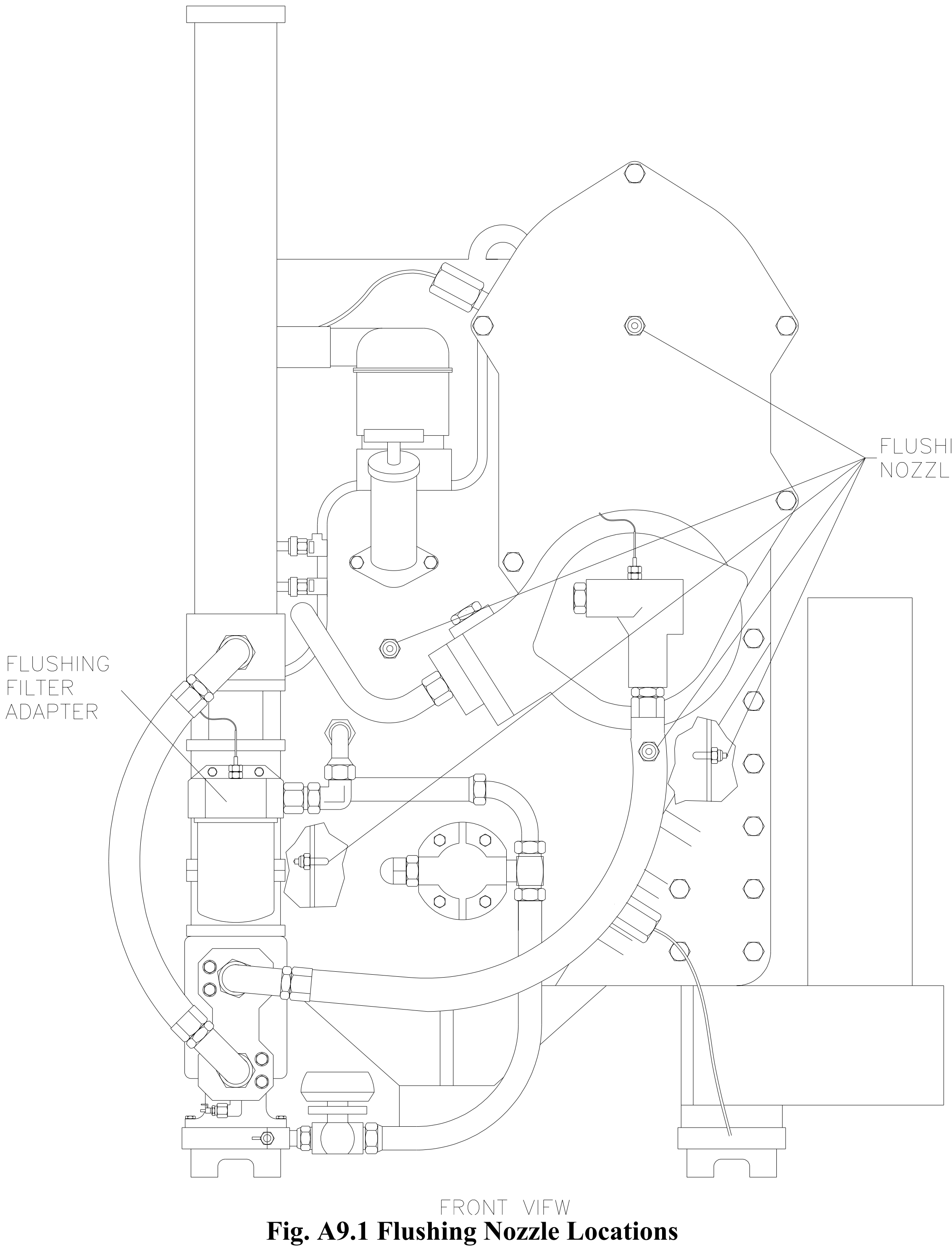


Fig. A9.1 Flushing Nozzle Locations

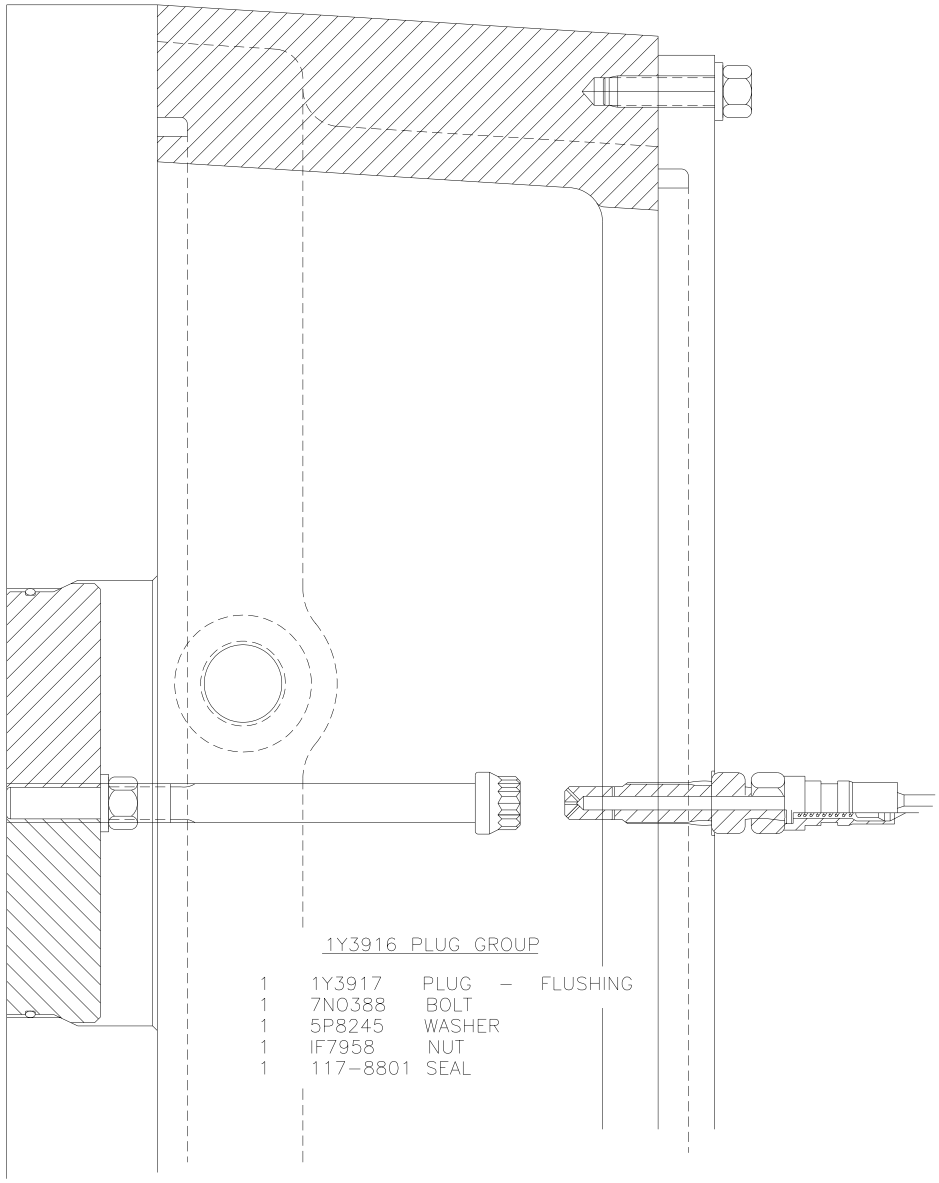


Fig. A9.2 Flushing Plug

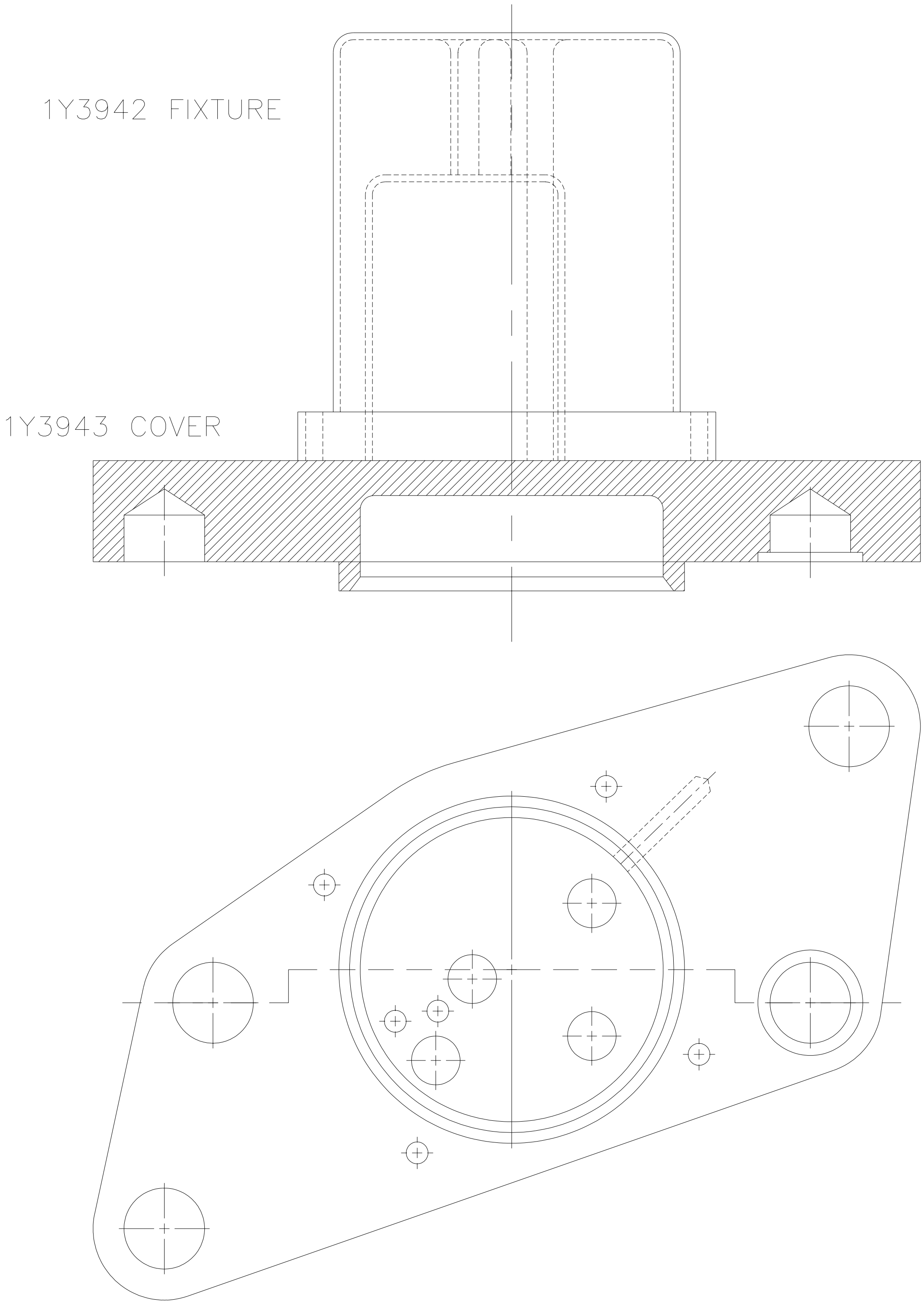


Fig. A9.3 Flushing Fixture

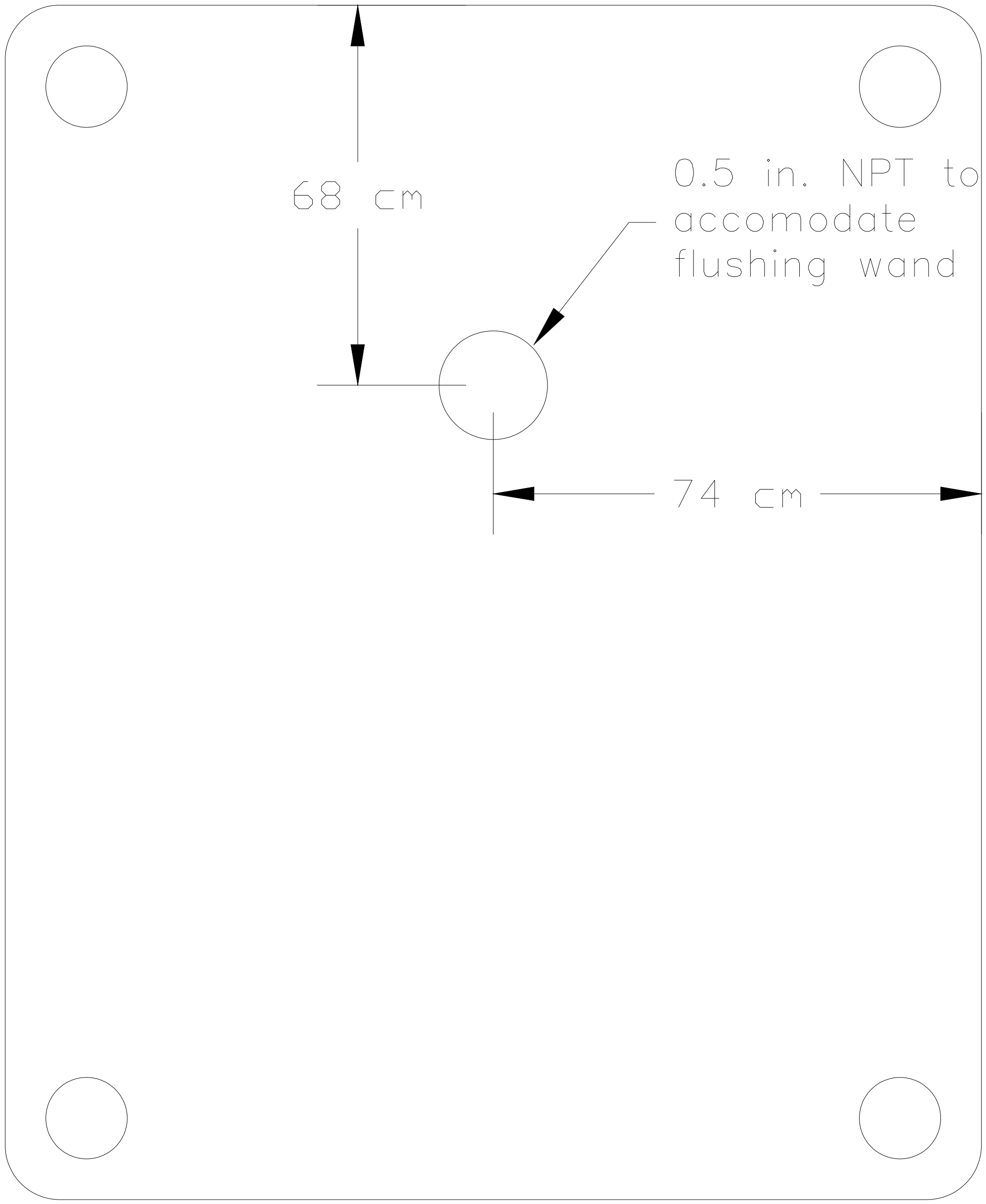


Fig. A9.4 Modification of Engine Side Covers for Flushing Wand

Table A10.1 Warm-up, Cool-down & Testing Conditions

Parameter	Units	Tol.	Test Specifications				
			Step 1 5 min	Step 2 5 min	Step 3 5 min	Step 4 10 min	Step 5 60 min
Speed	r/min	± 3	1000	1000	1400	1800	1800
Power	kW		Idle	10	28	43	~ 66
BMEP	kPa		-	400	900	1140	~ 1811
Torque	N·m	± 5[A]	-	100	175	220	~ 352
Fuel Rate	g/min	± 1[B]	-	~ 48	~ 95	~ 148	240
Fuel Timing	BTC		6	6	6	6	6
Fuel Rack Position	NA		~ 26	~ 38	~ 60	~ 74	~ 106
Humidity	g/kg	± 1.7	-	-	-	-	17.8
Temperatures							
Fuel at Filter	°C	± 3	~ 31	~ 32	~ 33	~ 36	42
Coolant to Jug	°C			~ 51	~ 82	~ 86	101
Coolant from Head	°C	± 3		~ 52	~ 83	~ 90	105
Oil to Cooler	°C		-	-	-	-	~ 123
Oil Manifold	°C	± 3	-	-	-	-	120
Inlet Air at Manifold	°C	± 3	-	-	60	60	60
Exhaust at Manifold	°C		~ 120	~ 275	~ 340	~ 370	~ 605
Pressures							
Fuel from Head	kPa	± 20	275	275	275	275	275
Coolant to Jug	kPa	[C]	~ 44	~ 44	~ 70	~ 81	~ 81
Oil Manifold	kPa	± 20	415	415	415	415	415
Inlet Air Barrel (absolute)	kPa(abs)	± 1	120	120	157	225	292
Exhaust Barrel (absolute)	kPa(abs)	± 1	-	104	146	217	252
Crankcase	kPa						~ .20
Flows							
Coolant	L/min	± 2	~ 34	~ 34	~ 65	75	75
Blowby	L/min		-	-	-	~ 35	~ 35
Air	kg/h		-	-	-	-	~ 390

[A]Engine controlled to Torque Specification for Steps 2, 3, 4, and 5 min of Step 5
[B]Engine controlled to Fuel Rate Specification for last 55 min of Step 5
[C]Air Pressure at coolant tower controlled to 35kPa

Table A10.2 Ramp-up Setpoints Between Warm-up Steps

Torque	At 5 min (beginning at Step 2 thru Step 4)	20 N·m/min
	At the beginning of Step 5	14 N·m/min
Speed	At 10 min (beginning at Step 3)	100 r/min/min
Inlet Air Pressure	At 10 min (beginning at Step 3)	12 kPa(abs)/min
Exhaust Pressure	At 10 min (beginning at Step 3)	12 kPa(abs)/min
Inlet Air Temperature	At 0 min (at start of test)	5 °C/min

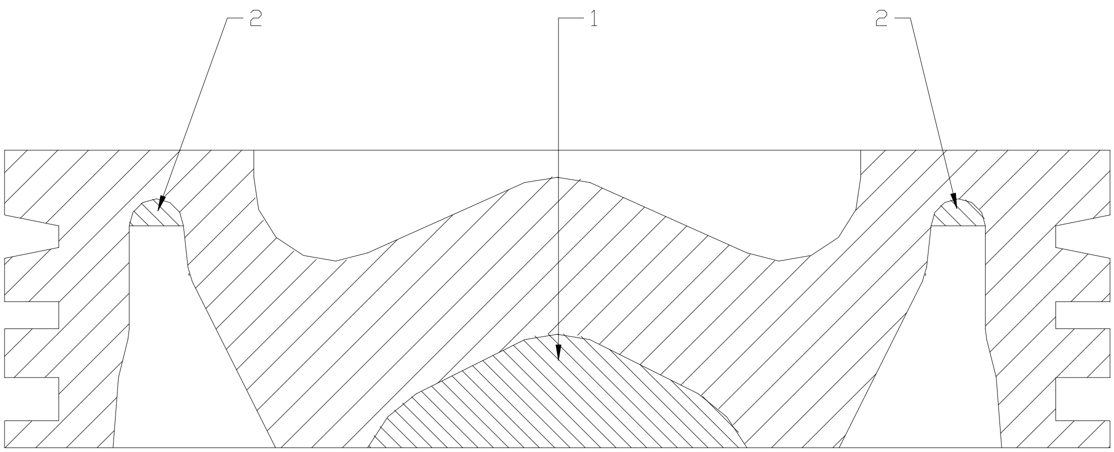
A11. PISTON AND LINER RATING MODIFICATIONS

A11.1 The 1R piston deposits are accessed using the Modified CRC Diesel Piston Rating Method described in CRC Manual No. 20. Three levels of carbon (heavy, medium and light) are rated for grooves one and three. Only two levels of carbon (heavy and light) are rated for the second groove and all lands, and only one level of carbon (light) is rated for the cooling gallery and under-crown. The carbon deposit factors are 1.00 for heavy, 0.5 for medium and 0.25 for light carbon. The varnish merit values range from 1.0 to 10 using the CRC Rust/Varnish Rating Scale where 10 is clean and 1.0 is maximum intensity. The merit varnish values are converted to demerit values resulting in deposit factors that range from 0 for clean to 9.0 for maximum intensity. The merit varnish values are converted to demerit values using the following equation:

Demerit Varnish Zonal Rating = Area% X (10 – Merit Rating) Eq. A11.1

Example: 15% X (10.0 – 8.5) = 0.15 X 1.5 = 0.22 Demerits using rounding guidelines presented in Practice E 29[10]

Figure A11.1 shows the deposit rating areas for the under-crown and cooling gallery of the piston crown. Remove the oil cooling gallery baffle prior to rating.



Area (1) – Under-crown: All surfaces of the under-crown including transition radius, but not the vertical sides of the pin bore struts.
Area (2) - Cooling gallery: Only the upper radius area.

Fig. A11.1 Under-crown and Cooling Gallery Rating Areas

A11.2 The rating location factors were chosen to yield separation between low and high calibration oils. All required rating equipment, such as the rating booth and particular lamp used, are described in CRC Manual No. 20.
A11.3 Use the following procedure for calculating this test method's piston deposit ratings:
A11.3.1 Rate the piston as is normally done according to the Modified CRC Diesel Piston Rating Method described in CRC Manual No. 20.
A11.3.2 For groove three, land three, land four, the cooling gallery and under-crown, replace the rater-assigned varnish merit values with the following restricted factors.

Rater-Assigned Varnish Merit Value	Restricted Factor
1.0 – 4.0	7.5
4.1 – 7.0	4.5
7.1 – 9.9	1.5

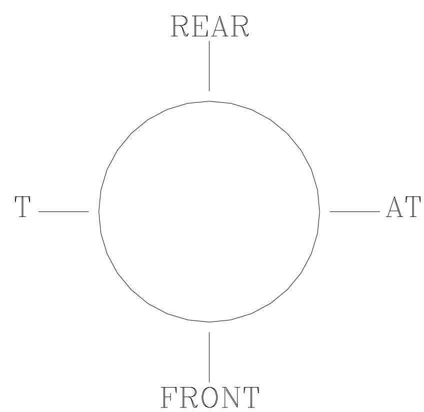
A11.3.3 Calculate a demerit value for each area.
A11.3.4 Round each demerit to the nearest 0.01 demerits according to Practice E 29.[10]
A11.3.5 Add the demerits to get the individual unweighted demerit value for each piston location.
A11.3.6 Multiply the unweighted demerit value by its location factor to get the individual weighted demerit rating for each piston location.
A11.3.7 Round each individual weighted demerit rating to the nearest 0.01 demerits.
A11.3.8 Add all individual weighted demerit ratings to get WDP.
A11.3.9 Round WDP to the nearest 0.1 demerits.
A11.3.10 Top groove carbon (TGC) equals the total carbon demerits for groove one.
A11.3.11 Top land carbon (TLC) equals the total carbon demerits for land one.

A11.4 Liner Rating Procedure – Liner rating should follow the sequence outlined herein. If deposits above ring travel are to be evaluated this should be done immediately upon completion of the test or disassembly.

A11.4.1 <u>Liner Preparation</u>

A11.4.1.1 Marking:

Thrust and anti-thrust sides are marked T & AT along with appropriate test identification (run number, and so forth.).



A11.4.1.2 Cutting:

Liners are cut along the front and rear, leaving the thrust and anti-thrust halves.

A11.4.1.3 Surface Preparation:

Caution should be observed in the handling of the liners due to the sharpness of the cut edges. Wipe both halves of the liner using Stoddard solvent on a dampened soft rag followed by a clean soft dry rag.

A11.4.2 <u>Definition of Terms</u>

A clear plastic segmented overlay (see X1.5) is recommended as a useful rating aid in estimating the percentage of the area covered.

A11.4.2.1 Bore Polishing:

Those areas of surface which are instantly recognizable as mirror finish regardless of random crosshatch honing marks.

A11.4.2.2 Scuffing:

Localized adhesive wear distinguished by concentrated marks in the direction of motion, observed as a matte finish which is caused by a momentary welding and tearing of metal.

(1) Bore polishing and scuffing should be differentiated between and reported separately.

A11.4.2.3 Scratching:

Random singular lines in the direction of motion generally are a result of debris or installation of components. These need not be quantified, but should be noted in the appropriate remarks section.

A11.4.3 Liner Rating

A11.4.3.1 Rating Environment:

Rate liners in the CRC rating booth with the same light as specified to rate pistons or a two-bulb fluorescent desk lamp.

A11.4.3.2 Bore Polishing:

The overlay is inserted in the liner half and the 10-15% segments with 1% indicators used as a guide in estimating the amount of polishing. Record the percent polish for each segment and then summarize those 10 areas for each half. Tracing paper or equivalent may be used for a permanent record of the liner polishing.

(1) Area Rated

The area to be rated is generally defined as the area swept by the rings which is the distance from the top of the first ring at T.D.C. to the bottom of the ring at B.D.C..

A11.4.3.3 Liner Scuffing Rating:

Liner scuffing can be rated in a similar manner as bore polishing.

A11.4.3.4 Above Top Ring Travel Conditions:

Area percentages may be determined in the liner by use of the 20-segmented template. Carbon deposits can be rated in two levels. Other conditions such as polishing, scratching/scuffing can be reported in area covered, if required.

A12. RETURN GOODS AUTHORIZATION CLAIM FORM

RETURN GOODS AUTHORIZATION CLAIM FORM

Return Goods Authorization Number: ____________________.
Claim Date: ______________.
Contact: Caterpillar Inc
Engine System Tech Dev.
P.O. Box 610
Mossville, Il 61552
Phone: 309-636-5247
Fax: 309-675-1598
Attn: R.A. Riviere

Part Number / Quantity: _______________________/_________.
Part Name / Hrs On Part: _____________________/__________.
Date Part Purchased: _______________.
Engine Serial Number: ______________________.
Test Lab
Name: ____.

Address: ____.

Contact Person's Name: ________________________________.

Phone Number: _____________________________.

Fax Number: ______________________________.

Name of Dealer That Sold Part: __________________________________.
INCLUDE DOCUMENTATION AND PHOTOS OF NONCONFORMING PART

APPENDIXES

NON-MANDATORY INFORMATION

X1 Various Examples of Supplemental Information for Reference Purposes

	Groove 1			Groove 2			Groove 3			Cooling Gallery			Under Crown		
CARBON	A%	Fct	Dem	A%	Fct	Dem	A%	Fct	Dem	A%	Fct	Dem	A%	Fct	Dem
	5	1.00	5.00	5	1.00	5.00	5	1.00	5.00						
	5	0.50	2.50				5	0.50	2.50						
	5	0.25	1.25	5	0.25	1.25	5	0.25	1.25	5	0.25	1.25	5	0.25	1.25
	Subtotal		8.75	Subtotal		6.25	Subtotal		8.75	Subtotal		1.25	Subtotal		1.25
VARNISH	9	8.5	0.76	9	8.5	0.76	11	8.5	0.82	7	7.5	0.52	7	7.5	0.52
	7	7.5	0.52	7	7.5	0.52	7	7.5	0.52	9	4.5	0.40	9	4.5	0.40
	9	6.5	0.58	9	6.5	0.58	3	6.5	0.22	7	1.5	0.10	7	1.5	0.10
	7	5.5	0.38	7	5.5	0.38	13	5.5	0.58						
	9	4.5	0.40	9	4.5	0.40	9	4.5	0.40						
	7	3.5	0.24	7	3.5	0.24	5	3.5	0.22						
	9	2.5	0.22	9	2.5	0.22	11	2.5	0.16						
	7	1.5	0.10	7	1.5	0.10	7	1.5	0.10						
	9	0.5	0.04	9	0.5	0.04	3	0.5	0.04						
	Subtotal		3.24	Subtotal		3.24	Subtotal		3.06	Subtotal		1.02	Subtotal		1.02
	Total		11.99	Total		9.49	Total		11.81	Total		2.27	Total		2.27
	Loc Fct		2	Loc Fct		3	Loc Fct		20	Loc Fct		0.50	Loc Fct		1
	WTD		23.98	WTD		28.47	WTD		236.20	WTD		1.14	WTD		2.27

	Land 1			Land 2			Land 3			Land 4		
CARBON	A%	Fct	Dem	A%	Fct	Dem	A%	Fct	Dem	A%	Fct	Dem
	5	1.00	5.00	5	1.00	5.00	5	1.00	5.00	5	1.00	5.00
	5	0.25	1.25	5	0.25	1.25	5	0.25	1.25	5	0.25	1.25
	Subtotal		6.25	Subtotal		6.25	Subtotal		6.25	Subtotal		6.25
VARNISH	9	8.5	0.76	9	8.5	0.76	11	8.5	0.82	11	8.5	0.82
	7	7.5	0.52	7	7.5	0.52	7	7.5	0.52	7	7.5	0.52
	9	6.5	0.58	9	6.5	0.58	3	6.5	0.22	3	6.5	0.22
	7	5.5	0.38	7	5.5	0.38	13	5.5	0.58	13	5.5	0.58
	9	4.5	0.40	9	4.5	0.40	9	4.5	0.40	9	4.5	0.40
	7	3.5	0.24	7	3.5	0.24	5	3.5	0.22	5	3.5	0.22
	9	2.5	0.22	9	2.5	0.22	11	2.5	0.16	11	2.5	0.16
	7	1.5	0.10	7	1.5	0.10	7	1.5	0.10	7	1.5	0.10
	9	0.5	0.04	9	0.5	0.04	3	0.5	0.04	3	0.5	0.04
	Subtotal		3.24	Subtotal		3.24	Subtotal		3.06	Subtotal		3.06
	Total		9.49	Total		9.49	Total		9.31	Total		9.31
	Loc Fct		1	Loc Fct		3	Loc Fct		20	Loc Fct		60
	WTD		9.49	WTD		28.47	WTD		186.20	WTD		558.60

Piston Number 1	Ring Stuck?	Scuffed Area %	WDR	1074.8	UWD	75.43
Top Ring			TGC	8.75	TLHC %	
Intermediate Ring			TLC	6.25	TGF %	
Oil Ring					IGF %	
Piston					TLFC %	
Cylinder Liner				Undercrown Carbon %		

Fig. X1.1 Rating Worksheet Example

(If testing candidate lubricants in accordance with Specification D4485, the results of multiple testing should be reported on this form)

1R TEST SUMMARY SHEET

OIL CODE NO.:

TEST NO.	EOT DATE	OIL CODE NO.	TEST LAB	STAND NO.	RUN NO.	WDR	TGC	TLC	BTOC g/h 0-252	ETOC g/h 468-504	BTOC – ETOC g/h
1^{ST}											
2^{ND}											
3^{RD}											
4^{TH}											
TEST AVG											
1^{ST}											
2^{ND}											
3^{RD}											
OUTLIER MIN. LEVEL						(1)	(2)	(3)			
2 TEST AVERAGE WITH OUTLIER REMOVED											
3 TEST AVERAGE WITH OUTLIER REMOVED											
ACCEPTANCE LIMITS											
1^{ST} TEST PASS											
2 TEST PASS											
3 TEST PASS											

NOTES:
(1) WDR 3 TEST AVG + ____.
(2) TGF 3 TEST AVG + ____.
(3) TLC 3 TEST AVG + ____.

Fig. X1.2 Example of Multiple Test Summary Sheet

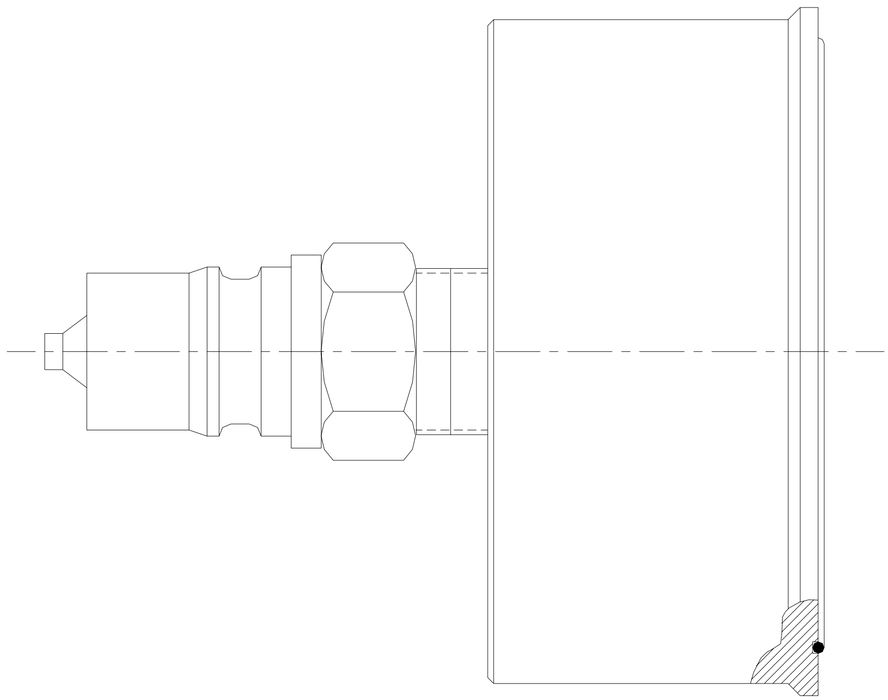


Fig. X1.3 Oil Filter Flushing Adapter Example

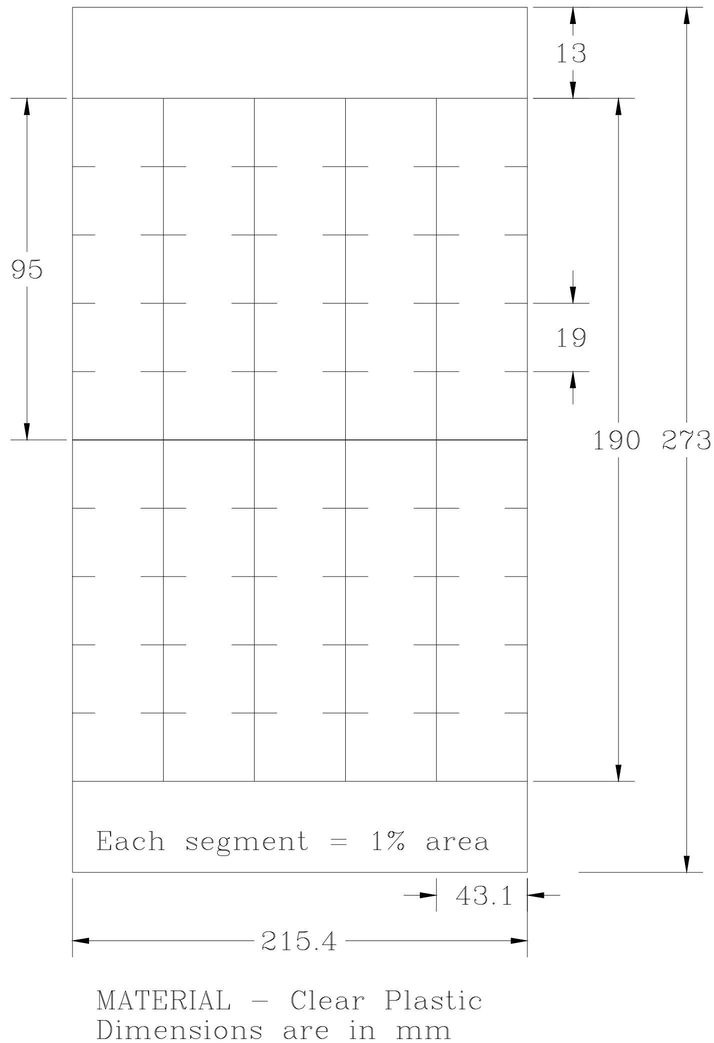


Fig. X1.4 Bore Polish Grid

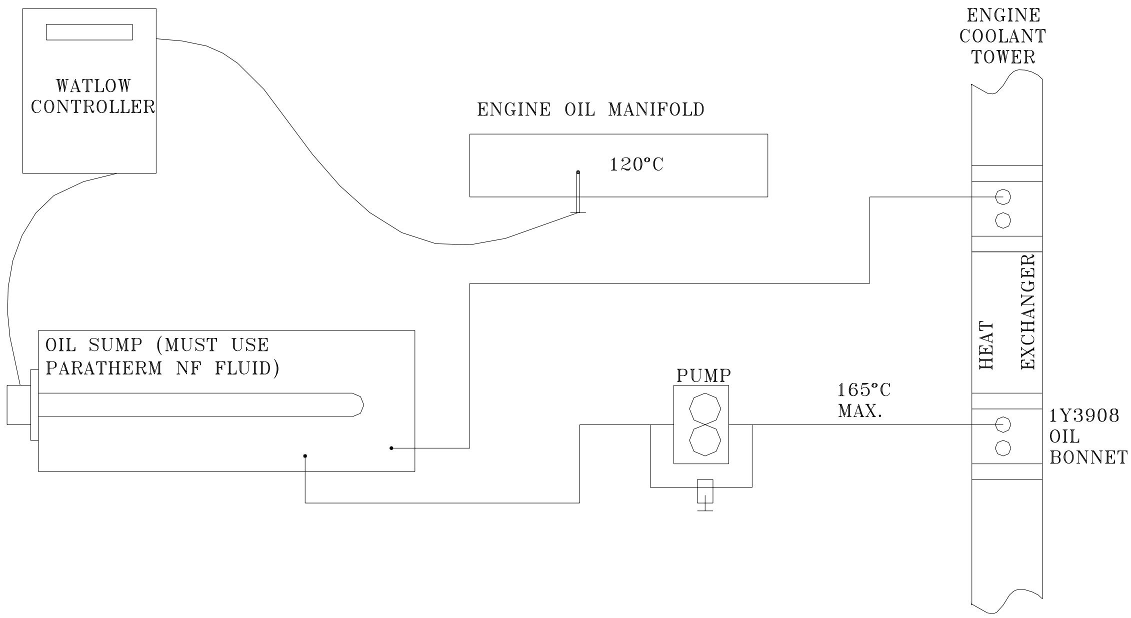
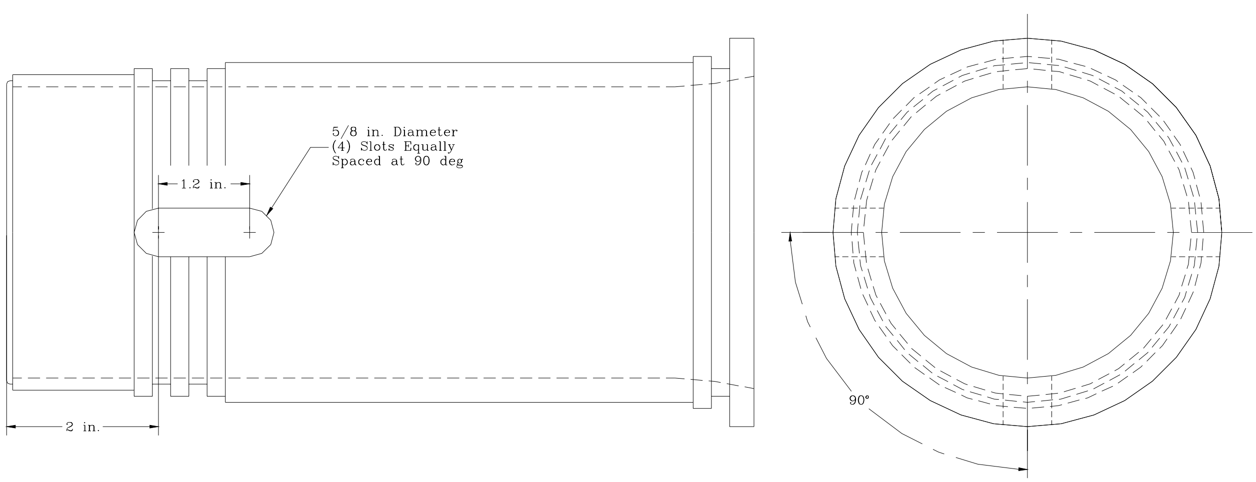


Fig. X1.5 Engine Oil Heating System



Use a 1Y3555 liner from the 1K/1N test. The liner shall be free of I.D. distortion or surface distress.

Fig. X1.6 Ring Side Clearance Measurement Fixture

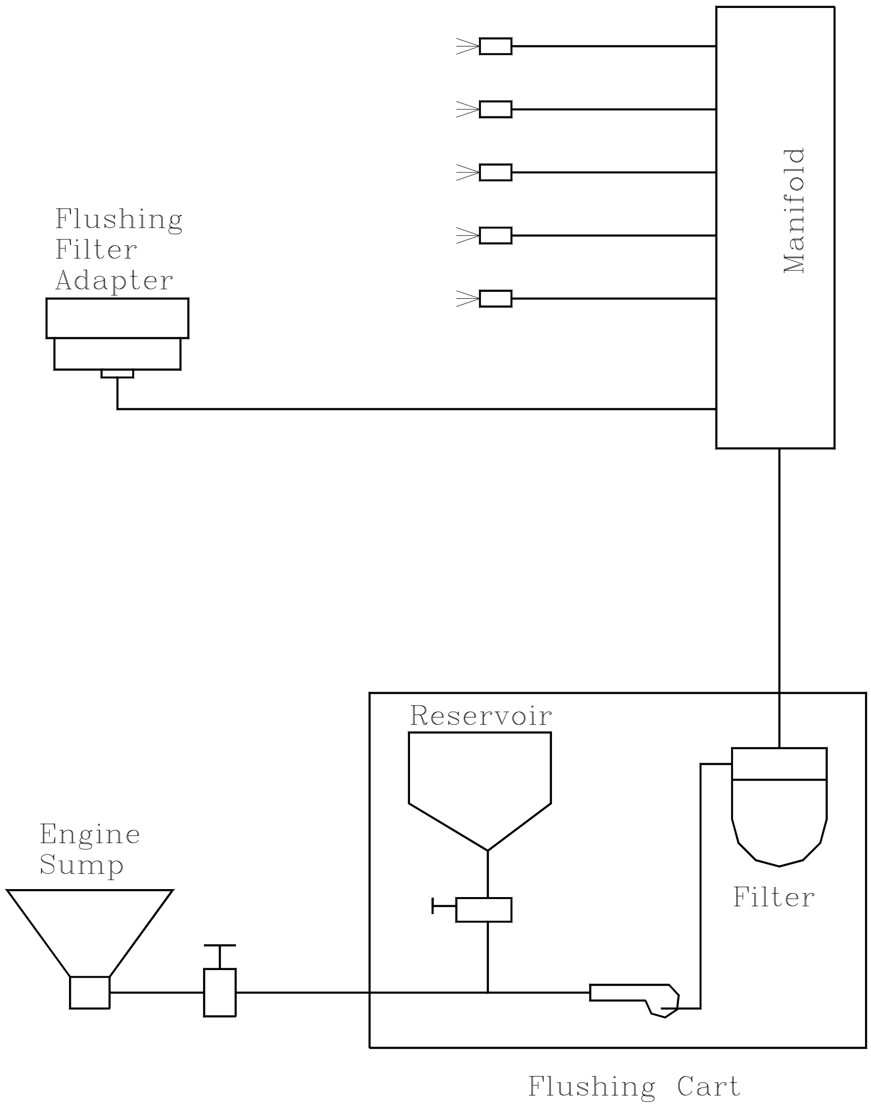


Fig. X1.7 Flushing Cart Flow Schematic

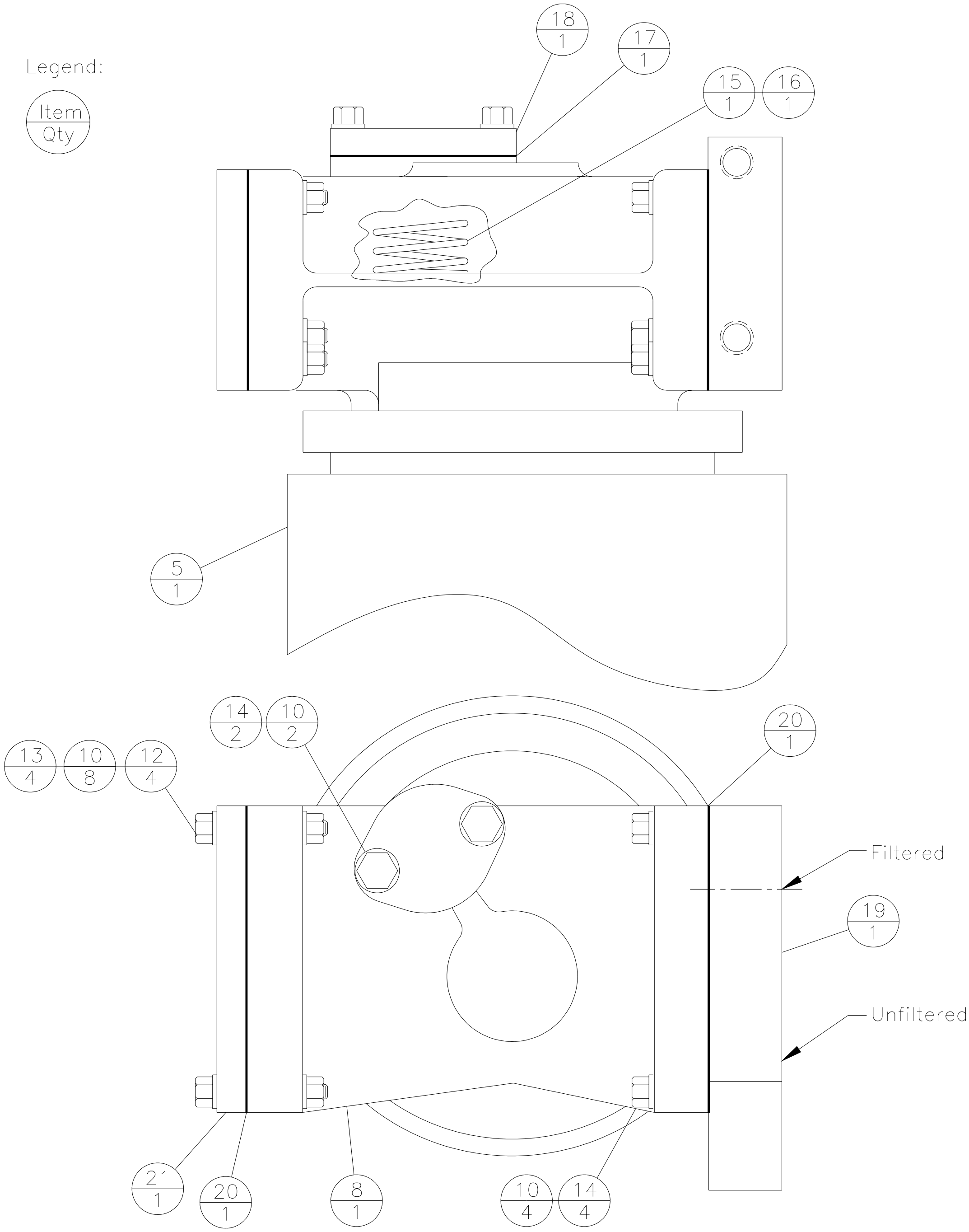


Fig. X1.8 Oil Flushing Hardware 1R-0716 and 2P-4301

Table X1.1 Parts List for Oil Flushing Hardware

Item	Qty	Part No.	Name
5	1	1R-0716	Filter assembly
8	1	2P-4301	Base assembly
10	17	5M-2894	Washer
12	4	0S-1571	Bolt (3/8)
13	4	9S-8752	Nut
14	6	0S-1588	Bolt (3/8)
15	1	4N-8150	Spring
16	1	9M-0853	Plunger
17	1	2P-3760	Gasket
18	1	2P-3761	Cover
19	1	9L-5611	Cover
20	2	2P-4305	Gasket
21	1	9N-5609	Cover

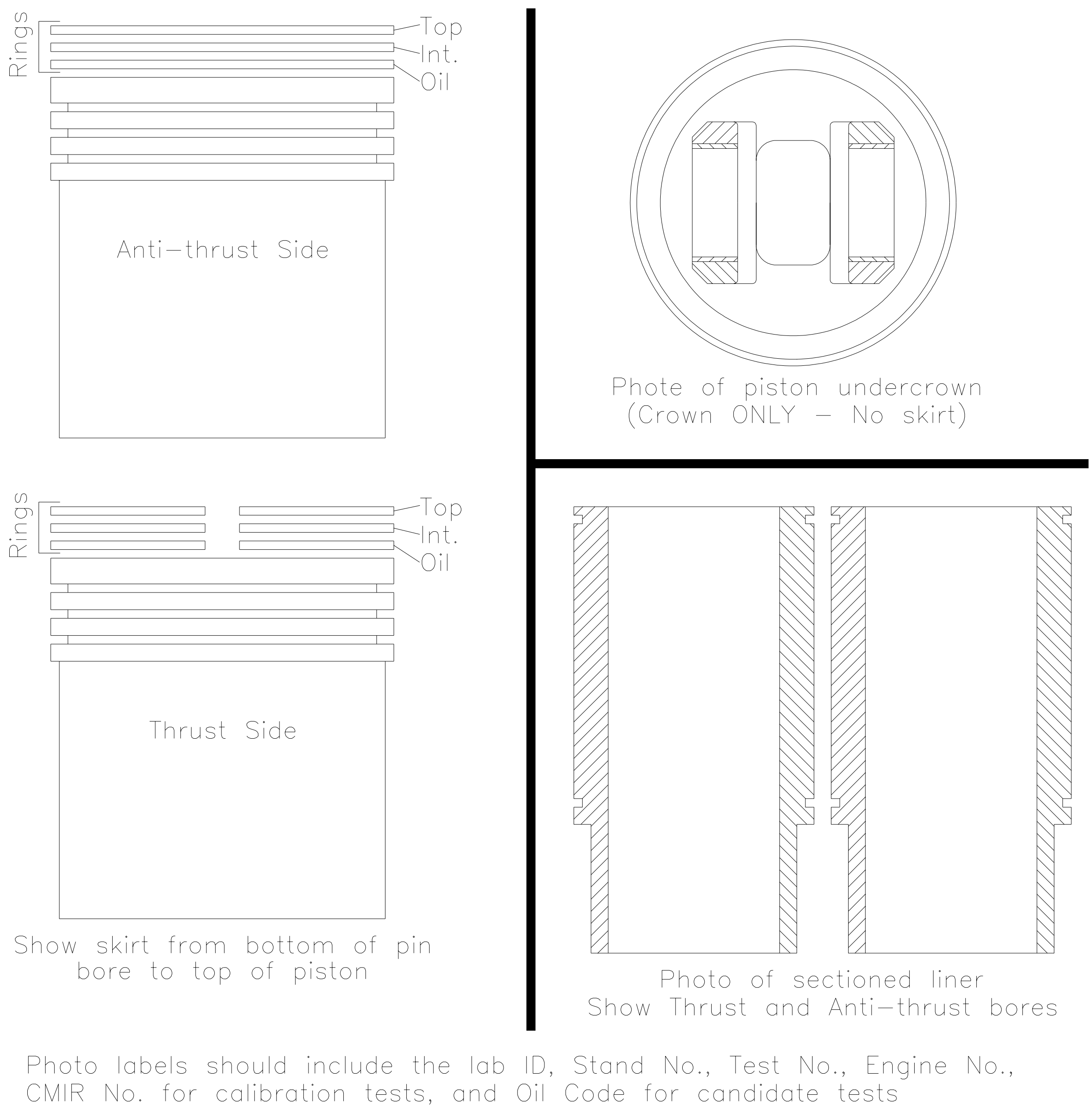


Fig. X1.9 Example of Piston, Rings and Liner Photograph Layout

X2. Safety

X2.1 The operating of engine tests can expose personnel and facilities to a number of safety hazards. It is recommended that only personnel who are thoroughly trained and experienced in engine testing should undertake the design, installation and operation of engine test stands. Each laboratory conducting engine tests should have their test installation inspected and approved by their Safety Department. Personnel working on the engines should be provided with the proper tools, be alert to common sense safety practices and avoid contact with external moving or hot parts.

X2.2 When engines are operating at high speeds, heavy-duty guards are required and personnel should be cautioned against working alongside the engine and coupling shaft. Barrier protection should be provided for personnel. All fuel, oil lines and electrical wiring should be properly routed, guarded and kept in good order. Scraped knuckles, minor burns and cuts are common if proper safety precautions are not taken. Safety masks or glasses should always be worn by personnel working on the engines and no loose or flowing clothing should be worn near running engines. The external parts of the engine and the floor area around the engines should be kept clean and free of oil and fuel spills. In addition, working areas should be free of all tripping hazards.

X2.3 Leaking fuel represents a fire hazard and exhaust gas fumes are noxious. Do not allow containers of oil or fuel to accumulate in the testing area. The test installation should be equipped with a fuel shut-off valve which is designed to automatically cut off the fuel supply to the engine when the engine is not running. A remote station for cutting off fuel from the test stand is recommended. Suitable interlocks should be provided so that the engine is automatically shut down when any of the following events occur: the engine dynamometer loses field current, engine over-speeds, low oil pressure, high water temperature, exhaust system fails, room ventilation fails or the fire protection system is activated. Consider a vibration pickup interlock if equipment operates unattended. Fixed fire protection equipment should be provided and dry chemical fire extinguishers should be available at the test stands.