Date: 5/4/2020

To: Subcommittee D02.BO members

Tech Contact: Sid Clark, slclark@comcast.net

Work Item #: WK-72772

Ballot Action: New Sequence IVB Test Method

Rationale: A new passenger car engine oil classification has been approved and this is a new standard.

Standard Test Method for Evaluation of Automotive Engine Oils in the Sequence IVB Spark-Ignition Engine[1]

This standard is issued under the fixed designation DXXXX; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

Portions of this test method are written for use by laboratories that make use of ASTM Test Monitoring Center (TMC)[2] services (see Annex A1-4).

The TMC provides reference oils and engineering and statistical services to laboratories that desire to produce test results that are statistically similar to those produced by laboratories previously calibrated by the TMC.
In general, the Test Purchaser decides if a calibrated test stand is to be used. Organizations such as the American Chemistry Council require that a laboratory utilize the TMC services as part of their test registration process. In addition, the American Petroleum Institute and the Gear Lubricant Review Committee of the Lubricant Review Institute (SAE International) require that a laboratory use the TMC services in seeking qualification of oils against their specifications.

The advantage of using the TMC services to calibrate test stands is that the test laboratory (and hence the Test Purchaser) has an assurance that the test stand was operating at the proper level of test severity. It should also be borne in mind that results obtained in a non-calibrated test stand may not be the same as those obtained in a test stand participating in the ASTM TMC services process.

Laboratories that choose not to use the TMC services may simply disregard these portions.
ASTM International policy is to encourage the development of test procedures based on generic equipment. It is recognized that there are occasions where critical/sole-source equipment has been approved by the technical committee (surveillance panel/task force) and is required by the test procedure. The technical committee that

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

Current edition approved X X, 202X. Published X 202X. Originally approved in 202X. Last previous edition approved in 202X as DXXXX. DOI: 1X.XXXX/DXXXX.

oversees the test procedure is encouraged to clearly identify if the part is considered critical in the test procedure. If a part is deemed to be critical, ASTM encourages alternate suppliers to be given the opportunity for consideration of supplying the critical part/component providing they meet the approval process set forth by the technical committee.

An alternate supplier can start the process by initiating contact with the technical committee (current chairs shown on ASTM TMC website). The supplier should advise on the details of the part that is intended to be supplied. The technical committee will review the request and determine feasibility of an alternate supplier for the requested replacement critical part. In the event that a replacement critical part has been identified and proven equivalent the sole-source supplier footnote shall be removed from the test procedure.

1. Scope

1.1 This test method measures the ability of an engine crankcase oil to control valve-train wear in spark-ignition engines at low operating temperature conditions. This test method is designed to simulate extended engine cyclic vehicle operation. The Sequence IVB Test Method uses a Toyota 2NR-FE water cooled, 4 cycle, in-line cylinder, 1.5L engine. The primary result is bucket lifter wear. Secondary results include cam lobe nose wear and measurement of iron (Fe) wear metal concentration in the used engine oil. Other determinations such as fuel dilution of the crankcase oil, non-ferrous wear metal concentrations, total fuel consumption, and total oil consumption, can be useful in the assessment of the validity of the test results.[2]

1.2 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.2.1 Exceptions—Where there is no direct SI equivalent such as pipe fittings, tubing, NPT screw threads/diameters, or single source equipment specified.

1.3 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. Specific warning statements are provided throughout this document as necessary in each particular section.

2. Referenced Documents

2.1 ASTM *Standards:*[3]

C534-03 Standard Specification for Preformed Flexible Elastomeric Cellular Thermal Insulation in Sheet and Tubular Form

D86 Test Method for Distillation of Petroleum Products at Atmospheric Pressure

D235 Specification for Mineral Spirits (Petroleum Spirits) (Hydrocarbon Dry Cleaning Solvent)

D287 Test Method for API Gravity of Crude Petroleum and Petroleum Products (Hydrometer Method)

D323 Test Method for Vapor Pressure of Petroleum Products (Reid Method)

D381 Test Method for Gum Content in Fuels by Jet Evaporation

D445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)

D525 Test Method for Oxidation Stability of Gasoline (Induction Period Method)

---

[2] The ASTM Test Monitoring Center will update changes in this test method by means of Information Letters. Information letters may be obtained from the ASTM Test Monitoring Center (TMC), 6555 Penn Ave., Pittsburgh, PA 15206-4489, Attention: Administrator. www.astmtmc.cmu.edu. This edition incorporates all Information Letters through No. 13–1.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

D664 Test Method for Acid Number of Petroleum Products by Potentiometric Titration

D1298 Test Method for Density, Relative Density, or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method

D1319 Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Absorption

D2622 Test Method for Sulfur in Petroleum Products by Wavelength Dispersive X-ray Fluorescence Spectrometry

D2789 Test Method for Hydrocarbon Types in Low Olefinic Gasoline by Mass Spectrometry

D3525 Test Method for Gasoline Diluent in Used Gasoline Engine Oils by Gas Chromatography

D4052 Density and Relative Density of Liquids by Digital Density Meter

D4057 Practice for Manual Sampling of Petroleum and Petroleum Products

D4175 Terminology Relating to Petroleum Products, Liquid Fuels, and Lubricants

D4294 Test Method for Sulfur in Petroleum and Petroleum Products by Energy Dispersive X-ray Fluorescence Spectrometry

D4485 Specification for Performance of Active API Service Category Engine Oils

D5185 Test Method for Multielement Determination of Used and Unused Lubricating Oils and Base Oils by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES)

D5191 Standard Test Method for Vapor Pressure of Petroleum Products and Liquid Fuels

D5453 Standard Test Method for Determination of Total Sulfur in Light Hydrocarbons, Spark Ignition Engine Fuel, Diesel Engine Fuel, and Engine Oil by Ultraviolet Fluorescence

D6304 Standard Test Method for Determination of Water in Petroleum Products, Lubricating Oils, and Additives by Coulometric Karl Fischer Titration.

E29 Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

E84 Standard Test Method for Surface Burning Characteristics of Building Materials

E168 Standard Practice for General Techniques of Infrared Quantitative Analysis

E230 Specification and Temperature-Electromotive Force (EMF) Tables for Standardized Thermocouples

2.2 SAE *Standards*[4]

J300 Engine Oil Viscosity Classification

J304 Engine Oil Tests

J1423 Classification of Energy-Conserving Engine Oil for Passenger Cars and Light-Duty Trucks

2.3 API *Standard:*

API 1509 Engine Oil Licensing and Certification System[5]

2.4 ANSI *Standard:*

ANSI MC96.1-1975 Temperature Measurement—Thermocouples[6]

2.5 *GMNA Standards:*

GM6277M[7]– Coolant – Extended Life – Ethylene Glycol (**Warning—**Health hazard—see appropriate MSDS)

---

[4] Available from the Society of Automotive Engineers (SAE), 400 Commonwealth Dr., Warrendale, PA 15096-0001. This standard is not available separately. Order the SAE Handbook Vol 2 or the SAE Fuels and Lubricants Standards Manual HS-23.

[5] Available from American Petroleum Institute (API), 1220 L. St., NW, Washington, DC 20005-4070, http://www.api.org.

[6] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[7] Available from retailers, auto parts stores, or any Shell retailer / distributor.

Note 1 — Shellzone[8] dex-cool 50/50 pre-diluted with de-ionized H_2O meeting the specification for GM6277M, GM North American Standard has been found satisfactory for this purpose.

2.6 *Other Standards / Manuals:*

Sequence IVB Engine Assembly Manual, updated by the Sequence IVB Surveillance Panel, available from the ASTM Test Monitoring Center Website. http://www.astmtmc.cmu.edu

Data Acquisition and Control Automation II Task Force Report dated June 17th, 1997, available from the ASTM Test Monitoring Center Website. http://www.astmtmc.cmu.edu

3. Terminology

Note 2 — ASTM D4175 - **Standard Terminology Relating to Petroleum Products, Liquid Fuels, and Lubricants** – lists terms and definitions internationally recognized for testing procedures as they may apply to Petroleum Products, Liquid Fuels, and Lubricant testing. ASTM D4175 may provide the user of this Standard Test Procedure a more in-depth reference to the definitions listed in section (3.1 Definitions).

3.1 *Definitions:*

3.1.1 *air-fuel ratio, n—in internal combustion engines,* the mass ratio of air-to-fuel in the mixture being induced into the combustion chambers.

3.1.2 *automotive, adj*—descriptive of equipment associated with self-propelled machinery, usually vehicles driven by internal combustion engines.

3.1.3 *blowby, n— in internal combustion engines,* that portion of the combustion by-products and unburned air/fuel mixture that leaks past piston rings into the engine crankcase during operation.

3.1.4 *calibrate, v*—to determine the indication or output of a device (e.g., thermometer, manometer, engine) with respect to that of a standard.

3.1.5 *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.

3.1.5.1 *Discussion*—In several automotive lubricant standard test methods, the ASTM Test Monitoring Center provides testing guidance and determines acceptability.

3.1.6 *corrosion, —the chemical or electrochemical reaction between a material,* usually a metal surface, and its environment that can produce a deterioration of the material and its properties.

3.1.7 *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 piston rings.

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

3.1.8 *lubricant test monitoring system (LTMS), n*—an analytical system in which ASTM calibration test data are used to manage lubricant test precision and severity (bias).

3.1.9 *lubricant, n*—any material interposed between two surfaces that reduces the friction or wear, or both, between them.

3.1.10 *mass fraction of B,* w_B, *n*—mass of a component B in a mixture divided by the total mass of all the constituents of the mixture.

3.1.10.1 *Discussion*—Values are expressed as pure numbers or the ratio of two units of mass (for example, mass fraction of lead is $w_B = 1.3 \times 10^{-6} = 1.3$ mg/kg).

3.1.11 *Material Safety Data Sheet (MSDS), n*—a fact sheet summarizing information about material identification; hazardous ingredients; health, physical, and fire hazards; first aid; chemical reactivity's and incompatibilities; spill, leak, and disposal procedures; and protective measures required for safe handling and

[8] ShellZone is a registered trademark of Shell Trademark Management BV. Available from retailers, auto parts stores, or any Shell retailer / distributor.

storage.

3.1.12 *non-reference oil*, *n*—any oil, other than a reference oil; such as a research formulation, commercial oil, or candidate oil.

3.1.13 *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 a combination thereof.

3.1.14 *quality index (QI)*, *n*—a mathematical formula that uses data from controlled parameters to calculate a value indicative of control performance.

3.1.15 *Quantity*, *n*—*in the SI*, a measurable property of a body or substance where the property has a magnitude expressed as the product of a number and a unit; there are seven, well-defined base quantities (length, time, mass, temperature, amount of substance, electric current, and luminous intensity) from which all other quantities are derived (for example, volume whose SI unit is the cubic metre).

3.1.15.1 *Discussion*—Symbols for quantities must be carefully defined; are written in italic font, can be upper or lower case, and can be qualified by adding further information in subscripts, or superscripts, or in parentheses (for example, t_{fuel} = 40 °C, where *t* is used as the symbol for the quantity Celsius temperature and t_{fuel} is the symbol for the specific quantity fuel temperature).

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

3.1.16.1 *Discussion*—Reference oils are used to calibrate testing facilities, to compare the performance of other oils, or to evaluate other materials (such as seals) that interact with oils.

3.1.17 *standard test*, *n*—a test on a calibrated test stand, using the prescribed equipment according to the requirements in the test method, and conducted according to the specified operating conditions.

3.1.18 *test oil*, *n*—any oil subjected to evaluation in an established test procedure.

3.1.18.1 *Discussion*—It can be any oil selected by the laboratory conducting the test. It could be an experimental product or a commercially available oil. Often, it is an oil that is a candidate for approval against engine oil specifications (such as manufacturers' or military specifications, etc.)

3.1.19 *test parameter*, *n*—a specified component, property, or condition of a test procedure.

3.1.19.1 *Discussion*—Examples of *components* are fuel, lubricant, reagent, cleaner, and sealer; of *properties* are density, temperature, humidity, pressure, and viscosity; and of *conditions* are flow rate, time, speed, volume, length, and power.

3.1.20 *test procedure*, *n*—one where test parameters, apparatus, apparatus preparation, and measurements are principal items specified.

3.1.21 *test stand*, *n*—a suitable foundation (such as a bedplate) to which is mounted a dynamometer, and which is equipped with a suitable data acquisition system, fluids process control system, supplies of electricity, compressed air, and so forth, to provide a means for mounting and operating an engine in order to conduct a Sequence IVB engine oil test.

3.1.22 *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.

3.1.23 *volume fraction of B*, φ_B, *n*—volume of component B divided by the total volume of all the constituents of the mixture prior to mixing.

3.1.23.1 *Discussion*—Values are expressed as pure numbers or the ratio of two units of volume (for example, φ_B = 0.012 = 1.2 % = 1.2 cL/L).

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *aging*, *n*—engine operation at steady state after completion of break-in, to pacify silicon leaching from gaskets, seals, and RTV silicon (room-temperature-vulcanizing silicon) type sealing materials.

3.2.2 *break-in*, *n*—initial engine operation to reach stabilization of the engine performance after new parts are installed in the engine.

3.2.3 *lifter volume loss*, *n*—the difference between the post-test and pre-test volume of a valve-train bucket lifter as measured by a Keyence VR-3000 or later model 3D macroscope.

3.2.3.1 *Discussion*—The pass-fail criteria is the average intake lifter volume loss, the average volume loss of all

8 intake bucket lifters. The average of all 8 exhaust bucket lifter volume loss is also calculated.

3.2.4 *cam lobe wear*, *n*—the difference between pre-test and post-test measurement of a cam lobe from heel to nose in µm.

3.2.5 *golden stand, n*—Sequence IVB test stand built in accordance with the Sequence IVB test method by the approved supplier(s).

3.2.6 *flushing*, *n*—the installation of a fresh charge of lubricant and oil filter for the purpose of running the engine to reduce and eliminate remnants of the previous oil charge.

3.2.6.1 *Discussion*—Flushing may be carried out in an iterated process to ensure a more thorough process of reducing previous oil remnants.

3.2.7 *reference plane*, *n*—The depth above which volume is calculated for Keyence volume measurements.

3.2.8 *lifter crown*, *n*—the maximum difference in height measured along to reference axis of the bucket lifters.

3.2.10 *camshaft lobe failure*, *n*—A severe form of wear of a camshaft lobe surface, that influences engine operation and makes it impossible to complete a test.

3.2.10.1 *Discussion*—Tests that experience camshaft lobe failure may be considered non-interpretable because the phenomenon may not have a repeatable relationship with the test oil.

3.2.11 *Degreasing Solvent*—Mineral spirits meeting the requirements of Specification D235, Type II, Class C for Aromatic Content (0 to 2) volume %, Flash Point (61°C, min) and Color (not darker than +25 on Saybolt Scale or 25 on Pt-Co Scale). (**Warning-**Combustible-Health hazard-see appropriate MSDS). A Certificate of Analysis is required for each batch of solvent.

3.2.12 *Keyence VR Macroscope*–A wide area optical 3D measurement device produced by the Keyence Corporation used to generate volume loss wear results for Sequence IVB tests.

4. Summary of Test Method

4.1 *Test Numbering Scheme*—Use the test numbering scheme shown below:

AAAAA-BBBBB-CCCCC

Where:
AAAAA = the stand number
BBBBB = the number of tests since the last reference calibration test on that stand.
CCCCC = the total number of Sequence IVB tests conducted on that test stand.

Example: Test number 6-10-175 represents the 175th Sequence IVB test conducted on test stand 6 and the tenth test since the last calibration test. Consecutively number all tests. Number the stand calibration tests beginning with zero for the BBBBB field. Multiple-length Sequence IVB tests are multiple runs for test numbering purposes, such as double-length tests which are counted as two runs and triple-length tests which are counted as three runs. For example, if test 1-3-28 is a doubled-length test, number the next test conducted on that stand 1-5-30.

4.2 Test Engine—This procedure uses a Toyota 2NR-FE water cooled, 4 cycle, in-line four-cylinder, 1.5 L engine as the test apparatus. The engine incorporates dual overhead camshafts, four valves per cylinder (2 intake; 2 exhaust), and a direct acting mechanical bucket lifter valve-train design. The critical test parts (camshafts, direct acting mechanical bucket lifters) are replaced prior to each test. A 95 minute break-in schedule, followed by a 50-h aging schedule, for Silicon (Si) pacification, is conducted whenever the long block or cylinder head are replaced with new components, or the long block is rebuilt due to camshaft lobe failure. In addition, a 50-h final break-in schedule (section 11.10) is conducted following engine aging (section 11.9) whenever the long block is replaced with new components.

4.3 *Test Stand*—The complete test stand is available from Test Engineering Inc. Thermocouples are to be installed by individual test labs at the locations shown in Annex A7. Mount the engine so that there is a 4.5° incline from the exhaust to the intake side and an angle of 0° from front to back. Control the intake air, provided to the engine air filter housing, for temperature, pressure, and humidity. Control the backpressure of the exhaust leaving the engine.   Install the engine on a test stand equipped with computer control of engine speed, torque, various temperatures, pressures, flows, and other parameters outlined in the test procedure (see Section 11).

4.4 *Test Sequence*—After an engine run-in and aging schedule, or after the completion of a previous test, install new test camshafts and bucket lifters, spark plugs, and a new timing chain tensioner. Flush the external oil system with degreasing solvent (**Warning-**Combustible-Health hazard-see appropriate MSDS) (see Section 3.2.11) and the oil pan with EF-411using external pumps and connections. After completing the external oil system and oil pan flush procedures, remove the external oil flush connections and connect all required oil system test lines. Perform four engine flushes, (see section 11.12.1 Engine Flushes) using fresh oil charges for each flush. After completing the fourth flush, drain and install the fresh test oil charge. Run the test for a total of 200 h, with no scheduled shutdowns. A single test cycle is composed of two 7-s steady-state stages separated by 8-s transitions. This test cycle (two steady-state stages and two transitions) is repeated 24,000 times.

4.5 *Analyses Conducted*—At the completion of the test, the camshaft lobes are measured for heel-to-toe wear and the bucket lifters are measured for volume loss. Use these measurements to determine the average, minimum and maximum wear for the intake and exhaust bucket lifters and the intake and exhaust camshaft lobes. Determine the oil consumption by calculating the difference between the mass of the used drain oil and the mass of the engine's initial oil charge considering oil removed for intermediate oil samples. Analyze the end of test used oil for wear metals, fuel dilution, kinematic viscosity at 40°C, total acid number, total base number, oxidation and nitration by FTIR, and Karl Fischer water content. Retain a final drain sample of 1Litre for a minimum of 90 days. Retain the camshafts and bucket lifters for a minimum of 6 months.

5. Significance and Use

5.1 This test method was developed to evaluate automotive lubricant's effect on controlling valve-train wear and overall engine wear for overhead camshaft engines with direct acting bucket lifters.

5.2 Average intake lifter volume loss is used as a measure of an oil's ability to prevent valve-train wear.

5.3 End-of-test oil iron concentration is used as a measure of an oil's ability to prevent overall engine wear.

NOTE 4 —This test method may be used for engine oil specifications such as API SN, SN-Plus, SP, and ILSAC GF- 6.

6. Apparatus

NOTE 5 — Coordination with the ASTM Committee D02, Subcommittee B, Sequence IV Surveillance Panel is a prerequisite to the use of any equivalent apparatus. Figures are provided throughout the test method to suggest appropriate design details and depict some of the required apparatus.

6.1 *Test Engine*—This test method uses a 2011 model Toyota 2NR-FE, in-line 4-cylinder, 16 valve, 4-cycle, water-cooled, port fuel-injected gasoline engine with a displacement of 1.496 L. See Annex A9 for a parts list. Nominal oil sump volume is 3.0 L. The cylinder block and cylinder head are aluminum. The engine features dual overhead camshafts and direct acting bucket lifters. The engine compression ratio is 10.5 to 1. The engine is rated to 132 N·m of torque at 3000 r/min. The ignition timing and multi-port fuel injection system is electronically controlled by a test-specific Engine Control Module (ECM).

6.1.1 *Engine Buildup Area*—The ambient atmosphere of the engine buildup and measurement areas shall be reasonably free of contaminants and maintained at a uniform temperature. Care should be exercised to eliminate the use of any materials which would introduce abrasive dust type particles of any nature in the engine build areas. Maintain the specific humidity at a uniform level to prevent the accumulation of rust on engine parts. The engine buildup area shall maintain uniform temperatures and background luminous intensity to ensure repeatable dimensional measurements performed in the engine buildup area.

6.1.2 *Measurement/Metrology Area*— Use uniform temperatures and background lighting to ensure repeatable dimensional measurements.

6.1.3 Use a Keyence macroscope on a base-plate free of external vibrations.

6.1.4 *Engine Operating Area*—The laboratory ambient atmosphere shall be reasonably free of contaminants and general wind currents, especially if the valve-train parts are installed while the engine remains in the operating area. The temperature and humidity level of the operating area is not specified.

6.1.5 *Parts Cleaning Area*—This test method does not specify the ambient atmosphere of the parts cleaning area (**Warning—**Use adequate ventilation in areas while using solvents and cleansers).

6.2 *External Engine Modifications*—Modify the test engine for the valve-train wear test. Install the modified front cover and oil pan from the approved supplier. Install an oil filter adapter at the location of the stock oil filter housing, as shown in the Sequence IVB Engine Assembly Manual Section 1. Install fittings for various temperature and pressure measurements as required by the test method. Replace the Toyota production rocker arm cover with a specially manufactured aluminum jacketed rocker arm cover (part# OHTIVB-002-1). Route the rocker arm cover coolant through this jacket.

6.3 *Test Stand and Laboratory Equipment*—This engine-dynamometer test is designed for operation using computer control instrumentation and computer data acquisition. Provide an intake air system for the precise control of engine intake air humidity, temperature, and cleanliness.

6.3.1 Computer *Data Acquisition System*—Sections 6.3.1.1 – 6.3.1.3 detail the test stand data logging criterion for operational data with a computer data acquisition system using sensor configurations, and compliances with the Data Acquisition and Control Automation II[9] guidelines. Consider a test that has greater than 2 h without data acquisition on any controlled parameter to be operationally invalid.

6.3.1.1 *Frequency of Logged Data*—Log data at 1 Hz during all 4 stages of all test cycles.

6.3.1.2 *Resolution of Logged Data*—The laboratory provided data acquisition system must provide 32 analogs to digital channels that meet the resolution requirements in Table 1.

6.3.1.3 System *Time Response for Logged Data*—Do not exceed the controlled operational parameters for system time response for measurement shown in Table 2. The system time response includes the total system of sensor, transducer, analog signal attenuation, and computer digital filtering. Use single-pole type filters for attenuation.

TABLE 1 Data Acquisition Resolution Requirements

Parameter	Units	Required Resolution
Engine Speed	r/min	1
Torque	N-m	1
Air-to-Fuel Ratio	AFR	0.05
All Temperatures Except Exhaust	°C	0.1
Exhaust Temperature	°C	1
All Gauge Pressures	kPa	0.1
Barometer (Absolute)	kPa	0.1
Humidity	g/kg	0.1

[9] **ASTM TMC Technical Guidance Committee Report available referenced on www.asmtmc.cmu.edu**

TABLE 2 System Time Response

Parameters	Time Response, max (one-time constant)
Temperatures	2.8 s
Pressures	1.7 s
Coolant Flow	8.0 s
Torque	2.0 s
Speed	1.8 s

6.3.1.4 *Quality Index*—The Quality Index (QI) is an overall statistical measure of the variation from test targets of the steady-state operational controlled parameters. The Sequence IVB Surveillance Panel has chosen the QI upper and lower control limits, for Humidity, Temperature, Pressure, Torque, and Flow shown in Table 3, and for Engine Speed (Variable Target) QI Control Limits shown in Table 4.

$$1-\frac{1}{n}\sum_{i=1}^{n}\left(\frac{U+L-2X_i}{U-L}\right)^2 = QI \qquad (1)$$

where:

X_i = values of the parameter measured,

U = allowable upper limit of X,

L = allowable lower limit of X, and

n = number of data points used to calculate QI.

TABLE 3 QI Control Limits

Parameter	U	L
Intake Air Humidity	12.00	11.00
Engine Coolant Out Temperature*	53.50	50.75
Exhaust Backpressure **	107.50	101.50
Fuel Rail Temperature	24.50	23.50
Intake Air Pressure	0.50	0.00
Intake Air Temperature	32.75	31.25
Oil Gallery Temperature	58.00	50.00
RAC Coolant Out Temperature	20.75	19.25
Torque	26.50	23.50
Engine Coolant Flow Rate	80.40	79.60
RAC Coolant Flow Rate	120.75	119.25
Blow-by Gas Temperature	29.50	28.50

Load Cell Temperature	49.00	41.00
Engine Coolant Pressure	80.00	60.00
Fuel Rail Pressure	345.00	325.00

*Only calculated during stages 1and 2
**Only calculated during stage 2

TABLE 4 Engine Speed (Variable Target) QI Control Limits

Cycle Time, s	Set point, r/min	U, r/min	L, rpm
1	800	950	650
2	800	900	700
3	800	875	725
4	800	850	750
5	800	850	750
6	800	850	750
7	800	850	750
8	927	1077	777
9	1357	1607	1107
10	1888	2288	1488
11	2300	2700	1900
12	2731	3131	2331
13	3168	3568	2768
14	3610	4010	3210
15	4041	4441	3641
16	4300	4400	4200
17	4300	4375	4225
18	4300	4350	4250
19	4300	4325	4275
20	4300	4325	4275
21	4300	4325	4275
22	4300	4325	4275
23	4136	4236	4036
24	3734	3984	3484
25	3283	3683	2883
26	2829	3229	2429
27	2382	2782	1982
28	1946	2346	1546
29	1523	1923	1123
30	1116	1516	716

6.3.1.5 *Bad Quality Data* (BQD) Table 5 shows the BQD limits.

TABLE 5 BQD Limits

Parameter	U	L
Intake Air Humidity	20.00	1.00
Engine Coolant Out Temperature	195.00	0.00
Exhaust Backpressure *	200.00	0.00
Fuel Rail Temperature	195.00	0.00
Intake Air Pressure	5.00	-1.00
Intake Air Temperature	195.00	0.00
Oil Gallery Temperature	195.00	0.00
RAC Coolant Out Temperature	195.00	0.00
Engine Speed	5500.00	0.00
Torque	200.00	0.00
Engine Coolant Flow Rate	200.00	0.00
RAC Coolant Flow Rate	200.00	0.00
Blow-by Gas Temperature	195.00	0.00
Load Cell Temperature	195.00	0.00
Engine Coolant Pressure	200.00	0.00
Fuel Rail Pressure	500.00	0.00

Where missing data or Bad Quality Data (BQD), or both, are encountered, calculate the adjusted Quality Index (QI_{ADJ}) using the following equation:

$$QI_{ADJ} = QI\left(\frac{n}{N}\right) + QI\left(\frac{n}{N}\right) \times \left(\frac{N-n}{N}\right) \qquad (2)$$

where:

Q = QI calculated without missing/BQD,

I = points,

n = number of data points used to calculate QI, and

N = number of data points for a complete data set.

If the QI calculation of a controlled parameter is less than zero, investigate the reason, assess its impact on test operational validity, and document such finding in the final test report. For calibration tests, review the operational validity assessment with the TMC. Annex A2 describes calibration procedures using the TMC reference oil, including their storage and conditions of use, the conducting of tests and the reporting of results.

6.3.2 *Test Stand Configuration*—Mount the engine on the test stand like its vehicle orientation (0° in front; sideways 4.5° up on intake manifold side). This orientation is important to the return flow of oil in the cylinder head and ensures reproducible oil levels. Directly couple the engine flywheel to the Midwest MW1014A dynamometer through the approved driveshaft.

6.3.3 *Dynamometer Excitation and Throttle Control*—A DyneSystems Non-Interlock 5 which is provided as part of the golden stand assembly is the only system permitted to be used for dynamometer excitation and throttle control.

6.3.4 Intake-air Supply System—The intake air supply system shall deliver at least 1000 L/min (2000 L/min preferred) of conditioned and filtered air to the test engine during the 200-h test, while maintaining the intake-air parameters detailed in Table 13.

6.3.4.1 *Induction Air Humidity*—Measure the intake air specific humidity in the main system duct or at the test stand. If using a main system duct dew point temperature reading to calculate the specific humidity, verify the dew point periodically at the test stand. Maintain the duct surface temperature above the dew point temperature at all points downstream of the humidity measurement point to prevent condensation and loss of humidity level.

6.3.4.2 *Intake Air Filtering*—Use the production intake air cleaner assembly with filter, at the engine. Use a snorkel adapter that fits over the intake air box inlet to connect the controlled air duct to the air cleaner. Ensure that the top of the air cleaner assembly has been modified for installation of the intake pressure sensor line. Refer to 6.3.4.5 for installation position

6.3.4.3 *Intake Air Flow*—Do not measure intake airflow.

6.3.4.4 *Intake Air Temperature*—For final control of the inlet air temperature, install an electric air heater strip within the air supply duct. The duct material and heater elements design shall not generate corrosion debris that could be ingested by the engine.

6.3.4.5 *Intake Air Supply Pressure*—Locate the pressure sensing tube on the top cover of the air cleaner 190 mm ± 10 mm from the front (straight edge of the top surface) and 65 mm ± 10 mm from the left (viewed from the front of the box). The tube shall have a depth of 25 mm ± 4 mm into the air cleaner.

6.3.5 *Fuel Supply System*—This test method requires approximately 750 L of unleaded Haltermann KA24E Green test fuel per test (24000 cycles). A fuel supply pressure of at least 124 kPa (18 psi) to the fuel conditioning system is required. Use a Motorcraft E7T2-9C407-BA fuel pump. The fuel conditioning system is part of the golden stand supplied by Test Engineering Inc.

7. Reagents and Materials

NOTE 6 — Use 12 L and 2600 g (~3000 mL) of the non-reference test oil sample to perform the 200 h Valve-train Wear test.

7.1 *Coolant for Engine and Rocker Arm Cover*— Use a mixture of ShellZone[8] DEX-COOL antifreeze/coolant and de-ionized water with a volume fraction of water of 50 %. (**Warning—**Health hazard—see appropriate MSDS).

7.2 *Fuel*—Use Haltermann KA24E[10] Green test fuel for this test method (**Warning—**Flammable health hazard). It is dyed green to preclude unintentional contamination with other test fuels. Refer to the TMC (https://www.astmtmc.cmu.edu). Use approximately 750 L of fuel for each test (24000 cycles). This fuel has a hydrogen-to-carbon ratio of 1.80 to 1.

7.2.1 *Fuel Approval Requirements*—The fuel is blended to a sulfur content of 130 ± 10 ppm and the fuel supplier's requirements. Base the fuel batch acceptance upon the physical and chemical specifications given in Annex A10. Engine validation tests are not necessary for fuel batch acceptance.

7.2.2 *Fuel Analysis*—Monitor the test fuel using good laboratory practices. Analyze each fuel shipment to determine the value of each parameter for fuel sulfur as described in Test Method D5453, existent gum as described in Test Method D381, RVP as described in Test Method D5191, and API Gravity as described in Test Method

[10] The sole source of supply of this fuel known to the committee at this time is Haltermann Products, 1201 Sheldon Rd., P.O. Box 429, Channelview, TX 77530–0429, USA.

D4052. Compare the results to the original values supplied by the fuel supplier. The analytical results shall be within the tolerances shown in parentheses beside each parameter. This provides a method to determine if the fuel batch is contaminated or has aged prematurely. If any analytical result falls outside the tolerances, the laboratory shall contact the fuel supplier for problem resolution.

7.2.2.1 *Fuel Deterioration*—Analyze the fuel semiannually to ensure the fuel has not deteriorated excessively or been contaminated in storage.

7.2.2.2 Analyze the fuels using Test Methods D5453, D4052, D381, and D5191.

7.2.3 *Fuel Shipment and Storage*—Ship the fuel in containers with the minimum allowable venting as dictated by all safety and environmental regulations, especially when shipment times are anticipated to be longer than one week. Store the fuel in accordance with all applicable safety and environmental regulations. If the run tank has more than one batch of fuel, document the most recent batch in the test report.

7.3 *Lubricating Oils:*

7.3.1 *Break-in Lubricating Oil*—An engine break-in procedure as shown in 11.2.6 is immediately conducted following the replacement of new, major engine components (that is, engine short-block, or cylinder head, or both). Use the proper reference oil, 1006-2, from the TMC for the break-in procedure. Use 3 L of this reference oil for each break-in procedure.

7.3.2 *Break-In #2 Lubricating Oil* - A second engine break-in procedure (see Section 11) is conducted following the initial Break-In cycle. Use the proper reference oil, 1012, from the TMC for break-in procedure. Use 19L of this reference oil for each break-in #2 procedure.

7.3.3 *Short-block Assembly Lubricant and External Oil System Flush* —For engine short-block inspection and reassemble, use EF-411[11] oil as the assembly lubricant. Also used during external oil system flushing.

7.4 Miscellaneous Materials*:*

7.4.1 *Solvents and Cleansers*—No substitutions for 7.4.1.1 – 7.4.1.3 are allowed. Use adequate safety provisions with all solvents and cleaners.

7.4.1.1 *Degreasing Solvent*—Use only mineral spirits meeting the requirements of Specification D235, Type II, Class C for Aromatic Content ((0 to 2) vol %), Flash Point (61°C, min) and Color (not darker than +25 on Saybolt Scale or 25 on Pt-Co Scale). (**Warning-**Combustible-Health hazard-see appropriate MSDS) Obtain a Certificate of Analysis for each batch of solvent from the supplier.

7.4.1.2 *Pentane*— (**Warning—**Flammable. Health hazard.) Available from petroleum solvent suppliers.

7.4.1.3 *Cylinder Block and RAC Cleaning Detergent*—Tri-sodium phosphate and any commercial coolant cleanser. (**Warning—** Caustic. Health hazard.)

7.4.1.4 Use Ultrasonic-7 soap[12] and Ultrasonic-B[12] degreaser in ultrasonic parts washers to clean engine block, cylinder heads and fixed phasers. Cleaning solution shall be at a temperature of 65 °C ± 5 °C.

7.4.1.5 Alternatively, use a 50/50 Brulin US Solution[13] of 815 GD and 815 QR-NF with a volume fraction of 12.5 % provided that the laboratory has conducted a successful reference oil test using this solution.

7.4.2 *Sealing Compounds*—Use a silicone based gasketing compound during engine assembly (for example, oil pan). Use only ACDelco Engine Sealant[14] part number 12378521 or ThreeBond Engine Sealant[15] part number TB 1217F recommended silicone gasket materials.

8. Oil Blend Sampling Requirements

8.1 Sample *Selection and Inspection*—The non-reference oil sample shall be uncontaminated, and representative

---

[11] The sole source of supply of this product known to the committee at this time is Exxon-Mobil Oil Corp., Attention Illinois Order Board, P.O. Box 66940, AMF O'Hare, IL 60666, USA.

[12] Available from TEI, 12718 Cimarron Path, San Antonio, TX 78249, USA, Tel: (210) 690-1958.

[13] The sole source of supply of this product known to the committee at this time is Brulin & Company, 2920 Dr. Andrew J. Brown Av, Indianapolis, IN 46205, 317.923.3211. csr@brulin.com.

[14] Available from retailers, autoparts stores, or any General Motors dealer.

[15] ThreeBond is a registered trademark of ThreeBond International, Inc. Available from retailers, autoparts stores.

of the lubricant formulation being evaluated.

NOTE 7 — If the test is registered using the American Chemistry Council[16] protocols, the assigned oil container formulation number shall match the registration form.

8.2 Non-*reference Oil Sample Quantity*—Use a minimum of 15 L of new oil to complete the Sequence IVB test, including the oil flushes. Normally the supplier provides a 19 L new oil sample to allow for inadvertent losses.

8.3 Reference *Oil Sample Quantity* -The TMC provides a 19 L reference oil sample for each stand calibration test.

9. Preparation of Apparatus

NOTE 8 — This section details those recurring preparations necessary for test operation. This section assumes the engine test stand facilities and other hardware described in Section 6 are in place.

9.1 *Test Stand Preparations:*

9.1.1 *Instrumentation Calibration*—Calibrate all sensors and indicators before or during the test for the type instrumentation used. See Section 10 for the calibration requirements.

9.1.2 *External Oil System Cleaning*—Use clean mineral spirits followed by forced-air drying to clean the external oil system.

9.1.3 *Air Cleaner Filter*—Replace the air cleaner filter element when an engine is replaced, or more frequently if intake air pressure is insufficient.

9.1.4 *Draining Exhaust Piping*—Prior to the start of each test, drain the low point of the exhaust piping to eliminate water accumulation. Drain water during a test if exhaust pressure control becomes unstable.

9.1.5 *External Hose Replacement*—Inspect all external hoses used on the test stand and replace any hoses that have become unserviceable. Check for internal wall separations that could cause flow restrictions. Inspect and replace the external oil system hoses as needed.

9.1.6 *Stand Ancillary Equipment*—Service the dynamometer and driveline components, as required. The dynamometer torque measurement shall be accurate (no unaccounted forces from hoses, load cell temperature gradients, or trunnion bearing hysteresis).

9.2 *General Engine Assembly Preparations*—Refer to the Sequence IVB Engine Assembly Manual, available from the ASTM Test Monitoring Center Website. http://www.astmtmc.cmu.edu.

10. Data Acquisition, Reference Oil Application, and Equipment Calibration and Maintenance

10.1 Data *Acquisition:*

10.1.1 Computer *Data Acquisition*—The test stand should log operational data using a computer data acquisition system, sensor configuration processes are described in 10.1.2 – 10.1.3.1

10.1.2 Frequency *of Logged Test Cycle Data*—Log the test cycle data at a sampling rate of 1-Hz.

10.1.3 Signal *Conditioning*—Do not exceed the controlled operational parameters for system time response as shown in Table 1. The system time response includes the total system of sensor, transducer, analog signal attenuation, and computer digital filtering. Use single-pole type filters for attenuation. For temperature sensors only grounded thermocouples are acceptable.

10.1.3.1 Isolated *Inputs*—Use signal-conditioning modules to provide isolated inputs to the digital computer.

10.2 Reference *Oil Application:*

NOTE 9 —10.2.6 and 10.2.7 and Annex A1-4 describe the involvement of the TMC in respect to calibration procedures and acceptance criteria for a testing laboratory and a test stand, and the issuance of Information Letters and memoranda affecting the test method.

[16] American Chemistry Council, 1300 Wilson Boulevard, Arlington, VA 22209.

10.2.1 Testing *of Reference Oils*—Periodically conduct tests on reference oils according to the following:

10.2.1.1 Conduct reference oil tests on each calibrated test stand within a laboratory according to TMC guidelines.

10.2.1.2 Obtain reference oils directly from the TMC. These oils are formulated or selected to represent specific chemical types or performance levels, or both. They are usually supplied directly to a testing laboratory under code numbers to ensure that the laboratory is not influenced by prior knowledge of acceptable results in assessing the test results. The TMC determines which specific reference oil the laboratory shall test.

10.2.1.3 Unless specifically authorized by the TMC, do not analyze reference oils, either physically or chemically. Identification of reference oils by such analyses could undermine the confidentiality required to operate an effective reference oil system. Therefore, reference oils are supplied with the explicit understanding that they will not be subjected to analyses other than those specified in this procedure, unless specifically authorized by the TMC. If so authorized, prepare a written statement of the circumstances involved, the name of the person authorizing the analysis, and the data obtained; furnish copies of this statement to the TMC.

10.2.2 Reference *Oil Test Frequency*—Conduct reference oil tests according to the following frequency requirements:

10.2.2.1 For a given, calibrated test stand, conduct an acceptable reference oil test after no more than 15 test starts have been conducted, or after 6 months have elapsed, whichever occurs first.

10.2.2.2 After starting a laboratory reference oil test, non-reference oil tests may be started on any other calibrated test stand.

10.2.2.3 Reference oil test frequency may be adjusted due to the following reasons:

10.2.3 Procedural *Deviations*—On occasions when a laboratory becomes aware of a significant deviation from the test method, such as might arise during an in-house review or a TMC inspection, the laboratory and the TMC shall agree on an appropriate course of action to remedy the deviation. This action may include the shortening of existing reference oil calibration periods.

10.2.4 Parts *and Fuel Shortages*—Under special circumstances, such as industry-wide parts or fuel shortages, the Surveillance Panel may direct the TMC to extend the time intervals between reference oil tests. These extensions shall not exceed one regular calibration period.

10.2.5 Reference *Oil Test Data Flow*—To ensure continuous severity and precision monitoring, calibration tests are conducted periodically throughout the year. There may be occasions when laboratories conduct a large portion of calibration tests in a short period of time. This could result in an unacceptably large time frame when very few calibration tests are conducted. The TMC can shorten or extend calibration periods as needed to provide a consistent flow of reference oil test data. Adjustments to calibration periods are made such that laboratories incur no net loss (or gain) in calibration status.

10.2.6 Special *Use of the Reference Oil Calibration System*—The Surveillance Panel has the option to use the reference oil system to evaluate changes that have potential impact on test severity and precision. This option is only taken when a program of donated tests is not feasible. The Surveillance Panel and the TMC shall develop a detailed plan for the test program. This plan requires all reference oil tests in the program to be completed as close to the same time as possible, so that no laboratory/stand calibration is left in an excessively long pending status. To maintain the integrity of the reference oil monitoring system, each reference oil test is conducted to be interpretable for stand calibration. To facilitate the required test scheduling, the Surveillance Panel may direct the TMC to lengthen and shorten reference oil calibration periods within laboratories such that the laboratories incur no net loss (or gain) in calibration status.

10.2.7 Donated *Reference Oil Test Programs*—The Surveillance Panel is charged with maintaining effective reference oil test severity and precision monitoring. During times of new parts introductions, new or re-blended reference oil additions, and procedural revisions, it may be necessary to evaluate the possible effects on severity and precision levels. The Surveillance Panel may choose to conduct a program of donated reference oil tests in those laboratories participating in the monitoring system, to quantify the effect of a change on severity and precision. Typically, the Surveillance Panel requests its panel members to volunteer enough reference oil test results to create a robust data set. Broad laboratory participation is needed to provide a representative sampling of the industry. To ensure the quality of the data obtained, donated tests are conducted on calibrated test stands. The Surveillance Panel shall arrange an appropriate number of donated tests and ensure completion of the test program in a timely manner.

10.2.8 Reporting *of Reference Oil Test Results*—Report the results of all reference oil tests to the TMC according to the following directives:

10.2.8.1 Transmit results to the TMC within five days of completing post-test measurements by way of electronic data transfer protocol as outlined in the Data Communication Committee, Electronic Test Report Transmission Model (ETRTM). The ETRTM can be obtained from the TMC.

10.2.8.2 If the test was conducted during a time extension permitted by the TMC, so indicate in the Comments section of the test report.

10.2.8.3 For an acceptable reference oil test, conducted following an unacceptable reference oil test, provide sufficient information in the Comments section of the test report to indicate how the problem was identified and corrected, insofar as possible, and how it was related to non-reference oil tests conducted during the period that the problem was being solved.

10.2.9 Evaluation *of Reference Oil Test Results*—The TMC evaluates the reference-oil test results for both operational validity and statistical acceptability. The TMC may consult with the test laboratory in case of difficulty, as follows:

10.2.9.1 Immediately upon receipt of the reference-oil test results from the test laboratory, the TMC evaluates the laboratories decision on operational validity. For operationally valid tests, the TMC then evaluates the pass/fail parameters according to the Sequence IVB Lubricant Test Monitoring System. If the test is judged acceptable, the reference oil code is disclosed by the TMC to the test laboratory. The TMC conveys to the test laboratory its preliminary findings based on the limited information available to them.

10.2.9.2 Subsequently, upon receipt of the information detailed in Annex A1-4 the TMC reviews all reference-oil test results and reports to determine final test acceptability.

10.2.9.3 The TMC decides, with consultation as needed with industry experts (testing laboratories, members of the ASTM Technical Guidance Committee and of the Surveillance Panel, and so forth), whether the reason for any failure of a reference oil test is a false alarm, testing stand, testing laboratory, or industry-related problem. The Sequence IVB Surveillance Panel shall adjudicate all industry problems.

10.2.10 Status *of Non-Reference Oil Tests Relative to Reference Oil Tests*—Non-reference oil tests may proceed within a given laboratory during reference oil testing based upon the following:

10.2.10.1 During the time of conducting a reference oil test on one test stand, non-reference oil tests may be conducted on other previously calibrated stands. If the reference oil test is acceptable to the TMC, the non-reference oil tests shall be considered to have been run in a satisfactorily calibrated laboratory.

10.2.10.2 If a reference oil test is unacceptable, and it is determined that the problem is isolated to an individual test stand, consider other test stands to remain calibrated, and testing of non-reference oils may proceed on those other stands.

10.2.10.3 If a reference oil test is unacceptable, and it is determined that the problem is laboratory related, non-reference tests running during the problem period shall be considered invalid unless there is specific evidence to the contrary for each test.

10.2.11 Status *of Test Stands Used for Non-Standard Tests*—If a non-standard test is conducted on a previously calibrated test stand, conduct a reference oil test on that stand to demonstrate that it continues to be calibrated, prior to running standard tests.

10.3 Equipment *Calibration:*

10.3.1 Instrumentation *Calibration*—Perform a thorough recalibration adjustment of all instrumentation and transducers, including computer channels, according to the requirements that follow. Perform additional calibration checks whenever operational data indicates an abnormality. Standards used for instrumentation calibration shall be traceable to that country's specific national standards organization. The accuracy of the standard shall be a minimum of four times better than the accuracy of the test stand instrumentation.

10.3.2 Dynamometer *Torque Measurement*—Scale the final readout of engine torque (N·m). Calibrate the force measurement and readout system with deadweights. Coolant flow through the dynamometer, reaction forces due to coolant plumbing, and brinelled trunnion bearings of the dynamometer may affect calibration by temperature excursions of the dynamometer electronic force transducer. When calibrating, ensure the dynamometer coolant flow indicator is in the green and that the load cell temperature has been stabilized at 45°C ± 1°C for a minimum of one hour. Perform this calibration prior to every test start.

10.3.3 Instrument Calibration—Document all instrument calibrations. Retain all calibration documentation for a minimum of 3 years.

10.3.3.1 Upon initial stand installation and every 6 months thereafter perform a full instrumentation calibration according to Table 6.

TABLE 6 Parameters to be Calibrated Every 6 Months

Items
Temperatures
Intake Air Temperature, °C
Engine Oil Gallery Temperature, °C
Engine Oil Sump Temperature, °C
Coolant Temperature into Engine, °C
Coolant Temperature Out of Engine, °C
Fuel Rail Temperature, °C
Exhaust Gas Temperature, °C
Valve Cover Coolant in Temperature, °C
Valve Cover Coolant Out Temperature, °C
Dynamometer Load Cell Temperature, °C
Test Cell Air Temperature, °C
Blow-by Gas Temperature, °C
Blow-by Coolant Temperature, °C
Pressures
Engine Coolant Pressure, kPa
Crankcase Gas Pressure, kPa
Oil Gallery Pressure, kPa
Fuel Rail Pressure, kPa
Exhaust Pressure, kPa (absolute)
Intake Air Pressure, kPa
Intake Manifold Pressure, kPa (absolute)
Barometric Pressure, kPa (absolute)
Flows
Air Fuel Ratio, afr
Blow-by Flow Rate, sl/min
Fuel Flow Rate, kg/h
Engine Coolant Flow Rate, L/min
Valve Cover Coolant Flow Rate, L/min
General
Intake Air Humidity, grains/kg
Engine Speed, r/min
Engine Torque (N-m)

10.3.4 Humidity *of Induction Air Calibration:*

10.3.4.1 Calibrate the primary laboratory measurement system at each test stand every 6 months using a hygrometer with a minimum dew point accuracy of ± 0.55 °C at 16 °C. Locate the sample tap on the air supply line to the engine, between the main duct and 1000 mm upstream of the intake air cleaner. The calibration consists of a series of paired humidity measurements comparing the laboratory system with the calibration hygrometer. The comparison period lasts from 20 min to 2 h with measurements taken at intervals of (1 to 6) min, for a total of 20 paired measurements. The measurement interval shall be appropriate for the time constant of the humidity measurement instruments.

10.3.4.2 Verify that the flow rate is within the equipment manufacturer's specification and that the sample lines are non-hygroscopic. Correct dew point hygrometer measurements to standard conditions (101.12 kPa) using the appropriate equation. Compute the difference between each pair of readings and calculate the mean and standard deviation of the twenty-paired readings. The absolute value of the mean difference shall not exceed 1.43 g/kg, and the standard deviation shall not be greater than 0.714 g/kg. If these conditions are not met, investigate the cause, make repairs, and recalibrate. Maintain calibration records for 2 years.

10.3.5 Keyence *Measurement Device* —Confirm the calibration of the Keyence measurement device with the reference standard before every use.

11. Procedure

11.1 When installing a new engine and cylinder head or both, conduct break-in and aging procedures, (see 11.8 and 11.9), before running official 200 h tests. After completing the break-in, install the official test valve-train parts as shown in the Sequence IVB Engine Assembly Manual. Then conduct the pre-test procedure shown in 11.3 and four fired oil-flushes as shown in section 11.3.1. After performing the four-fired oil-flushes, conduct the 200-h test as shown in section 11.3.2.

11.2 *Engine Start Procedure:* Whenever an engine is started this procedure should be followed.

11.2.1 Before starting the engine, check DyneSystems PAU status, and if necessary, perform reset procedure (See Fig. 1).

11.2.2 When starting the engine, set DyneSystems PAU throttle position to a set percent to achieve > 500 r/min (typical range is 5 – 15%). (See Fig. 1.)

11.2.3 When starting the engine, set DyneSystems PAU dynamometer excitation to 0%

11.2.4 Energize the starter motor for 7 s or until engine speed is greater than 500 r/min, whichever comes first. Then, turn off the starter motor. As soon as the engine speed is greater than 500 r/min proceed to target conditions.

Fig. 1 DyneSystems PAU

11.3 *Pre-test Procedure:*

11.3.1 *Pre-test stand cleaning*—Clean all pressure traps, the external oil system and the external blow-by system prior to starting all tests.

11.3.1.1 Remove, spray clean with degreasing solvent, (**Warning-**Combustible-Health hazard-see appropriate MSDS) and air dry the exhaust backpressure and crankcase pressure filters. Re-install the filters and inspect and replace the O-rings (Norgreen part 4380-700) as needed.

11.3.1.2 Disconnect the external oil supply and oil return lines from the remote oil filter housing adapter that is mounted on the engine (refer to Fig. 2).

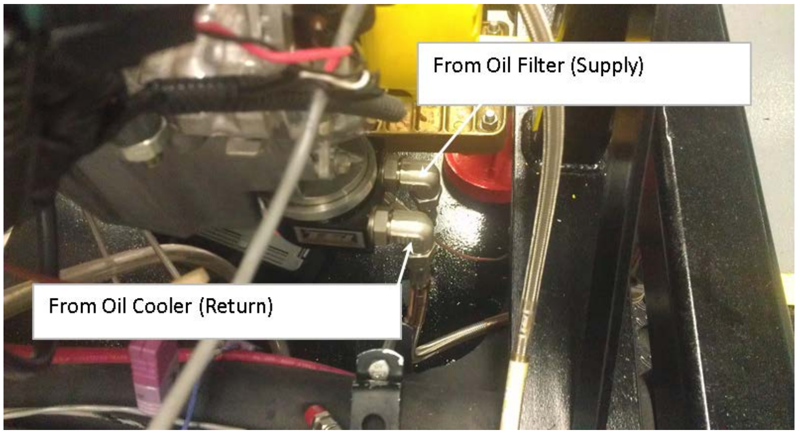


Fig. 2 Remote Oil Filter Housing Adapter

11.3.1.3 Connect the external oil supply and external oil return lines to a portable oil cleaning flush cart of minimum 1-gal capacity that is equipped with a circulation pump with a flow capacity of at least 3.8 L/m (1.0 gpm). Charge the flush cart with solvent and energize the flush cart pump. Allow the solvent to circulate for 5 min. De-energize flush cart, open both heat exchanger drain valves and allow the external oil system to drain. Close drain valves, re-charge the flush cart, re-energize the flush cart and allow solvent to recirculate for approximately 1 h.

11.3.1.4 After solvent has circulated for at least one hour, de-energize the flush cart pump and open both heat exchanger drain valves and allow the external oil system to drain.

11.3.1.5 Disconnect the external oil supply and external oil return lines from the flush cart and connect the external oil system to a clean and dry compressed air supply at 103 to 206 kPa (15 to 30 psi.). Allow the air to flow through the system for at least 15 minutes to dry the system.

11.3.1.6 Disconnect the supply and return lines from the compressed air source and connect the external oil supply and external return lines back to the remote oil filter housing adapter that is mounted on the engine. Close the heat exchanger drain valves.

11.3.1.7 Remove the Oberg oil filter element (B in Fig. 3) for cleaning. Clear any debris retained in the Oberg oil filter element with degreasing solvent (**Warning-**Combustible-Health hazard-see appropriate MSDS) and air dry. Re-install the Oberg oil filter element in the Oberg filter housing (see Fig. 3) and secure the four retaining bolts. Part number and supplier info is available in Appendix A-1.

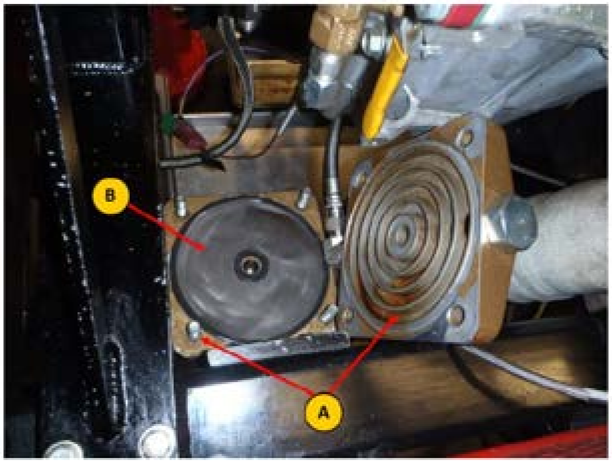


Fig. 3 Disassembled Oberg Filter Housing (A) with filter element (B)

11.3.1.8 Disconnect the oil pressure sense line between the engine and oil sample valve. Rinse this line using clean degreasing solvent (**Warning-**Combustible-Health hazard-see appropriate MSDS) and air dry.

11.3.1.9 Disconnect the oil pressure sense line between the oil sample valve and the oil pressure transducer. Rinse this line using clean degreasing solvent (**Warning-**Combustible-Health hazard-see appropriate MSDS) and air dry.

11.3.1.10 Open the oil sample valve and allow any trapped oil to drain. Then close the valve and reconnect both oil pressure and sample lines to their respective locations.

11.4. *Oil pan flush*—Flush the oil pan with EF-411 oil supplied by an external pump prior to all tests.

11.4.1 Pour 1 gallon of new EF-411 into a clean oil flush apparatus.

11.4.2 The apparatus must include a pump with at least 1 gpm of flow, an oil filter, and if pipe fittings are used, they must be black or stainless. A NAPA 1-8429 oil filter adapter, and unused Motorcraft FL 1A oil filter, and GP-201-12L pump are examples of suitable parts.

11.4.3 Connect the apparatus supply to the #8 AN fitting on the side of the modified Sequence IVB oil pan and the return to the rear oil pan drain plug.

11.4.4 Run the pump and circulate the EF-411through the oil pan for 10 min.

11.4.5 Turn off the pump, remove the apparatus, and allow the EF-411 to drain for 5 min.

11.4.6 Re-install a stainless-steel cap on the #8 fitting on the side of the oil pain and re-install the oil pan drain plug.

11.5 Blow-by system cleaning—Clean the blow-by heat exchanger, plumbing and oil separator before every test. Reference Annex A8 and Annex A12 for detailed instruction.

11.5.1 Remove the blow-by heat exchanger, plumbing and oil separator from the test stand and remove the insulation from the plumbing and oil separator

11.5.2 Disassemble the heat exchanger and oil separator for cleaning.

11.5.3 Spray clean the inside of separator and gas side of the heat exchanger with degreasing solvent (**Warning-**Combustible-Health hazard-see appropriate MSDS) and air dry.

11.5.4 Remove all the short Tygon hose sections between the valve cover and external blow-by system heat exchanger and replace as needed.

11.5.5 Spray clean the inside of all plumbing fittings and any Tygon hose sections that will be reused.

11.5.6 Insulate the oil separator and blow-by plumbing, and reinstall on the test stand, in accordance with the Oil Separator and Blow-by Plumbing Insulation Procedure, Annex A8.

11.5.7 Reconnect the external blow-by system and assembly components to the valve cover.

11.6 *Engine coolant fill procedure*—Charge the engine coolant, rocker cover coolant, and blow-by heat exchanger coolant tanks with coolant that conforms to section 7.1 prior to the start of all tests.

11.6.1 Fill the engine coolant system with approximately 26 L of coolant so that coolant is visible within 50 mm of the top of tank level indicator.

11.6.2 Fill the rocker cover coolant system with approximately 20 L of coolant so that coolant is visible within 50 mm of the top of tank level indicator.

11.6.3 Fill the blow-by coolant system so that coolant is visible within 50 mm of the top of tank level indicator.

11.6.4 Pressurize the coolant system to 70 kPa ± 10 kPa.

11.6.5 Minimize air bubbles in the engine, valve cover, and blow-by coolant systems.

11.7 *Dynamometer load cell calibration*—Calibrate the load cell in accordance with the specifications in Table 7 below. A Dyne Systems Traceable Weight Set DS-A266 is recommended.

TABLE 7 Dynamometer Load Cell Calibration Reference

Calibration Point	Reference Calibration Target Mass, kg	Resulting Reference Torque, N-m	Maximum Error
Zero	2.535	9.94	0.5%
Mid-rage	7.130	27.97	0.5%
Span	11.335	44.47	0.5%

11.7.1 Apply the calibration weights onto the dyno load arm that will result in the load cell being in tension. The calibration reference values used must be within ±0.2 kg of the values in Table 7.

11.7.2 Ensure that dynamometer load cell temperature has stabilized at 45 °C ± 1 °C before beginning calibration.

11.8 *Engine break-in procedure*—Conduct the break-in procedure and aging procedures prior to lubricant evaluation testing when installing a new engine block or new cylinder head assembly on a test stand. The break-in allows for monitoring test stand and engine performance. Use the engine block assembly for 6 tests and the head for 6 tests. Follow the break in conditions in Table 8. Use the following break-in steps:

11.8.1 Install break-in parts according to Assembly Manual Section 2. Install a stock unmodified Toyota intake camshaft, stock valve springs, and unmeasured bucket lifters for break-in.

11.8.2 Install the stock black plastic valve train cover (item D in Fig. 3 below) and stock crankcase ventilation setup.

11.8.3 Refer to Fig. 4, connect the PCV valve (A) in the valve cover to the intake manifold port (C) with the stock 19 mm ventilation hose (B).

11.8.4 Refer to Fig. 5, connect the valve cover port (A) to the intake air filter housing port (B) with a 15.8 mm diameter Tygon hose (C).

11.8.5 Refer to Fig. 6, connect the braided stainless-steel hose (B) from the crankcase pressure transducer to the quick disconnect (A) on the modified oil fill cap.

TABLE 8 Engine Break-in Schedule

Break-in Step #	**Duration, min**	**Engine Speed, r/min**	**Engine Load, N-m**	**Gallery Oil Temperature, °C**	**Coolant Out Temperature, °C**
1	10	800	6.3	50	50
2	10	1600	6.3	55	50
3	10	2000	25.0	60	55
4	10	2400	25.0	65	60
5	10	2400	46.9	70	65
6	15	2800	46.9	75	70
7	15	3200	46.9	80	75
8	15	3200	68.8	85	80

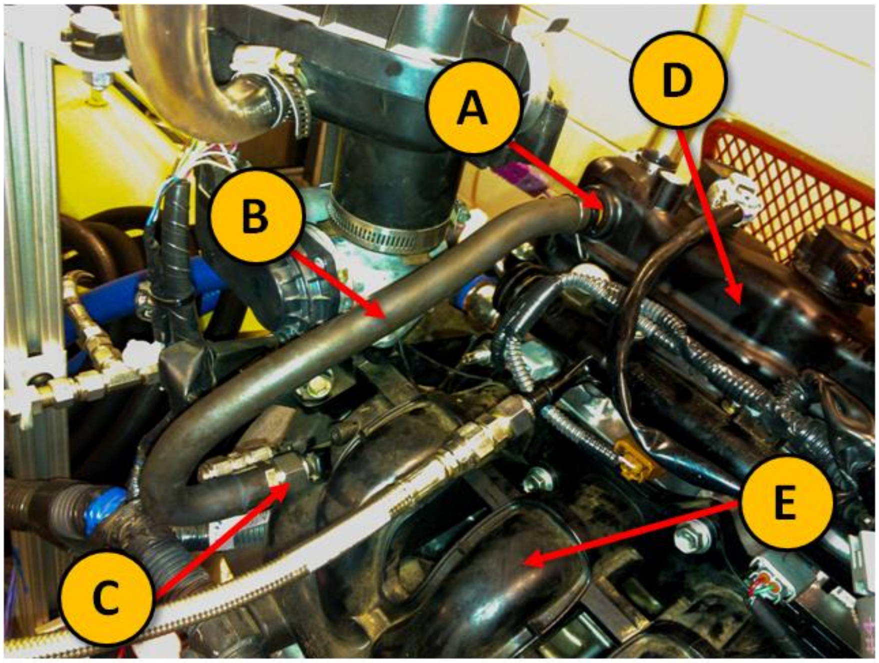


Fig. 4 Routing of crankcase gases. (A) stock PCV valve, (B) 19 mm diameter hose, (C) hose adapter to intake manifold, (D) stock valve train cover, (E) intake manifold. The 19 mm diameter hose is the OEM provided crankcase ventilation hose which is installed on new engines.

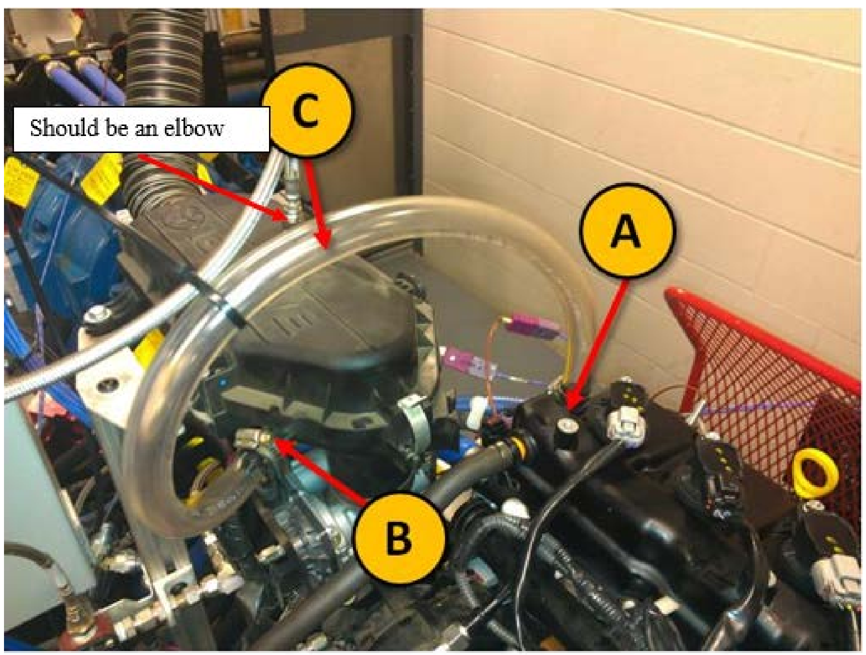


Fig. 5 Routing of fresh air. (A) Port to valve train cover, (B) port from intake air filter housing, (C) 15 mm diameter Tygon hose

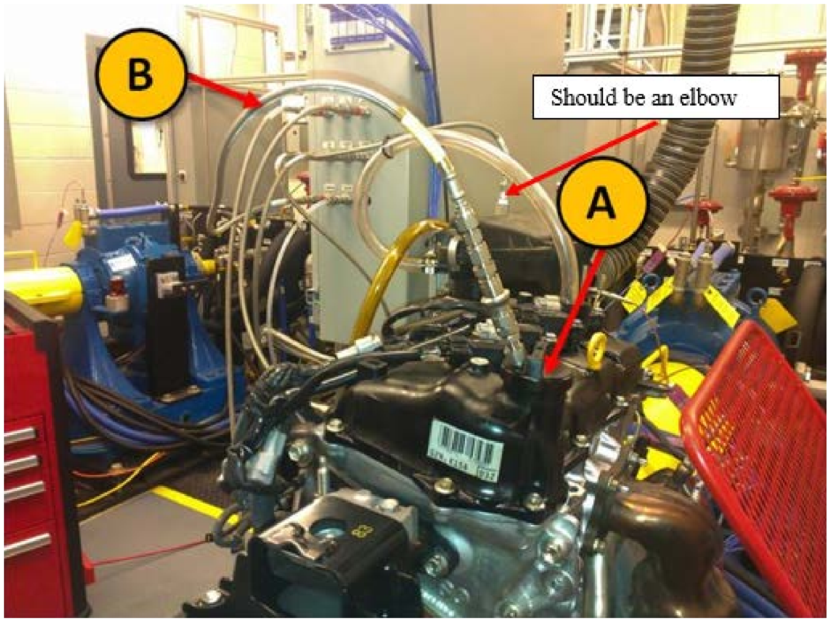


Fig. 6 Crankcase pressure measurement point. (A) Oil fill cap modified with 5 mm diameter quick disconnect, (B) 8 mm diameter steel-braided hose to pressure transducer

11.8.6 Perform all pre-test procedures, sections 11.8.1 to 11.8.5.

11.8.7 Fill the engine with 3000 mL of reference oil 1006-2 as break-in oil.

11.8.8 Start the engine and begin the break-in schedule provided in Table 8. Engine load and speed is ramped and stabilized within the first 45 s and 60 s respectively.

11.8.9 Control the parameters specified in Table 9 below to constant set-points over the entire course of the break-in, aging, and oil sampling.

TABLE 9 Break-in, Aging, and Oil Sampling Constant Set-points

Parameter	Set-point
Fuel rail temperature, °C	24 ± 3
Fuel rail pressure, kPa	335 ± 10
Coolant flow rate, L/min	80 ± 1
Coolant Pressure, kPa	70 ± 10
Exhaust backpressure, (absolute) kPa	103.5 ± 1.0
Intake air pressure, (gage) kPa	0.25 ± 0.1
Intake air temperature, °C	32 ± 2
Load cell temperature, °C	45 ± 2
Intake air humidity, g/kg	11.5 ± 0.5

11.8.10 Record the values of all the controlled parameters listed in Tables 8 and 9 during break-in steps 5 and 8.

11.8.11 Following the completion of engine break-in, establish the oil sampling conditions listed in Table 10. Engine load and speed is ramped and stabilized within the first 45 s and 60 s respectively.

TABLE 10 Break-in and Aging Oil Sampling Conditions

Engine Speed, r/min	Engine Load, Nm	Gallery Oil Temperature, °C	Coolant Out Temperature, °C
1000	10.0	80 Max	80 Max

11.8.12 Once the conditions have stabilized, take a 240 mL purge sample followed by a 3 mL to 10 mL oil sample and return the 240 mL purge sample to the oil fill cap. This step should be completed within 10 min of the oil sampling conditions being achieved. If that is not possible, the engine should be shutdown.

11.8.13 Turn off the engine and allow to rest for 10 min prior to checking the oil level with the OHT IVB dipstick (part # IVB022-3) that is located on the side of the oil pan. The scribe mark on the OHT dipstick should align with the mark on the dipstick tube when it is inserted. Ensure that no air is applied to the engine while checking the oil level.

11.9 *Engine aging procedure*— Engine oil aging ensures that the silicone sealant within the engine has been pacified. It should be done immediately following break-in using the same oil charge when a new engine or head is installed on a test stand.

11.9.1 Start the engine and run the aging conditions in Table 11 below and Table 8 for 5 h. Engine load and speed is ramped and stabilized within the first 45 s and 60 s respectively.

TABLE 11 Engine Aging Conditions

Engine Speed, r/min	Engine Load, Nm	Gallery Oil Temperature, °C	Coolant Out Temperature, °C
3000	50.0	80	80

11.9.2 After 5 h of aging have been completed, establish the oil sampling conditions listed in Table 9. Engine load and speed is ramped and stabilized within the first 45 s and 60 s respectively.

11.9.3 Once the conditions have stabilized, take a 240 mL purge sample followed by a 3 mL to 10 mL oil sample and return the 240 ml purge sample to the oil fill cap. This step should be completed within 10 min of the oil sampling conditions being achieved. If that is not possible, the engine should be shutdown.

11.9.4 Turn off the engine and allow to rest for 10 min prior to checking the oil level with the OHT IVB dipstick (part # IVB022-3) that is located on the side of the oil pan. The scribe mark on the OHT dipstick should align with the mark on the dipstick tube when it is inserted. Ensure that no air is applied to the engine while checking the oil level.

11.9.5 Conduct section 11.9.1-11.9.4 ten total times for a total of 50 h of aging.

11.9.6 Examine the results of the ASTM D5185 for high wear anomalies using Fe, Cu, and Al and to ensure the Si levels have plateaued. Also examine values of K as an indicator of coolant leaks. K values exceeding 15 ppm are suspicious and the engine should be evaluated for an internal coolant leak. If an internal coolant leak is confirmed, make repairs and repeat the run-in and aging procedure. An example of the plateau of Si during is given in Fig. 7 below.

11.9.7 Drain the oil charge after aging is completed.

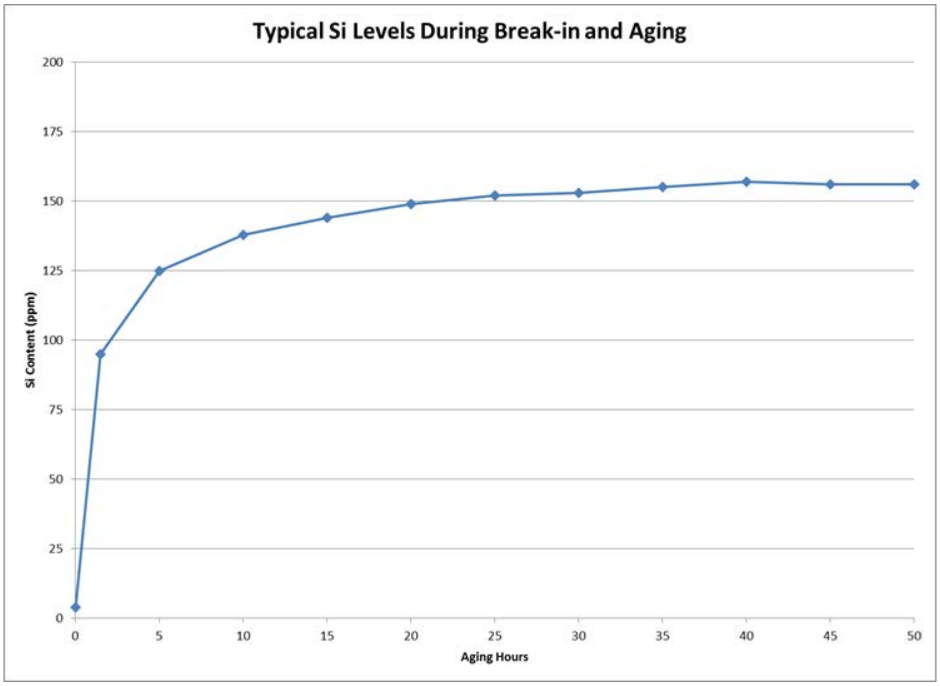


Fig. 7 Example of Si Plateau during break-in and aging

11.10 *Final break-in*—For new engines or heads, a 50-h final break-in step conducted over the test cycle is required following engine aging (section 11.9) and prior to any candidate or reference testing.

11.10.1 Using reference oil 1012 and the existing stock break-in parts, complete the flushing detailed in 11.12.1, except for taking oil samples during the flushes.

11.10.2 Conduct a 50-h test consisting of 6000 thirty second 4-stage cycles under the conditions specified by Table 4, Table 5, and Table 13.

11.10.3 Complete steps 11.10.1 to 11.10.4 to conduct a 50-h test at standard conditions. Obtain new and used oil samples (0 h; 25 h; 50 h), but only ASTM D5185 (ICP) analysis is required for final break-in.

11.10.4 After 50 h, which should be 6000 cycles, final break-in is complete.

11.11 *Engine silicone pacification*—Conduct the engine silicone pacification procedure when a used engine that has been reassembled is installed on a test stand. Removal and re-installation of an oil pan or front cover is considered reassembly.

11.11.1 Perform all pre-test procedures, sections 11.1.1 to 11.1.3.

11.11.2 Fill the engine with 3.0 L of reference oil 1006-2 as break-in oil.

11.11.3 Perform engine oil aging, see Section 11.9.

11.12 *Test Procedure:*

11.12.1 *Engine flushes*—Conduct four fired flushes with 3000 mL of test evaluation oil at the conditions listed in Table 12. Engine load and speed is ramped and stabilized within the first 60 s and 90 s respectively.

Table 12 Engine Oil Flush Operating Parameters

Parameter	**Setpoint**
Engine Speed	1500 r/min
Torque	10 N·m
Engine Coolant Out Temperature	50 °C
Engine Oil Gallery Temperature	50 °C
Exhaust Back Pressure (absolute)	103.5 kPa
Intake Air Pressure (gage)	0.25 kPa
Intake Air Temperature	32°C
Fuel Temperature	24°C
Rocker Cover Outlet Temperature	20°C
Coolant Flow Rate (Engine)	80 L/min
Coolant Flow Rate (Rocker Arm Cover)	120 L/min
Load Cell Temperature	45°C
Blow-by Gas Temperature	29°C
Coolant Temperature Heater	Heater OFF

11.12.2 Conduct the 1st engine flush by filling the engine with 3000 mL and operating at the Table 12 conditions for 6 min.

11.12.3 After the first flush, turn the engine off following the non-emergency shutdown procedure (11.15.1) and conduct a compression and leak-down test and record these values. Engine oil is required for the leak-down test

11.12.4 Drain the flush oil from the oil pain drain plug and the two-external oil system heat exchanger drain valves for 30 min. Retain an oil sample for analysis.

11.12.5 Conduct the 2nd flush by filling the engine with 3000 mL and operating at the Table 12 conditions for 38 min.

11.12.6 Drain the flush oil from the oil pain drain plug and the two-external oil system heat exchanger drain valves for 30 min. Retain an oil sample for analysis.

11.12.7 Repeat steps 11.12.3 and 11.12.4 for the 3rd and 4th flush.

11.13 *Test Operation*—Conduct a 200-h test consisting of 24000 thirty second 4-stage cycles under the conditions specified by Table 4, Table 5, and Table 13.

TABLE 13 Summary of Sequence IVB Test Operating Conditions

Parameter	Units	Ramp to Stage 1	Stage 1	Ramp to Stage 2	Stage 2
Duration	s	8	7	8	7
Engine Speed	r/min	4300 to 800	800	800 to 4300	4300
Engine Torque	N-m	25 ± 1.5	25 ± 1.5	25 ± 1.5	25 ± 1.5
Coolant Out Temperature	°C	52 ± 1.5	52 ± 1.5	52 ± 1.5	52 ± 1.5
Coolant Flow (Engine)	L/min	80 ± 0.4	80 ± 0.4	80 ± 0.4	80 ± 0.4
Coolant Flow (RAC)	L/min	120 ± 0.75	120 ± 0.75	120 ± 0.75	120 ± 0.75
Oil Gallery Temperature	°C	54 ± 5	54 ± 5	54 ± 5	54 ± 5
RAC Coolant Out Temperature	°C	20 ± 0.75	20 ± 0.75	20 ± 0.75	20 ± 0.75
Fuel Rail Temperature	°C	24 ± 0.5	24 ± 0.5	24 ± 0.5	24 ± 0.5
Load Cell Temperature	°C	45 ± 4	45 ± 4	45 ± 4	45 ± 4
Intake Air Temperature	°C	32 ± 0.75	32 ± 0.75	32 ± 0.75	32 ± 0.75
Blow-by Gas Temperature	°C	29 ± 0.5	29 ± 0.5	29 ± 0.5	29 ± 0.5
Intake Air Pressure	kPa	0.25 ± 0.25	0.25 ± 0.25	0.25 ± 0.25	0.25 ± 0.25
Intake Air Humidity	g/kg	11.5 ± 0.5	11.5 ± 0.5	11.5 ± 0.5	11.5 ± 0.5
Exhaust Pressure (Absolute)	kPa	-	-	-	104.5 ± 3
Engine Coolant Pressure	kPa	70 ± 10	70 ± 10	70 ± 10	70 ± 10
Fuel Rail Pressure	kPa	335 ± 10	335 ± 10	335 ± 10	335 ± 10
Air-to-Fuel Ratio (Not Controlled)	:1	Record	14.5 ± 0.5	Record	14.5 ± 0.5

11.13.1 Remove the 28 µm Oberg filter screen (part # OHT6A-013-2) from the Oberg housing (a component of the external oil system), clean with degreasing solvent, (**Warning**-Combustible-Health hazard-see appropriate MSDS), air dry and reinstall.

11.13.2 Weight out a 2600 g test oil charge and fill the engine.

11.13.3 Operate the engine at stage 1 idle conditions for 10 min then shutdown the engine and wait 10 min before measuring the oil level using the modified Sequence IVB dipstick inserted into the side of the oil pan. Engine load and speed is ramped and stabilized within the first 45 s and 60 s respectively.

11.13.4 Start the engine with stage 1 operating targets and run for at least 3 min and until reaching a coolant out temperature of at least 50°C and an oil gallery temperature of at least 50 °C. If these targets are still not achieved after 10 min, proceed to test. Engine load and speed is ramped and stabilized within the first 45 s and 60 s respectively when starting the engine.

11.14 Begin first cycle of test operations.

11.14.1 Intermediate oil samples are required at 25, 50, 75, 100, 125, 150, 175, and 200 test hours. 60 mL oil samples are taken at every 25-h interval.

11.14.2 The 0 h sample should be analyzed with methods D5185, D445, D664, D4739, D6304, and ASTM E168 (FTIR) using the fingerprint method to obtain oxidation and nitration.

11.14.3 All 60 mL oil samples should be analyzed with methods D5185, D445, D664, D4739, D3525, D6304, and

ASTM E168 (FTIR) using the fingerprint method to obtain oxidation and nitration.

11.14.4 At oil sampling intervals, test time is not accumulated, and the engine is operated at stage 1 conditions. Using the oil sampling port shown in Fig. 8, Remove a 240 mL purge sample into the return oil assembly device (part # OHTIVB-020-1) and then return it at the oil cap location using the same device shown in Fig. 9.

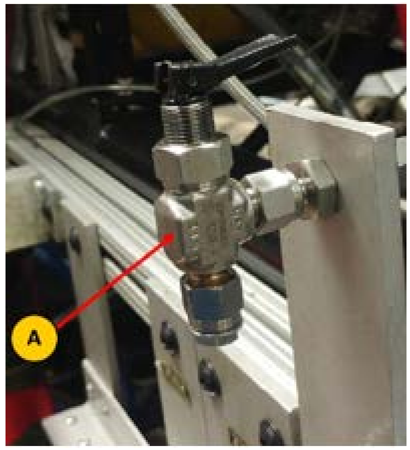
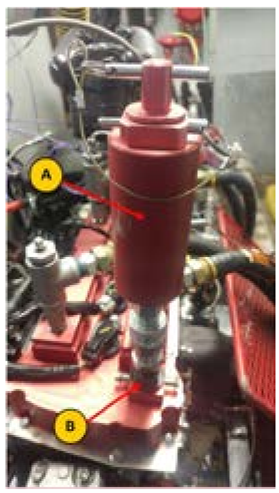


Fig. 8 Oil sampling port valve (A)



OHTIVB-020-1

Fig. 9 Oil purge return device (A) connected to the quick connect cap (B)

11.14.5 After the purge, take the volume of oil sample specified by the test hour and the instructions in step 11.2.3.4 and return the engine to test conditions. This step should be completed within 10 min of the oil sampling conditions being achieved. If that is not possible, the engine should be shutdown.

11.14.6 After 200 h, which should be approximately 24000 cycles, the test is concluded.

11.14.7 If the test parts are not removed within two hours of end of test, the “IVB extended shutdown oxidation protection procedure” shall be performed.

11.14.8 Prior to the start of the next test, engine health shall be assessed using the “Sequence IVB Engine Health Checklist” in Annex A10.

11.15 *Shutdowns and test resumes*—Shutdowns are permitted in both emergency and non-emergency situations. Non-emergency situations include any event where the shutdown is not immediate. The “IVB Extended Shutdown Oxidation Protection Procedure” in Annex A11 shall be performed for any shutdown lasting more than two hours.

NOTE 10—Test time is not accumulated during non-emergency shutdowns or any resume steps. Shutdowns and resumes are permitted during break-in, aging, silicone pacification, or test operation.

11.15.1 *Non-emergency engine shutdown procedure*—The following shutdown sequence should be conducted in a non-emergency shutdown:

1. Reduce speed and load to stage 1 conditions. Engine load and speed is ramped and stabilized within the first 45 s and 60 s respectively. Operate at stage 1 conditions for a maximum of 10 min.

2. Power off the electric fuel pump, and allow the engine to run for 5 s. Then, power off the ignition circuit to stop the engine.
3. Manually open the starter disconnect switch (off position). Turn on the manual emergency stop switch.
4. If a shutdown occurred during engine oil system flush mode or test mode, you may allow the engine coolant and rocker arm cover coolant pumps to remain on with the engine coolant flow and rocker arm cover coolant flow control valves fully open. Allow the engine coolant heater to control engine coolant out temperature to 52 °C and the rocker arm cover heat exchanger to control rocker arm cover coolant out temperature to 20 °C.
5. In the event of a shutdown lasting more than 30 min, it is permissible to turn off the engine coolant heater, the engine coolant pump and the rocker arm cover coolant pump in order to conserve power and place the test stand in a non-operative mode. The test laboratory may elect to turn off the load cell heater, as well.

11.15.2 If desired, a diagnostic oil level may be taken following an engine shutdown. Take oil levels after the engine has been off for 10 min.

11.15.3 Following any non-end-of-test shutdown, restart the engine with stage 1 operating targets and run for at least 3 min and until reaching a coolant out temperature of at least 50°C and an oil gallery temperature of at least 50 °C. If these targets are still not achieved after 10 min, proceed to test. Engine load and speed is ramped and stabilized within the first 45 s and 60 s respectively when starting the engine.

11.15.4 If a test shutdown's due to cam lobe failure(s), that test cannot be resumed and is deemed non-interpretable.

11.15.5 Any engines that experience lobe failure must be removed from service for full inspection of bearing and cylinder liner surfaces. A full rebuild with new main and rod bearings must be conducted in accordance with the IVB Engine Assembly Manual Section 4 before an engine can be returned to service.

11.15.6 Any test stand where a lobe failure occurred must complete the "Stand Maintenance after a Camshaft Lobe Failure" procedure in Annex A12 prior to the next test.

11.16 *Post-test procedures*

11.16.1 Optional *oil level procedure*— After 200 h of test operation and extraction of the final oil sample, allow the engine to run at stage 1 conditions for 10 min before shutting down. Let the engine soak for 10 min after shutdown and then measure the end-of-test oil level using the OHT IVB dipstick (see Fig. 10) inserted into the side of the oil pan.

Fig. 10

11.16.2 Check the engine's compression and leak-down.

11.16.3 *Oil consumption*— Drain the test oil from the oil pain drain plug and the two-external oil system heat exchanger drain valves for 30 min.

11.16.3.1 Weigh the drained test oil and calculate the oil consumption for the test by finding the difference between the initial charge and final drain and then subtracting the mass of the intermediate oil samples from that value. The initial 2600 g oil charge is equivalent to 3000 ml and that mass to volume ratio is used to calculate the mass of the intermediate 60 ml oil samples. Therefore, the final oil consumption would be calculated by the formula:

oil consumption = (2600 g – final oil drain mass) – (8 samples x mL/per sample x 2600 g / 3000 mL)

11.16.4 *Fuel consumption*— Document how much fuel was consumed over the course of the test.

Fuel Consumption = Fuel Consumed at End of Test – Fuel Consumed at Start of Test

11.16.5 *Post-test wear measurements:*

11.16.5.1 All volume loss measurements are to be conducted with a Keyence 3D macroscope in accordance with the IVB Keyence VR-3200 Procedure, Annex A6.

12. Determination of Results

12.1 *General*—This section describes techniques used to evaluate oil performance with respect to camshaft and lifter wear, and used oil iron content (as measured by Inductively Coupled Plasma Atomic Emission Spectrometry).

12.2 *Camshaft Lobe Wear*—Measure using the methods as described in Annex A5.

12.3 *Lifter Mass Loss*—Measure using the methods as described in Annex A5.

12.4 *Lifter Volume Loss*—Measure using the methods as described in Annex A6.

12.5 *Oil Analysis*—The results from the used oil analysis are recorded on the appropriate report form.

12.5.1 *Oil Sampling*—Take a 60 mL oil sample of the new oil, used oil at 25 h, used oil at 50 h, and used oil at 75 h, used oil at 100 h, used oil at 125 h, used oil at 150 h, used oil at 175 h and used oil at 200 h. Remove used oil samples during the oil sampling intervals, when test time is not accumulated, and the engine is operated at stage 1 conditions.

12.5.2 *Wear Metals*—Measure the new and used oil samples (0 h; 25 h; 50 h; 75 h; 100 h; 125 h; 150 h; 175 h; 200 h) for wear metal concentration (mg/kg), using Test Method D5185. Report aluminum, calcium, chromium, copper, iron, potassium, magnesium, nickel, sodium, lead, silicon and tin concentrations.

12.5.3 *Fuel Dilution*—Measure the used oil samples (25 h; 50 h; 75 h; 100 h; 125 h; 150 h; 175 h; 200 h) for mass percent fuel dilution by gas chromatography, using Test Method D3525. Fuel dilution typically ranges from (6.0 to 12.0 %).

12.5.4 *Kinematic Viscosity*— Measure the new and used oil samples (0 h; 25 h; 50 h; 75 h; 100 h; 125 h; 150 h; 175 h; 200 h) for kinematic viscosity at 40 °C (cSt), using Test Method D445.

12.5.5 *Total Acid Number (TAN)*—Measure the new and used oil samples (0 h; 25 h; 50 h; 75 h; 100 h; 125 h; 150 h; 175 h; 200 h) for total acid number (gkOH/g), using Test Method D664.

12.5.6 *Total Base Number (TBN)*—Measure the new and used oil samples (0 h; 25 h; 50 h; 75 h; 100 h; 125 h; 150 h; 175 h; 200 h) for total base number (gkOH/g), using Test Method D4739.

12.5.7 *Oxidation and Nitration*—Use Fourier Transform Infrared (FTIR) to measure oxidation using integrated IR techniques based on Practice E168, using the IIIG method as described in Annex A13. Carry out quantitative infrared analysis on the used oil samples (25 h; 50 h; 75 h; 100 h; 125 h; 150 h; 175 h; 200 h).

12.5.8 *Water Content*—Measure the used oil samples (25 h; 50 h; 75 h; 100 h; 125 h; 150 h; 175 h; 200 h) for water content by Karl Fischer (mg/kg), using Test Method D6304.

12.5.9 *Assessment of Interpretability*—A test is non-interpretable when a lobe failure(s) is identified.

13. Report

13.1 For reference oil results, use the standardized report form set available from the ASTM TMC[3] and data dictionary for reporting test results and for summarizing operational data.

NOTE 11—Report the non-reference oil test results on these same forms if the results are intended to be submitted as candidate oil results against a specification.

13.1.1 Fill out the report forms according to the formats shown in the data dictionary.

13.1.2 Transmit results to the TMC within five working days of test completion.

NOTE 12—Transmit the results electronically as described in the ASTM Data Communications Committee Test Report Transmission Model (Section 2—Flat File Transmission Format) available from the ASTM TMC. Upload files via the TMC's website.

13.2 Report all reference oil test results, whether aborted, invalidated, or successfully completed, to the TMC.

13.3 *Deviations from Test Operational Limits*—Report all deviations from specified test operational limits.

13.4 *Precision of Reported Units*—Use Practice E29 for rounding off critical pass/fail test result data; use the rounding-off method. Report the data to the same precision as indicated in the data dictionary.

13.5 In the space provided, note the time, date, test hour, and duration of any shutdown or off-test condition. Document the outcome of all prior reference oil tests from the current calibration sequence that were operationally or statistically invalid.

13.6 If a calibration period is extended beyond the normal calibration period length, make a note in the comment section and attach a written confirmation of the granted extension from the TMC to the test report. List the outcomes of previous runs that may need to be considered as part of the extension in the comment section.

14. Precision and Bias

14.1 *Precision:*

14.1.1 Test precision is established on the basis of operationally valid reference-oil test results monitored by the TMC.

14.1.2 *Intermediate Precision 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.

NOTE 13—Intermediate precision is the appropriate term for this test method, rather than repeatability, which defines more rigorous within-laboratory conditions.

14.1.2.1 *Intermediate Precision Limit (ip)*—The difference between two results obtained under intermediate precision conditions that in the long run, in the normal and correct conduct of the test method, exceed the value shown in Table 14 in only one case in twenty. When only a single test result is available, the intermediate precision limit can be used to calculate a range (test result ± intermediate precision limit) outside of which a second test result would be expected to fall about one time 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 Limit (R)*—The difference between two 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 14 in only one case in twenty. When only a single test result is available, the reproducibility limit can be used to calculate a range (test result ± reproducibility limit) outside of which a second test result would be expected to fall about one time in twenty.

TABLE 14 Test Precision for Sequence IVB[A]

Quantity, units	Intermediate Precision[B]		Reproducibility[C]	
	S_{ip}[D]	*ip*	S_R[D]	*R*
Average Intake Lifter Volume Loss[E]	0.1680	0.4657	0.2003	0.5552
End of Test Fe[F], mg/kg	0.2869	0.7953	0.3688	1.0222

[A] Average Intake Lifter Volume loss statistics are based on 28 tests conducted on 7 stands at 5 laboratories on ASTM TMC Reference Oils 300, 1011, and 1012, and were calculated on January 22, 2018. End of Test Iron statistics are based on 44 tests conducted on 9 stands at 5 laboratories on ASTM TMC Reference Oils 300, 1011, and 1012,

and were calculated on October 18, 2018.
[B] See 14.1.2.
[C] See 14.1.3.
[D] S is the estimated standard deviation.
[E] This parameter is transformed using Square root(result). When comparing two test results on this parameter, first apply this transformation to each test result. Compare the absolute difference between the transformed results with the appropriate (intermediate precision or reproducibility) precision limit.
[F]. This parameter is transformed using ln(result). When comparing two test results on this parameter, first apply this transformation to each test result. Compare the absolute difference between the transformed results with the appropriate (intermediate precision or reproducibility) precision limit.

14.1.4 The test precision for the Sequence IVB is shown in Table 14. The TMC updates precision data frequently; contact the TMC for this information.

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 (refer to the TMC for details).

ANNEXES
(Mandatory Information)

A.1 ASTM TEST MONITORING CENTER ORGANIZATION

A1.1 *Nature and Functions of the ASTM Test Monitoring Center (TMC)*—The TMC is a non-profit organization located in Pittsburgh, Pennsylvania and is staffed to: administer engineering studies; conduct laboratory inspections; perform statistical analyses of reference oil test data; blend, store, and ship reference oils; and provide the associated administrative functions to maintain the referencing calibration program for various lubricant tests as directed by TMC Subcommittee D02.B0 and the ASTM Executive Committee. The TMC coordinates its activities with the test sponsors, the test developers, the surveillance panels, and the testing laboratories. Contact TMC through the TMC Director at:
ASTM Test Monitoring Center
6555 Penn Avenue
Pittsburgh, PA 15206-4489
www.astmtmc.cmu.edu

A1.2 *Rules of Operation of the ASTM TMC*—The TMC operates in accordance with the
ASTM Charter, the ASTM Bylaws, the Regulations Governing ASTM Technical Committees, the Bylaws Governing ASTM Committee D02, and the Rules and Regulations Governing the ASTM Test Monitoring System.

A1.3 *Management of the ASTM TMC*—The management of the Test Monitoring System is vested in the Executive Committee elected by Subcommittee D02.B0. The Executive Committee selects the TMC Director who is responsible for directing the activities of the TMC.

A1.4 *Operating Income of the ASTM TMC*—The TMC operating income is obtained from fees levied on the reference oils supplied and on the calibration tests conducted. Fee schedules are established by the Executive Committee and reviewed by Subcommittee D02.B0.

A2. ASTM TEST MONITORING CENTER: CALIBRATION PROCEDURES

A2.1 *Reference Oils*—These oils are formulated or selected to represent specific chemical, or performance levels, or both. They are usually supplied directly to a testing laboratory under code numbers to ensure that the laboratory is not influenced by prior knowledge of acceptable results in assessing test results. The TMC determines the specific reference oil the laboratory shall test.

A2.1.1 *Reference Oil Data Reporting* – Test laboratories that receive reference oils for stand calibration shall submit data to the TMC on every sample of reference oil they receive. If a shipment contains any missing or damaged samples, the laboratory shall notify the TMC immediately.

A2.2 *Calibration Testing:*

A2.2.1 Full-scale calibration testing shall be conducted at regular intervals. These full-scale tests are conducted using coded reference oils supplied by the TMC. It is a laboratory's responsibility to keep the on-site reference oil inventory at or above the minimum level specified by the TMC test engineers.

A2.2.2 *Test Stands Used for Non-Standard Tests*—If a non-standard test is conducted on a previously calibrated test stand, the laboratory shall conduct a reference oil test on that stand to demonstrate that it continues to be calibrated, prior to running standard tests.

A2.3 *Reference Oil Storage*—Store reference oils under cover in locations where the ambient temperature is between -10 °C and +50 °C.

A2.4 *Analysis of Reference Oil*—Unless specifically authorized by the TMC, do not analyze TMC reference oils, either physically or chemically. Do not resell ASTM reference oils or supply them to other laboratories without the approval of the TMC. The reference oils are supplied only for the intended purpose of obtaining calibration under the ASTM Test Monitoring System. Any unauthorized use is strictly forbidden. The testing laboratory tacitly agrees to use the TMC reference oils exclusively in accordance with the TMC's published Policies for Use and Analysis of ASTM Reference Oils, and to run and report the reference oil test results according to TMC guidelines. Additional policies for the use and analysis of ASTM Reference Oils are available from the TMC.

A2.5 *Conducting a Reference Oil Test*—When laboratory personnel are ready to run a reference calibration test, they shall request an oil code via the TMC website.

A2.6 *Reporting Reference Oil Test Results*—Upon completion of the reference oil test, the test laboratory transmits the data electronically to the TMC, as described in Section 13. The TMC reviews the data and contacts the laboratory engineer to report the laboratory's calibration status. All reference oil test results, whether aborted, invalidated, or successfully completed, shall be reported to the TMC.

A2.6.1 All deviations from the specified test method shall be reported.

A3. ASTM TEST MONITORING CENTER: MAINTENANCE ACTIVITIES

A3.1 *Special Reference Oil Tests*—To ensure continuous severity and precision monitoring, calibration tests are conducted periodically throughout the year. Occasionally, the majority or even all the industry's test stands will conduct calibration tests at roughly the same time. This could result in an unacceptably large time frame when very few calibration tests are conducted.

The TMC can shorten or extend calibration periods as needed to provide a consistent flow of reference oil test data. Adjustments to calibration periods are made such that laboratories incur no net loss or gain in calibration status.

A3.2 *Special Use of the Reference Oil Calibration System*—The surveillance panel has the option to use the reference oil system to evaluate changes that have potential impact on test severity and precision. This option is only taken when a program of donated tests is not feasible. The surveillance panel and the TMC shall develop a detailed plan for the test program. This plan requires all reference oil tests in the program to be completed as close to the same time as possible, so that no laboratory/stand calibration status is left pending for an excessive length of time. To maintain the integrity of the reference oil monitoring system, each reference oil test is conducted to be interpretable for stand calibration. To facilitate the required test scheduling, the surveillance panel may direct the TMC to lengthen and shorten reference oil calibration periods within laboratories such that the laboratories incur no net loss or gain in calibration status. To ensure accurate stand, or laboratory, or both severity assessments, conduct non-reference oil tests the same as reference oil tests.

A3.3 *Donated Reference Oil Test Programs*—The surveillance panel is charged with maintaining effective reference oil test severity and precision monitoring. During times of new parts introductions, new or re-blended reference oil additions, and procedural revisions, it may be necessary to evaluate the possible effects on severity and precision levels. The surveillance panel may choose to conduct a program of donated reference oil tests in those laboratories participating in the monitoring system, to quantify the effect of a particular change on severity and precision. Typically, the surveillance panel requests its panel members to volunteer enough reference oil test results to create a robust data set. Broad laboratory participation is needed to provide a representative sampling of the industry. To ensure the quality of the data obtained, donated tests are conducted on calibrated test stands. The surveillance panel shall arrange an appropriate number of donated tests and ensure completion of the test program in a timely manner.

A3.4 *Intervals Between Reference Oil Tests*—Under special circumstances, such as extended downtime caused by industry-wide parts or fuel shortages, the TMC may extend the intervals between reference oil tests.

A3.5 *Introducing New Reference Oils*—Reference oils produce various results. When new reference oils are selected, participating laboratories will be requested to conduct their share of tests to enable the TMC to recommend industry test targets. ASTM surveillance panels require a minimum number of tests to establish the industry test targets for new reference oils.

A3.6 *TMC Information Letters*—Occasionally it is necessary to revise the test method and notify the test laboratories of the change, prior to consideration of the revision by Subcommittee D02.B0. In such a case, the TMC issues an Information Letter. Information Letters are balloted semi-annually by Subcommittee D02.B0, and subsequently by D02. By this means, the Society due process procedures are applied to these Information Letters.
A3.6.1 *Issuing Authority*—The authority to issue an Information Letter differs according to its nature. In the case of an Information Letter concerning a part number change which does not affect test results, the TMC is authorized to issue such a letter. Long-term studies by the surveillance panel to improve the test procedure through improved operation and hardware control may result in the issuance of an Information Letter. If obvious procedural items affecting test results need immediate attention, the test sponsor and the TMC issue an Information Letter and present the background and data supporting that action to the surveillance panel for approval prior to the semiannual Subcommittee D02.B0 meeting.

A3.7 *TMC Memoranda*—In addition to the Information Letters, supplementary memoranda are issued. These are developed by the TMC and distributed to the appropriate surveillance panel and participating laboratories. They convey such information as batch approvals for test parts or materials, clarification of the test procedure, notes and suggestions of the collection and analysis of special data that the TMC may request, or for any other pertinent matters having no direct effect on the test performance, results, or precision and bias.

A4. ASTM TEST MONITORING CENTER: RELATED INFORMATION
A4.1 *New Laboratories*—Laboratories wishing to become part of the ASTM Test Monitoring System will be requested to conduct reference oil tests to ensure that the laboratory is using the proper testing techniques. Information concerning fees, laboratory inspection, reagents, testing practices, appropriate committee membership, and rater training can be obtained by contacting the TMC Director.
A4.2 *Information Letters: COTCO Approval*—Authority for the issuance of Information Letters was given by the committee on Technical Committee Operations in 1984, as follows: “COTCO recognizes that D02 has a unique and complex situation. The use of Information Letters is approved providing each letter contains a disclaimer to the affect that such has not obtained ASTM consensus. These Information Letters should be moved to such consensus as rapidly as possible.”
A4.3 *Precision Data*—The TMC determines the precision of test methods by analyzing results of calibration tests conducted on reference oils. Precision data are updated regularly. Current precision data can be obtained from the TMC.

ANNEX A5

Camshaft and Lifter Measurements

A5.1 Preparing Pre-Test Lifters for Measurement:

A5.1.1 Record the following information for each lifter:

A5.1.1.1 Unique ID number engraved on the inside

A5.1.1.2 Lifter grade

A5.1.1.3 Position in the engine (including intake or exhaust side)

A5.1.2 This information needs to be properly documented and updated as needed throughout the course of the test.

A5.1.2.1 An example of this documentation is shown in Table A5.1.

Table A5.1 - Example of Lifter Identification Documentation

Intake Side								
Position	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
ID No.								
Grade								
Exhaust Side								
Position	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
ID No.								
Grade								

A5.1.3 Clean the lifters using pentane or heptane and allow the solvent to evaporate before taking any measurements.

A5.2 Measure the Pre-Test Lifter Weights:

A5.2.1 Use a calibrated scale to measure and record the weight of the lifters.

A5.2.2 These weights are to be reported to four decimal places in units of grams.

A5.2.3 A laboratory grade analytical balance, sourced from a supplier such as Mettler – Toledo, with a maximum capacity greater than 30 g, readability of 0.1 mg or better and repeatability of 0.1 mg or better, is required for these measurements.

A5.3 Preparing Post-Test Lifters for Measurement:

A5.3.1 Clean the lifters using pentane or heptane and allow the solvent to evaporate before taking any measurements.

A5.4 Measuring the Post-Test Lifter Weights:

A5.4.1 Use a calibrated scale to measure and record the weight of the lifters.

A5.4.2 These weights are to be reported to four decimal places in units of grams.

A5.4.3 A laboratory grade analytical balance, sourced from a supplier such as Mettler – Toledo, with a maximum capacity greater than 30 g, readability of 0.1 mg or better and repeatability of 0.1 mg or better, is required for these measurements.

A5.5 Preparing Pre-Test Camshafts for Measurement:

A5.5.1 Spray the camshafts with degreasing agent.

A5.5.1.1 Use a non-metallic/non-abrasive brush to thoroughly scrub the lobe surfaces.

A5.5.1.2 Dry the camshaft with compressed air.

A5.5.2 Visually inspect each camshaft lobe for defects or damage.

A5.5.2.1 Examples of such defects or damage are shown in Fig. A5.1.

A5.5.2.2 Reject any camshafts that have these abnormalities.

A5.5.3 Record the unique identification number for both the intake and exhaust camshafts.

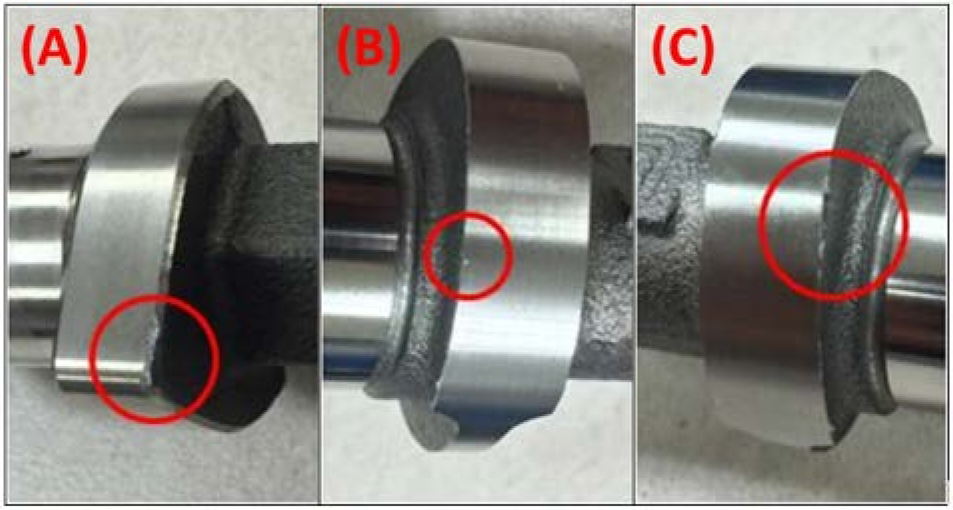


Fig. A5.1 - (A) Grinding Damage, (B) Pitting and (C) Shipping Damage

A5.6 Pre-Test Camshaft Diameter Measurements:

A5.6.1 Use a pin gage set to measure and record the diameter of all five oil feed holes on the journals of both the intake and exhaust camshafts (Fig. A5.2).

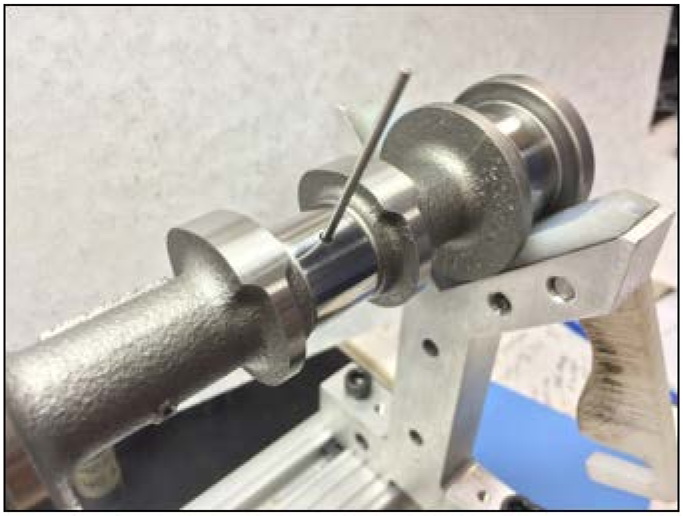


Fig. A5.2 - Measuring Oil Feed Hole Diameters Using a Pin Gage

A5.6.2 Place the camshaft on a V-Block fixture.

A5.6.2.1 The V-Blocks should be spaced so that each camshaft is supported on its 2nd and 5th journals.

A5.6.3 Place an indicator next to the camshaft so that the spindle head is in contact with Journal #3 and is orthogonal to the axis of the camshaft (Fig. A5.3).

A5.6.3.1 Rotate the camshaft until the indicator reads a minimum value.

A5.6.3.2 Zero the indicator.

A5.6.3.3 Rotate the camshaft again until the indicator reads a maximum value.

A5.6.3.4 Record this indicator measurement as the run-out of Journal #3.

A5.6.3.5 Repeat these steps to obtain the run-out measurement for Journal #4.

A5.6.3.6 Average the run-out measurements of Journal #3 and Journal #4 to calculate the overall run-out of the camshaft.

A5.6.3.7 Repeat these steps for the second camshaft.

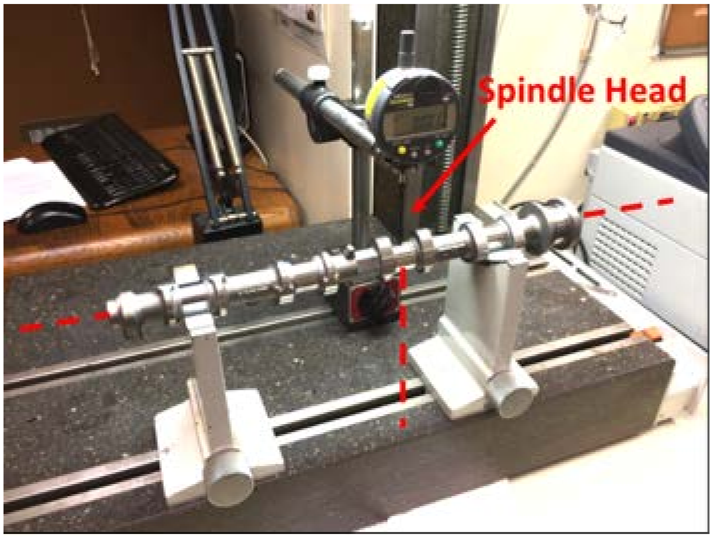


Fig. A5.3 - Correct Positioning of Indicator for Journal Run-Out Measurements

A5.6.4 Reject any camshaft that has a run-out value that exceeds 0.04 mm (0.00157-in.).

A5.6.5 Measure the diameter of Journal #1 with a (1 to 2) in. digital micrometer.

A5.6.5.1 A Mitutoyo Model #293-722-10 digital micrometer, or equivalent, is recommended for these measurements.

A5.6.5.2 Measure the diameter of the journal along both its x-axis and y-axis (Fig. A5.14).

A5.6.5.3 **NOTE:** The x-axis passes through the center of the oil feed hole and intersects the center of the journal.

A5.6.5.4 **NOTE:** The y-axis is orthogonal to the x-axis.

A5.6.5.5 Record the average of the x-axis and y-axis diameter measurements for Journal #1.

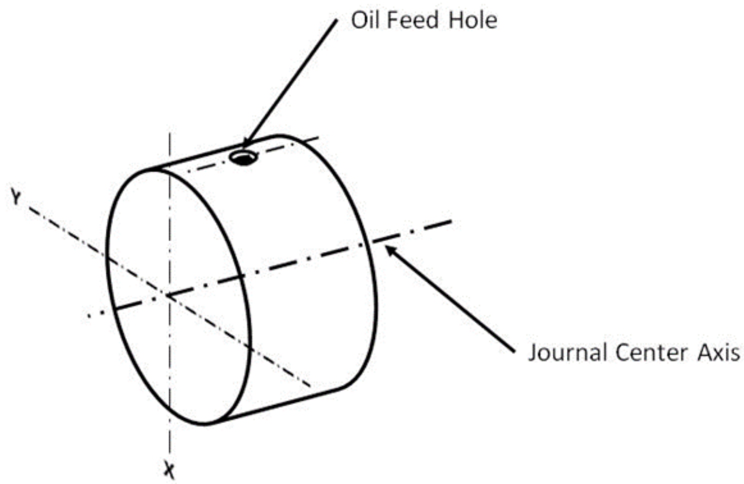


Fig. A5.4 - X and Y-Axis of Camshaft Journal

A5.6.6 Use a 0 to 1 in. digital micrometer to measure the diameter of Journal #2 through Journal #5.

A5.6.6.1 A Mitutoyo Model #293-721-10 digital micrometer, or equivalent, is recommended for these measurements.

A5.6.7 Reject any camshafts with journal diameters that exceed the following specifications in Table A5. 2:

Table A5.2 - Camshaft Journal Diameter Specifications

Item	Specified Condition
Journal #1	33.949 – 33.968 mm (1.3366 – 1.3372 in.)
Journal #2 - #5	22.949 – 22.965 mm (0.9035 – 0.9041 in.)

A5.7 Pre-Test Camshaft Lobe Heel-to-Toe Height:

A5.7.1 Place the camshaft on a V-Block fixture.

A5.7.1.1 The V-Blocks should be spaced so that each camshaft is supported on its 2nd and 5th journals.

A5.7.2 Calibrate a 1 to 2 in. snap gage using a cylindrical measurement standard.

A5.7.2.1 A Mitutoyo Model #201-152 snap gauge with a Mitutoyo Model #ID-C112AEB digital indicator attachment, or equivalent, is recommended for these measurements.

A5.7.2.2 The cylindrical measurement standard used for intake camshaft lobe heel-to-toe measurements has a diameter of 36.725 mm.

A5.7.2.3 The cylindrical measurement standard used for exhaust camshaft lobe heel-to-toe measurements has a diameter of 39.500 mm.

A5.7.3 Set the base circle of the camshaft lobe on the anvil of the snap gage and engage the spindle (Fig. A5.5).

A5.7.3.1 While keeping the snap gage centered on the lobe, slowly rotate the snap gage around the lobe until the digital indicator reads a maximum value.

A5.7.3.2 Record this measurement as the heel-to-toe height for the specific camshaft lobe.

A5.7.3.3 Repeat this measurement for the eight camshaft lobes on both the intake and exhaust camshafts.

Fig. A5.5 - Positioning the Snap Gage to Measure the Camshaft Heel-to-Toe Height

A5.7.4 Reject any exhaust camshafts that have heel-to-toe heights that exceed the following specifications in Table A5.3:

A5.7.4.1 **NOTE:** There are currently no heel-to-toe height specifications for the intake camshafts.

Table A5.3 – Exhaust Camshaft Heel-to-Toe Height Specifications

Exhaust Cam Limits	Specified Condition
Standard Lobe Height	39.462 – 39.562 mm (1.554 – 1.558 in.)
Minimum Lobe Height	39.362 mm (1.550 in.)

A5.8 Pre-Test Camshaft Lobe Surface Profile Traces:

A5.8.1 Profile traces are to be performed using a Precision Devices, Inc. (PDI) MicroAnalyzer 2000 profilometer that is using the Windows XP Version 3.6.15 operational software.

A5.8.2 Confirm that the TOYOTA_CAM.NDT template file is being used.

A5.8.3 Confirm the following settings on the *Delimitation* tab:

A5.8.3.1 The Find checkbox is selected and the filter width is set to 0.400 mm under the *Left Edge* field.

A5.8.3.2 The Find checkbox is selected and the filter width is set to 0.400 mm under the *Right Edge* field.

A5.8.3.3 The Fix Truncation to Part Edges checkbox is selected.

A5.8.3.4 The ASME B46.1-2002 standard is being used.

A5.8.4 Confirm the following settings on the Primary Extraction tab:

A5.8.4.1 The Two-Point Line radial button is selected under the Form Removal field.

A5.8.4.2 The filter cutoff is set to 0.00 µm under the Shortwave Cutoff field.

A5.8.5 Confirm the following settings on the Waviness Extraction tab:

A5.8.5.1 The Gaussian radial button is selected under the Waviness Short Cutoff field.

A5.8.5.2 The filter cutoff is set to 0.800 mm under the Waviness Short Cutoff field.

A5.8.6 Confirm the following settings on the Roughness Extraction tab:

A5.8.6.1 The Gaussian radial button is selected under the Roughness Cutoff field.

A5.8.6.2 The filter cutoff is set to 0.800 mm under the Roughness Cutoff field.

A5.8.7 Place the camshaft on a V-Block fixture.

A5.8.7.1 The V-Blocks should be spaced so that each camshaft is supported on its 2nd and 5th journals.

A5.8.8 Move the stylus until it is over the camshaft lobe that is to be measured.

A5.8.8.1 Rotate the camshaft until the nose of the lobe is pointed toward the stylus.

A5.8.8.2 Lower the stylus onto the surface of the camshaft lobe.

A5.8.8.3 Slowly rotate the camshaft until the stylus reaches the point of highest displacement.

A5.8.9 Obtain a trace that spans the width of the camshaft lobe.

A5.8.9.1 Report the roughness average (Ra), skew (Rsk) and waviness (Wt).

A5.8.9.2 Save the pre-test traces using the appropriate file naming convention.

A5.8.9.3 Repeat the measurements for all eight camshaft lobes for both the intake and exhaust camshafts.

A5.9 Preparing Post-Test Camshafts for Measurement:

A5.9.1 Spray the camshafts with Stoddard solvent.

A5.9.1.1 Use a non-metallic/non-abrasive brush to thoroughly scrub the lobe surfaces.

A5.9.1.2 Dry the camshaft with compressed air.

A5.10 Post-Test Camshaft Lobe Heel-to-Toe Height:

A5.10.1 Place the camshaft on a V-Block fixture.

A5.10.1.1 The V-Blocks should be spaced so that each camshaft is supported on its 2nd and 5th journals.

A5.10.2 Calibrate a 1 to 2 in. snap gage using a cylindrical measurement standard.

A5.10.2.1 A Mitutoyo Model #201-152 snap gauge with a Mitutoyo Model #ID-C112AEB digital, or equivalent, indicator attachment is recommended for these measurements.

A5.10.2.2 The cylindrical measurement standard used for intake camshaft lobe heel-to-toe measurements has a diameter of 36.725 mm.

A5.10.2.3 The cylindrical measurement standard used for exhaust camshaft lobe heel-to-toe measurements has a diameter of 39.500 mm.

A5.10.3 Set the base circle of the camshaft lobe on the anvil of the snap gage and engage the spindle (Fig. A5.6).

A5.10.3.1 While keeping the snap gage centered on the lobe, slowly rotate the snap gage around the lobe until the digital indicator reads a maximum value.

A5.10.3.2 Record this measurement as the heel-to-toe height for the specific camshaft lobe.

A5.10.3.3 Repeat this measurement for the eight camshaft lobes on both the intake and exhaust camshafts.

Fig. A5.6 - Positioning the Snap Gage to Measure the Camshaft Heel-to-Toe Height

ANNEX A6

A6. KEYENCE VR-3000 SETUP AND MEASUREMENT PROCEDURE

A6.1 **Hardware and Software Requirements**

A6.1.1 Hardware: Keyence VR-3000 series

A6.1.2 Software: Generation-2

A6.1.3 Fixture: Sequence IVB Keyence Lifter Fixture (IVB13751-KEY) and, if needed, Spacer (IVB13751-SPACER)

A6.2 **Keyence Settings**

A6.2.1 Viewer – Macroscope settings.

(1) The viewer settings file used is 40X-SETTINGS.zon.

Explanation: The viewer settings file is available from the ASTM Test Monitoring Center Website at:
http://www.astmtmc.cmu.edu/ftp/docs/gas/sequenceiv/procedure_and_ils/ivb/misc/

A6.2.1.1 The viewer settings file will establish the following settings in expert mode in the viewer:

(1) High magnification cam
(2) 40x magnification
(3) Mode: Standard
(4) Measurement direction: Both Sides
(5) Adjust brightness for measurement: Auto
(6) Stitching: Auto
(7) Enable AF: Disabled

A6.2.1.2 The viewer – File save setting options: (Manual)

(1) Set Manual-save settings (See Fig. 1).
(2) Select - **Tools>Options>3D Measurement – Auto stitching**
(3) Set - Enable auto stitching: Disabled

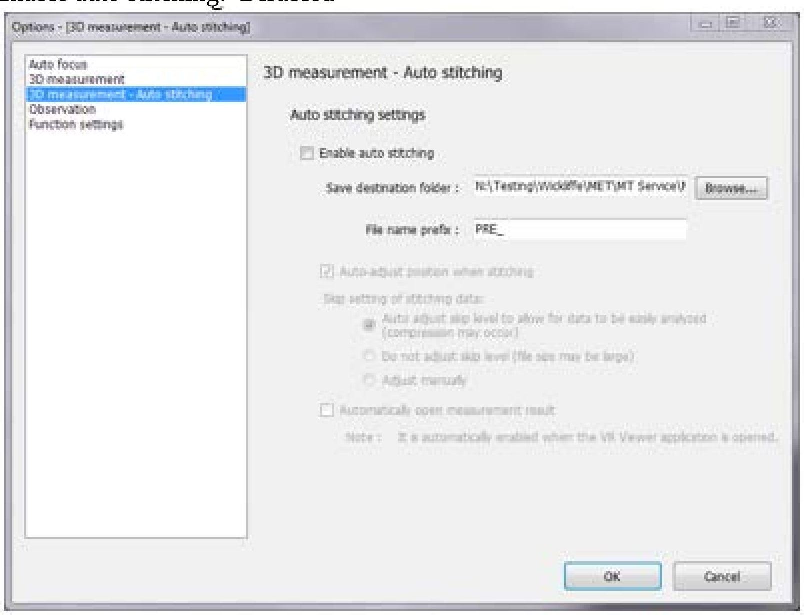


Fig.1

A6.2.1.3 The viewer – File save setting options: (Auto)

(1) Set Auto-save settings (See Fig. 2).
(2) Select - **Tools>Options>3D Measurement – Auto stitching**
(3) Set - Enable auto stitching: Enabled
(4) Select save destination folder:
(5) Select file name prefix:
(6) Set - Auto-adjust position when stitching: Enabled
(7) Under Skip setting of stitching data. Select radial button for "***Auto adjust skip level to allow for data to be easily analyzed***" this is equivalent to selecting the ~2000x2000 file size during manual save.

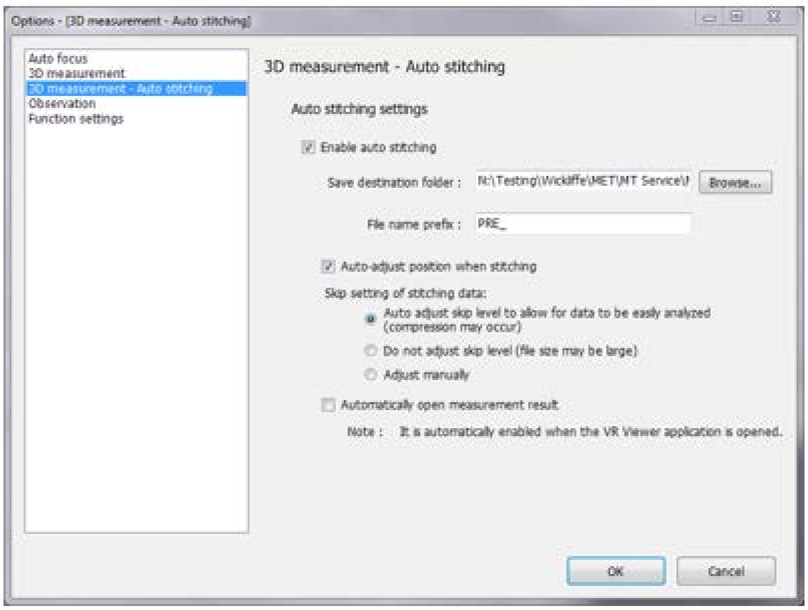


Fig.2

A6.3 **Analyzer – Template settings**.

(1) The analyzer template file used is 40X TEMPLATE-RING.zcs.

Explanation: The analyzer template file is available from the ASTM Test Monitoring Center Website at:
http://www.astmtmc.cmu.edu/ftp/docs/gas/sequenceiv/procedure_and_ils/ivb/misc/

A6.3.1 The analyzer template file uses the follow settings:

A6.3.1.1 Auto-position settings:

(1) Auto-position adjustment: On
(2) Select position alignment image: Height
(3) Restrict rotation search range when aligning position: Restrict to 0-degrees

A6.3.1.2 Reference Plane settings:

(1) The leveling ring should be set at 27.000 mm and bounded by an area between 26.950 – 27.050 mm.

A6.3.1.3 Height range settings:

(1) Set at min -0.010mm and max +0.010mm.

A6.3.1.4 Volume Measurement Settings.

(1) The area set for measurement is set as a 27.00mm circle.
(2) Height threshold: -0.050 mm

(3) Ignore small height differences: Not Enabled
(4) Ignore small areas: Enabled
(5) Include upper/lower limit surfaces in surface area measurement: Not Enabled

A6.3.1.5 High-Spot Measurement Settings:
(1) The area set for measurement is set as a 27.00mm circle.
(2) Height threshold: 0.010 mm.
(3) Ignore small height differences: Not Enabled
(4) Ignore small areas: Enabled
(5) Include upper/lower limit surfaces in surface area measurement: Not Enabled

A6.4 **Calibration and Verification**
Note: - Launch the Keyence Viewer software

A6.4.1 Calibration:
(1) Calibration shall be performed as needed, at the discretion of the operator.
(2) Follow the on-screen instructions in the viewer software.
(3) Ensure the measurements are within limits and save the file.

A6.4.1.1 Verification:
(1) To achieve successful verification of calibration it is recommended to warm up the Keyence for at least 30 minutes.
(2) Verification of width and height shall be performed prior to beginning measurements for the day using the high mag camera following the manufacturers on-screen procedure.

A6.4.1.2 Width verification:
(1) Select - **Tools>Maintenance>Verification>Measure width 20 times**
(2) Follow the on-screen instructions in the viewer software.
(3) Place the XY calibration standard on the stage.
(4) Select the camera magnification. (High Mag)
(5) Follow the on-screen instructions listed on the right side of the screen.
(6) Ensure the measurements are within limits and save the file.

A6.4.1.3 Height verification:
(1) Select - **Tools>Maintenance>Verification>Measure height 20 times**
(2) Follow the on-screen instructions in the viewer software.
(3) Place the Z calibration standard on the stage.
(4) Select the camera magnification. (High Mag)
(5) Follow the on-screen instructions listed on the right side of the screen.
(6) Ensure the measurements are within limits and save the file.

A6.4.1.4 Verification limits:
(1) Refer to the **Calibration Certificate** that comes with your Calibration Standard.
(2) Width (High Mag) = Your Calibration Standard Measurement Value ± 0.00200
(3) Height (High Mag) = Your Calibration Standard Measurement Value ± 0.0050

A6.5 **Lifter Preparation**
(1) Select the lifter to be measured.
(2) Clean the lifter with pentane or heptane as necessary.
(3) Blow off the lifter with air to remove any remaining lint or dust.
(4) Inspect for remaining particles on the surface of the lifter and repeat step (2) – (3) as needed.
(5) For post- test lifters only:
(a.) Apply talc powder to the top of the lifter using the applicator and brush off any excess powder.

(b.) Lightly blow off the lifter using a can of dust off (or similar) from approximately 6 inches away.

(6) Insert lifter into the fixture and align the etched marked on the lifter to the white lines on the fixture.

A6.6 Lifter Scanning Procedure

Note: - Confirm all settings as prescribed in sections (A6.2 – A6.5)

(1) Set the stitching area to include the two corners on the OHT lifter fixture. (See Fig.3)

(2) Select **Stitching settings**.

(3) Area specification method: Simple

(4) Use the **Add** button to add areas. (Add the two corners on the fixture as shown by “White areas” in Fig.3).

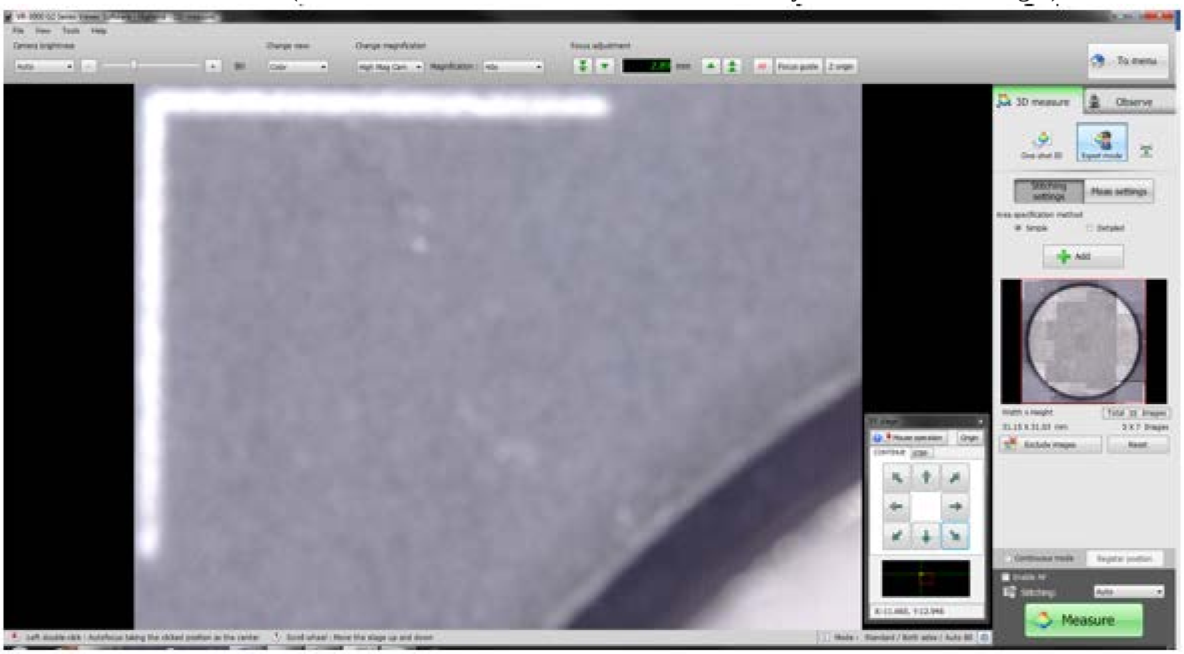


Fig.3

(5) Focus the objective on the lifter surface.

(a.) This can be accomplished by double-clicking on the lifter surface in the viewing window to auto-focus or by using the focus guide to manual focus.

A6.7 Instructions for Manual Save

Note: - Confirm all settings as prescribed in section (A6.2.1.2)

(1) Click **Measure**.

(2) Select **Auto position adjustment** on the right side of the screen. (See Fig.4)

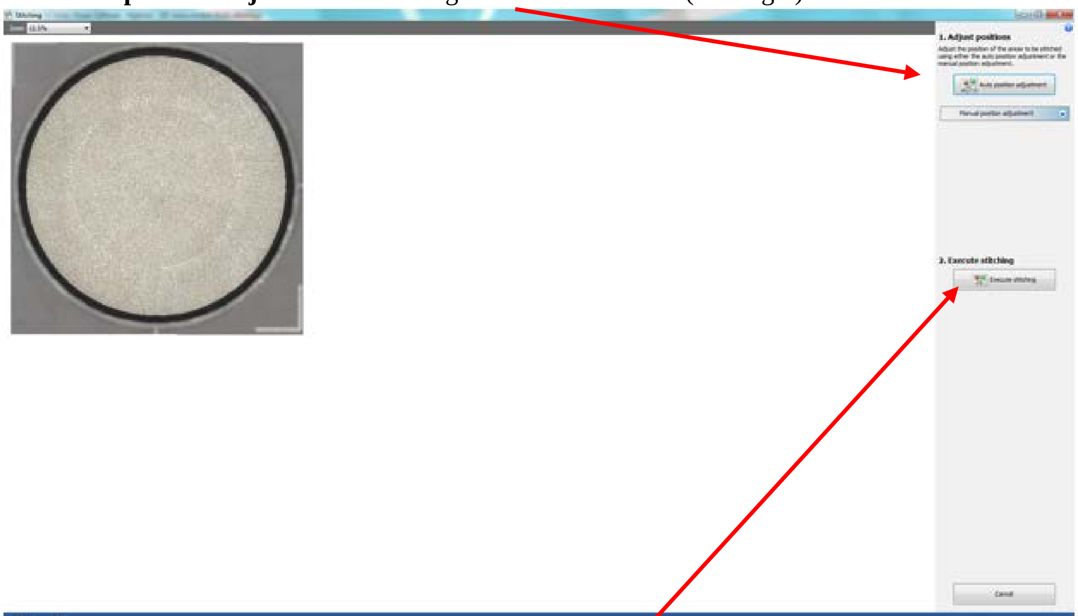


Fig.4

(3) Select **Execute stitching** on the right side of the screen.

(4) When stitching is complete;

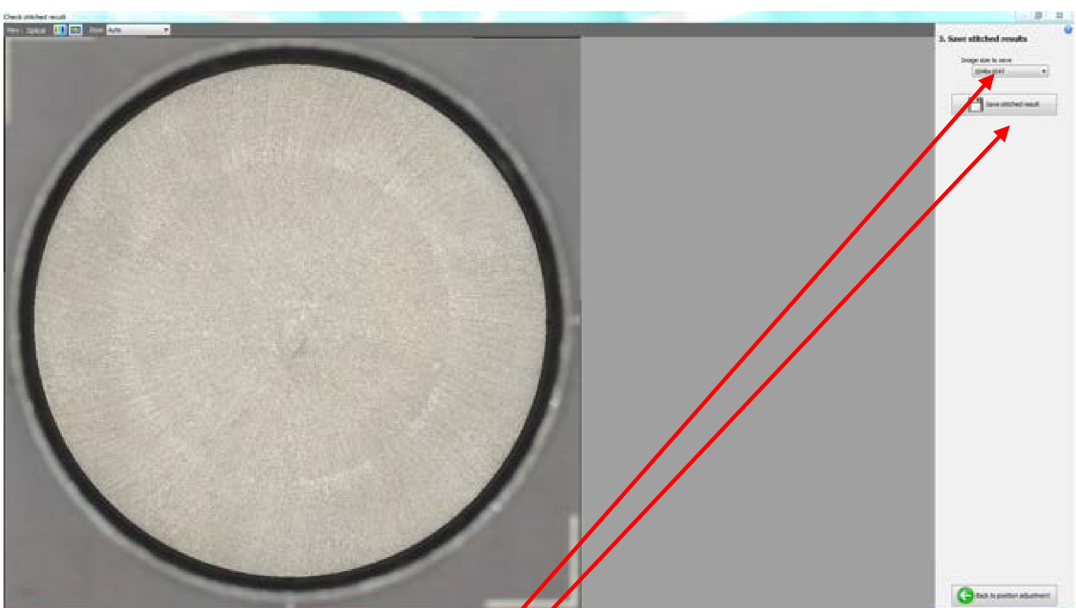


Fig.5

(5) Select **- Image size to save:** (See Fig.5)

(b.) Select - ~2000x2000 file size.

(c.) Select - **Save stitched result**.

(d.) Save the file.

A6.7.1 **Instructions for Auto-Save**

Note: - Confirm all settings as prescribed in sections (A6.2.1.3)

(1) Click **Measure**.
(2) When using Auto Save the Keyence software will automatically name the file.

A6.8 **Lifter Volume Measurement Procedure**

(1) Open image file(.zon) in the Analyzer software.
(2) Apply lifter template (see A6.3 (1)) to the analyzer.
(3) Pre-Test Measurements step (a.) Post-Test Measurements skip to step (4).
  (a.) Screen lifter for concavity:
  (b.) In the main tab, check the height image for concavity. The color scale that represents the (-0.010mm^2 to + 0.010mm^2) height scale is blue (low) to red (high). (See Fig 6)

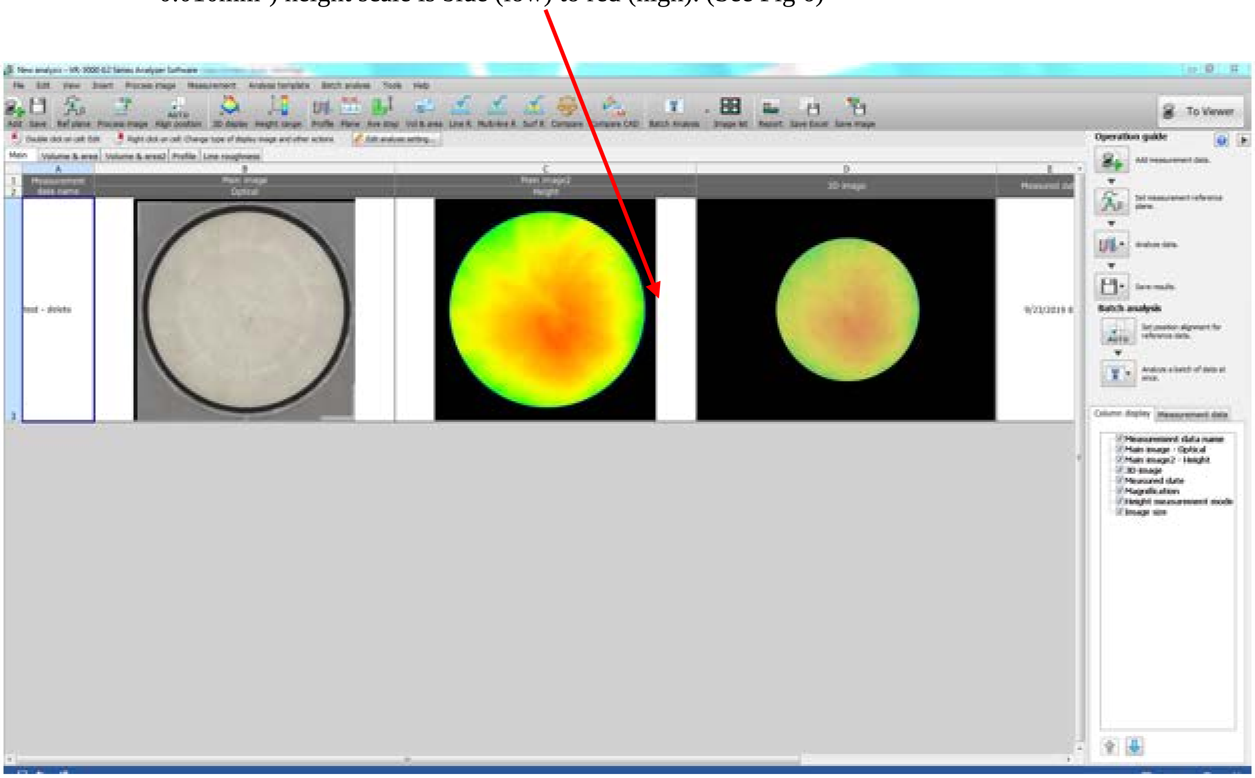


Fig. 6

  (c.) Concavity will normally appear as blue on the surface of the lifter.
  (d.) If concavity is unable to be determined by the height map the profile tool may be used to screen for concavity.
(4) Screen for high spot:
  (a.) Check the total volume in the "Volume & area2" tab.
  (b.) If the Total Volume is above 0.000:
    (1) For pre-test: clean the lifter and rescan.
    (2) For post-test: clean the lifter, apply powder to the lifter, and rescan.
(5) Volume measurement:
  (a.) Go to "Volume & area" tab.
  (b.) Record Total volume as lifter volume.

Annex A7.
THERMOCOUPLES

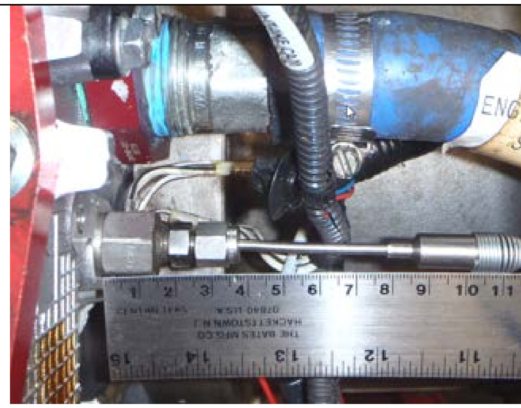
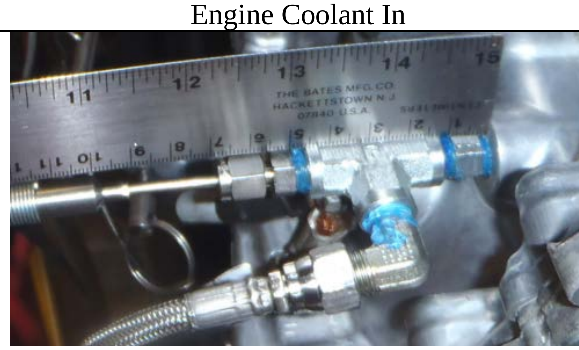
A7.1 This annex illustrates required locations and installation depths of the required Sequence IVB thermocouples.[17] Locate the sensing tip of all thermocouples in the center of the stream of the medium being measured unless otherwise specified. Table A7.1 provides the thermocouple type and size for each location.

TABLE A7.1 Thermocouple List

Figure #	**Description**	**Thermocouple Size**
A7.1	Engine Coolant Out	E-Type 1/8” x 4”
A7.2	Engine Coolant In	E-Type 1/8” x 4”
A7.3	Engine Oil Gallery	E-Type 1/8” x 4”
A7.4	Load Cell	E-Type 1/8” x 4”
A7.5	Intake Air	E-Type 1/8” x 4”
A7.6	Test Cell	E-Type 1/8” x 2”
A7.7	Fuel	E-Type 1/8” x 4”
A7.8	Oil Sump	E-Type 1/8” x 3”
A7.9	Valve Cover Blowby Gas Out	E-Type 1/8” x 4”
A7.10	Valve Cover Coolant In	E-Type 1/8” x 4”
A7.11	Valve Cover Coolant Out	E-Type 1/8” x 4”
A7.12	Exhaust Gas	E-Type 1/4” x 4”
A7.13	Dynamometer Coolant Out	E-Type 1/8” x 4”
A7.14	Blow-by Gas	E-Type 1/8” x 4”
A7.15	Blow-by Coolant Out	E-Type 1/8” x 3”

[17] Supplied by Test Engineering Inc. see Appendix X2, section X1.3

A7.2 Illustrates the appropriate location of thermocouples for each of the test specific applications required by the test procedure. (See sections A7.2.1 – A7.2.15)

A.7.2.1 Engine coolant out. (Refer to Fig. A7.1)	 Figure A7.1 Engine Coolant Out
A7.2.2 Engine coolant in. (Refer to Fig. A7.2)	 Figure A7.2 Engine Coolant In
A7.2.3 Engine Oil Gallery. (Refer to Fig. A7.3)	 Figure A7.3 Engine Oil Gallery

A7.2.4 Dynamometer Load Cell.
(Refer to Fig. A7.4)

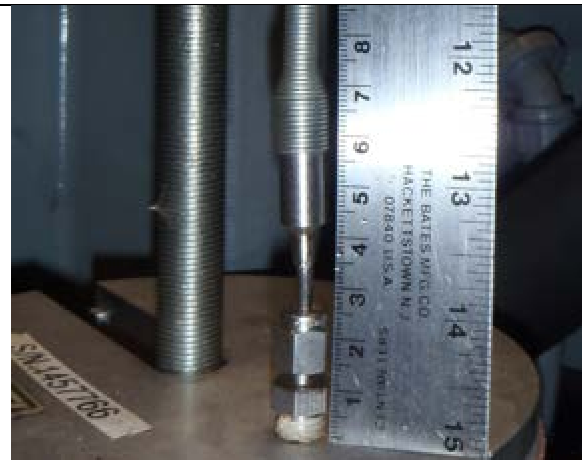


Figure A7.4

A7.2.5 Intake Air. (Refer to Fig. A7.5)

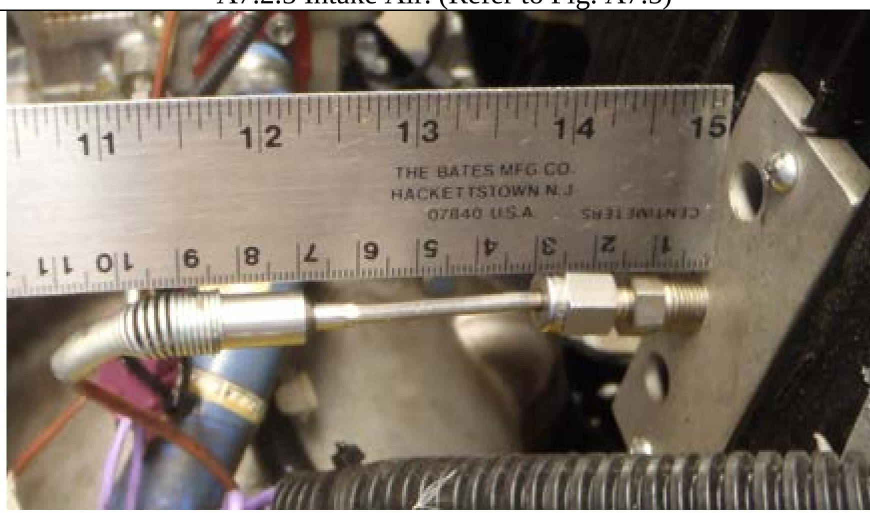


Figure A7.5 Intake Air

A7.2.6 Test Cell Ambient Air (Refer to Fig. A7.6)

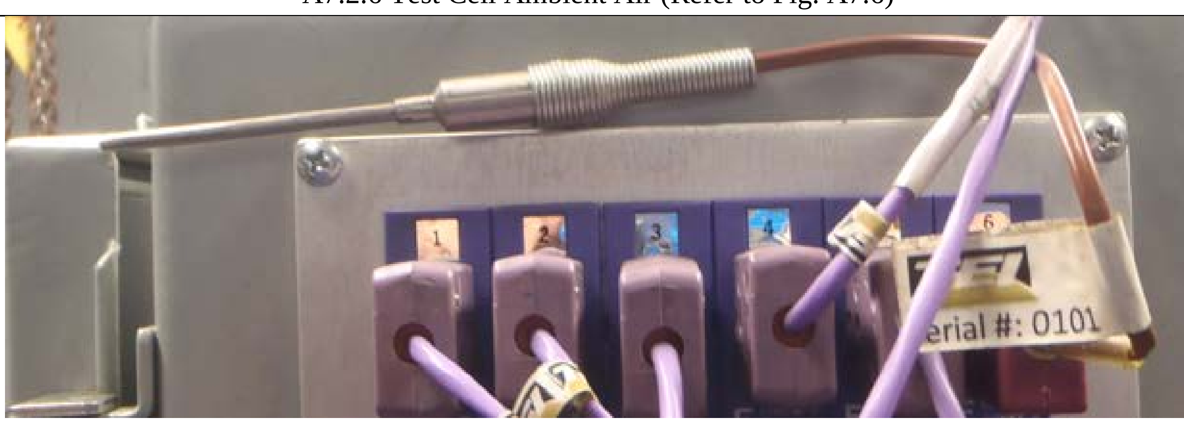


Figure A7.6 Test Cell

A7.2.7 Fuel Inlet. (Refer to Fig. A7.7)

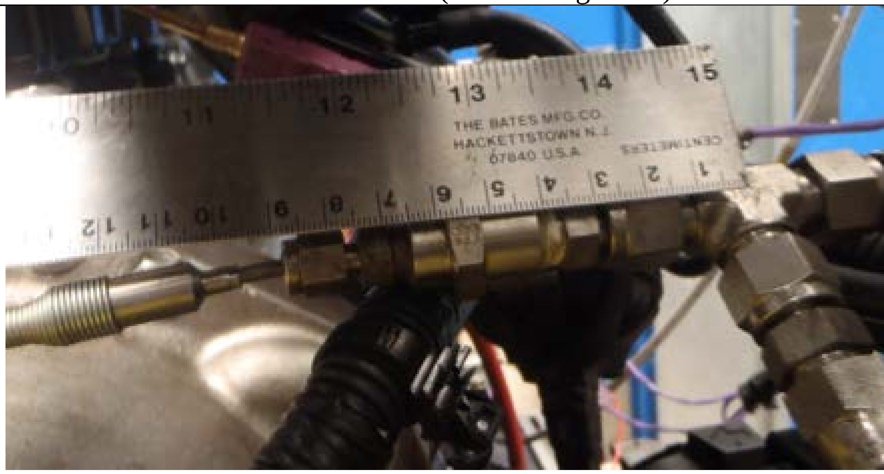


Figure A7.7 Fuel Inlet

A7.2.8 Oil Sump. (Refer to Fig. A7.8)

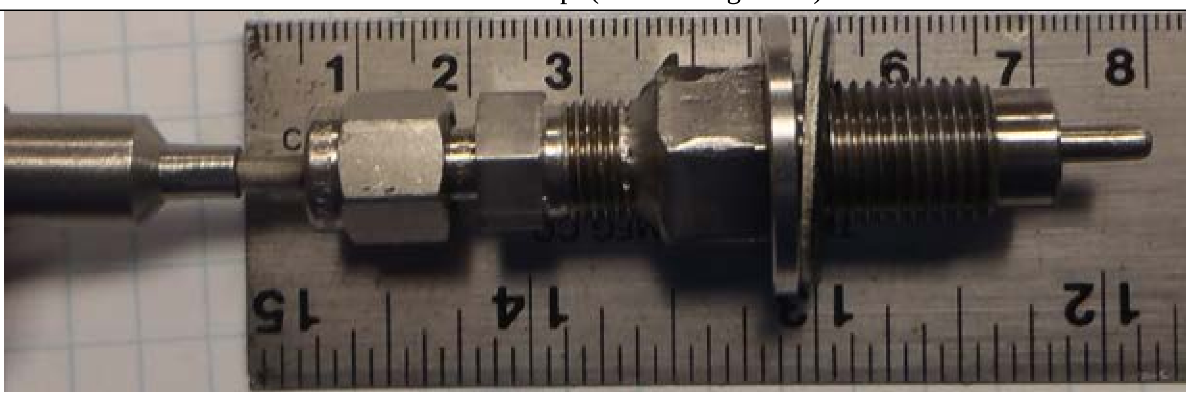


Figure A7.8 Test Cell

A7.2.9 Valve Cover Breather System Blowby Gas. (Refer to Fig. A7.9)

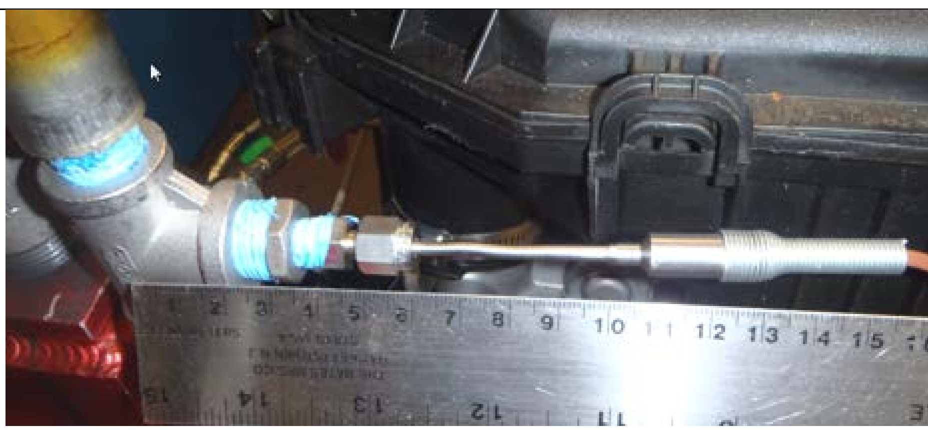


Figure A7.9 Valve Cover Breather System Blowby Gas

A7.2.10 Valve Cover Coolant In. (Refer to Fig. A7.10)

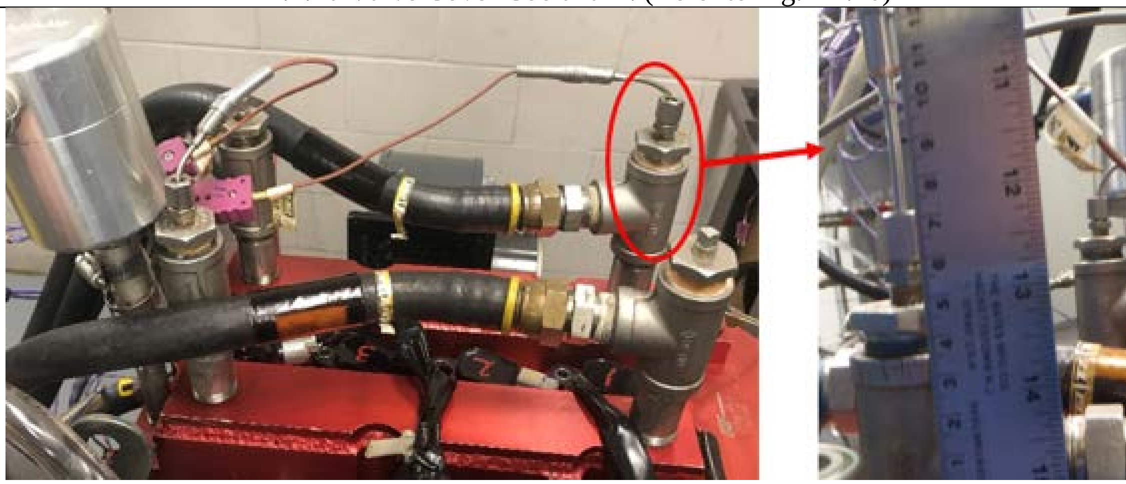


Figure A7.10 Valve Cover Coolant In

A7.2.11 Valve Cover Coolant Out. (Refer to Fig. A7.11)

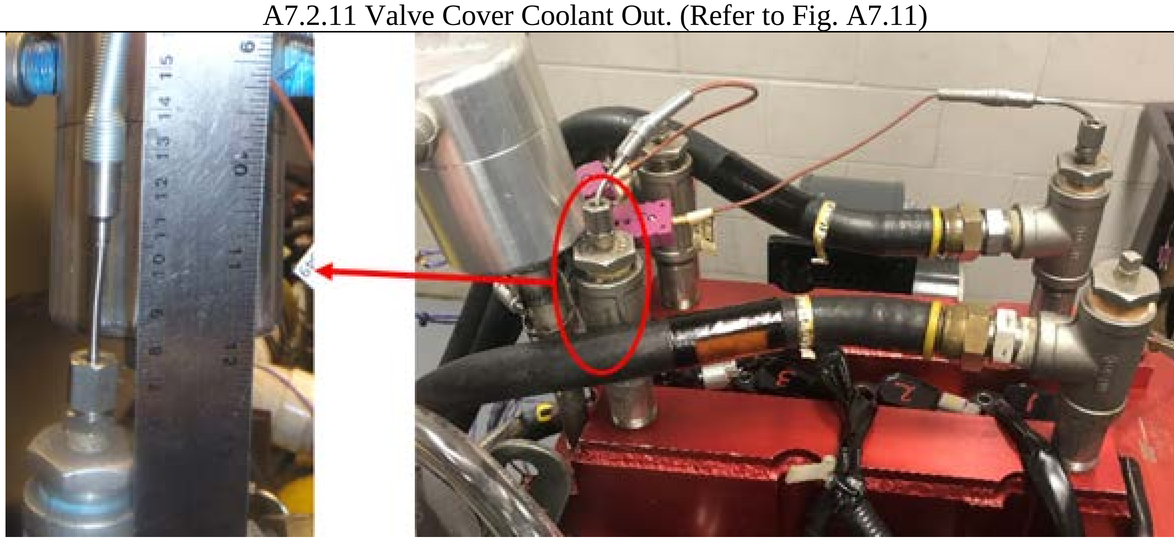
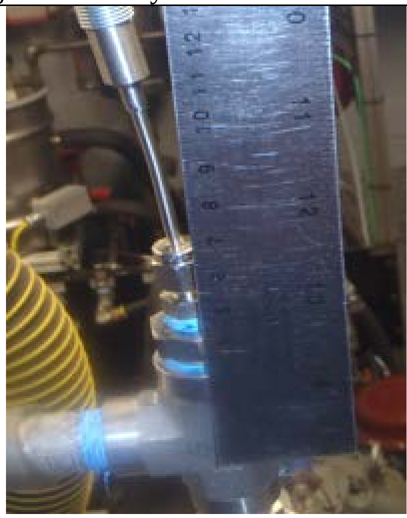
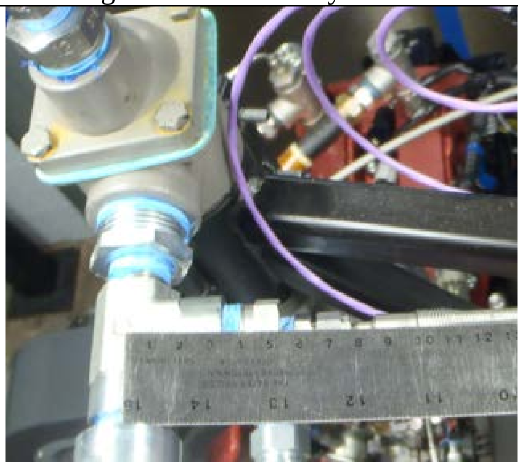


Figure A7.11 Valve Cover Coolant Out

A7.2.12 Exhaust Gas. (Refer to Fig. A7.12)

Figure A7.12 Exhaust Gas

A7.2.13 Dynamometer Coolant Out. (Refer to Fig. A7.13)	 Figure A7.13 Dynamometer Coolant Out
A7.2.14 Breather Tube Blow-by Gas Out. (Refer to Fig. A7.14)	 Figure A7.14 Blow-by Gas Out
A7.2.15 Blow-by Coolant Out. (Refer to Fig. A7.15)	 Figure A7.15

ANNEX A8
Oil Separator and Blow-by Plumbing Insulation Procedure

A8.1 Illustration Figures A8.1 through A8.4 show the locations and size information of the Tygon hose sections used for the oil separator assembly.

A8.1.1 Oil separator with Tygon hose sections overview. (Refer to Fig. A8.1)

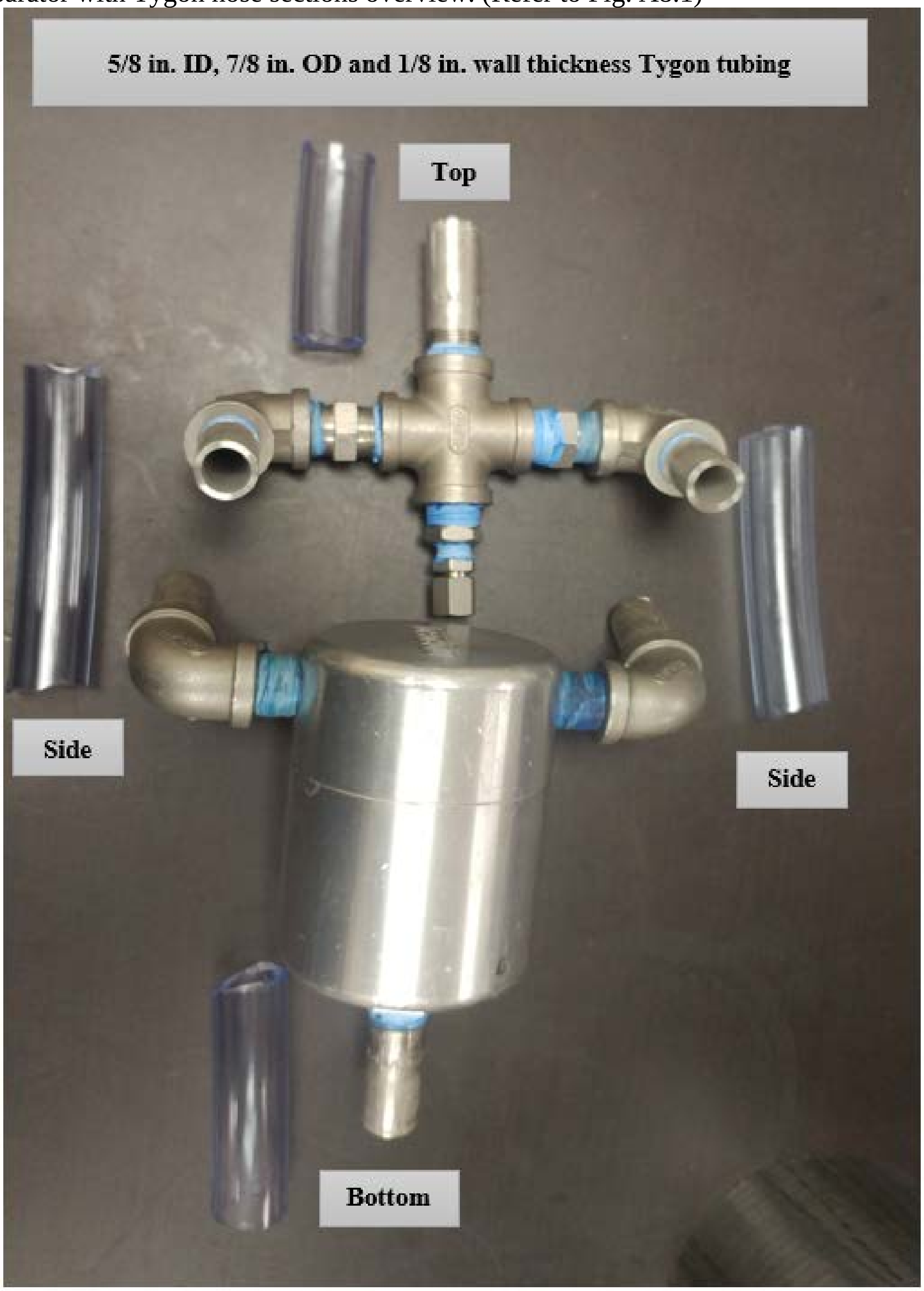


Figure A8.1 Tygon Hose Sections

A8.1.1 Oil separator side hoses, 2 each, 4 in. long. **(Refer to Fig. A8.2)**	 **Figure A8.2**
A8.1.2 Oil separator bottom hose, 3 in. long. **(Refer to Fig. A8.3)**	 **Figure A8.3**
A8.1.3 Oil separator top hose, 2 ½ in. long. **(Refer to Fig. A8.4)**	 **Figure A8.4**

A8.2 Ultra-Flex foam rubber insulation, sheet specification. (See Table A8.1)

Table A8.1 Sheet Foam used for insulating oil separator.

Ultra-Flexible Foam Rubber Insulation

Plain Back, ¾ in. Thick, 36 in. x 48 in. Sheet, Black, part number 9349K3

Insulation Type	Sheet/Strip
Thickness	¾ in.
Width	36 in.
Length	4 ft.
Temperature Range	-295° to 220° F
R Value	3
Heat Flow Rate	0.25 @ 75° F
Density	4.5 lbs./cu. ft.
Material	Buna-N/PVC Foam
Flexibility	Flexible
Cell Type	Closed
Backing Type	Plain
Color	Black
For Use Outdoors	No
Specifications Met	ASTM E84 25/50 for Flame and Smoke
Additional Specifications	SDS
RoHS	Compliant
Related Products	Contact Adhesive (16 oz.)
	White Latex Paint (1 qt.)

These soft Buna-N/PVC foam insulation sheets are extremely flexible. They can be used outdoors if coated in latex paint. The foam has a closed-cell construction, which restricts absorption of water, air, and gas. Install plain-back insulation using contact adhesive (sold separately).

A8.2.1 Schematic drawing of top and bottom sections of blow-by oil separator foam pieces fabricated from sheet foam.
(See Fig. A8.5)

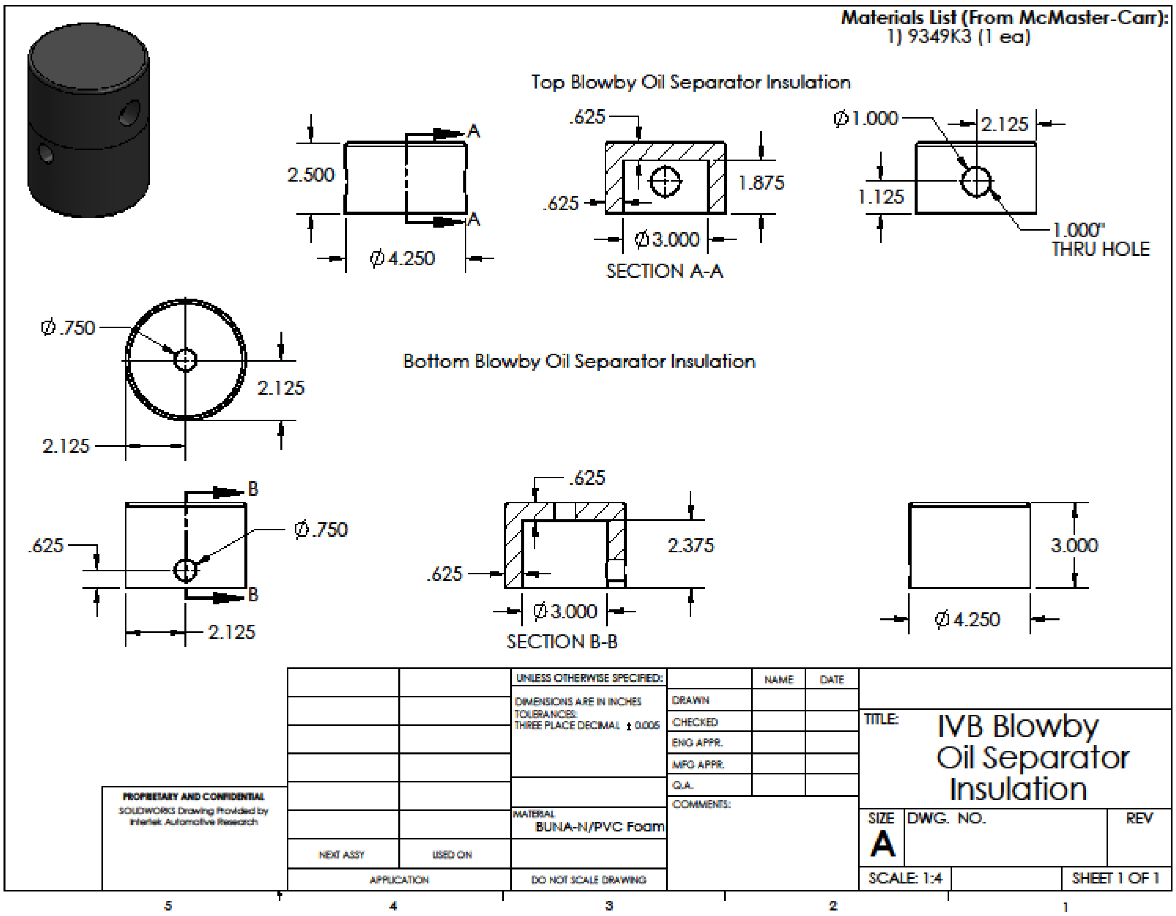
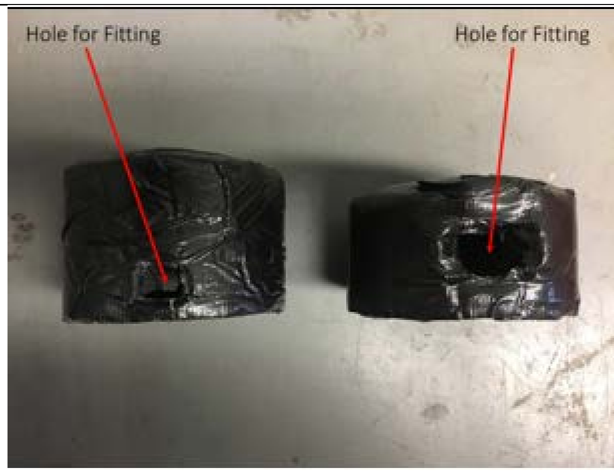
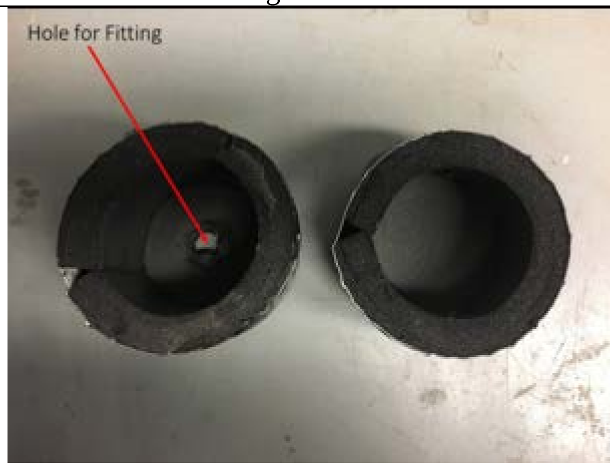


Fig. 8.5 Blow-by Oil Separator Insulation

A8.2.2 Visual reference of foam construction for top blow-by oil separator section outside view. (Refer to Fig. A8.6 and A8.5)	 Figure A8.6
A8.2.3 Visual reference of foam construction for bottom blow-by oil separator section inside view. (Refer to Fig. A8.7 and A8.5)	 Figure A8.7
A8.2.4 Visual reference of foam construction for bottom blow-by oil separator section outside view. (Refer to Fig. A8.8 and A8.5)	 Figure A8.8

A8.2.5 Visual reference of foam construction pieces assembled and taped to the oil separator. (Refer to Fig. A8.9)	 Figure A8.9
A8.2.6 Visual reference of foam construction pieces assembled and taped to the oil separator. (Refer to Fig. A8.10)	 Figure A8.10

A8.3 Ultra-Flex foam rubber insulation, pipe specification. (See Table A8.2)

Table A8.2 Foam pipe insulation used on hoses.

Ultra-Flexible Foam Rubber Pipe Insulation

½ in. Thick, 1-1/8 in. Insulation ID, 6 ft Length part number 4463K136

Insulation Type	Tube
Wall Thickness	½ in.
ID	1 1/8 in.
For Pipe Size	3/4
Length	6 ft.
Temperature Range	-295° to 220° F
Heat Flow Rate	0.25 @ 75° F
Density	4.5 lb/ft^3
Material	Buna-N/PVC Foam
Flexibility	Flexible
Tube Style	Un-slit
Color	Black
For Use Outdoors	No
Specifications Met	ASTM C534, ASTM E84 25/50 for Flame and Smoke
R Value	2
Additional Specifications	SDS
RoHS	Compliant

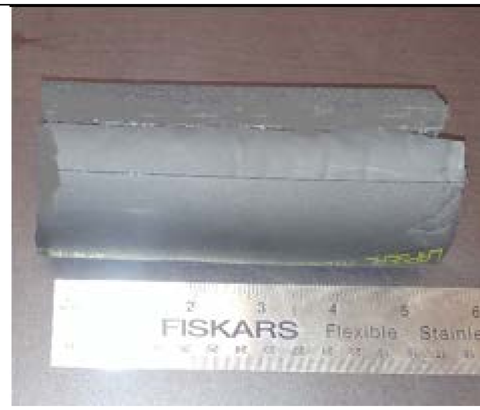
The soft Buna-N/PVC foam construction flexes for effortless installation over curved and irregular objects and bounces back to shape after compression. Use these tubes on chilled water and refrigeration lines and with hot water plumbing. They can be used outdoors if you coat them in latex paint and seal the seams and joints with contact adhesive (both sold separately). The foam has a closed-cell construction, which restricts absorption of water, air, and gas.

A8.4.1 Make 2 insulating tubes to cover the side hoses. Cut one end at 30°-degree angle. Cut the other end at 90°- degrees for an overall length of 11 in. (Refer to Fig. A8.11)	 Figure A8.11
A8.4.2 Install the Tygon side hoses and secure using micromesh clamps and slide the side insulation foam pieces pointed end first toward the separator,as shown. (Refer to Fig. A8.12)	 Figure A8.12
A8.4.3 Compress insulation, install drain back plumbing section and tighten hose clamp, repeat on the other side, as shown. (Refer to Fig's A8.13 and Fig. A8.14)	 Figure A8.13

A8.4.3 (Continued) Compress insulation, install drain back plumbing section and tighten hose clamp, repeat on the other side, as shown. (Refer to Fig's A8.13 and Fig. A8.14)	 Figure A8.14
A8.4.4 Install the top Tygon hose section and secure using a micromesh screw clamp. (Refer to fig. A8.15)	 Figure A8.15

A8.4.5 Prepare a section of insulation 5” in length with a 2” notch at one end to slip over the top Tygon hose and down around the 4-way Pipe Tee as shown. (Refer to Fig’s A8.15, A8.16, & A8.17)	 Figure A8.16
A8.4.5 (Continued)	 Figure A8.17
A8.4.6 Tape the two side hose insulation pieces to the oil separator, as shown. (Refer to Fig. A8.18)	 Figure A8.18

A8.4.7 Illustrates tapping the top hose insulation to the side insulation pieces. (Refer to Fig. A8.19)	 Figure A8.19
A8.4.8 Install the lower Tygon hose as shown. (Refer to Fig. A8.20)	 Figure A8.20
A8.4.9 Install the oil drain back assembly on test stand. Insure there is sufficient angle (approximately 4° degrees) to ensure the blow-by liquids drain back into the oil separator. Trim the upper and lower hoses no more than ½ in. to achieve the proper fit and angle as shown. (Refer to Fig. A8.21)	 Figure A8.21

A8.4.10 Prepare a 6” piece of round insulation with a slit through the length on one side and a hole 180° from the slit for the Rocker Cover Gas Out Thermocouple as shown. (Refer to Fig’s A8.22 & A8.23)	 Figure A8.22
A8.4.10 (Continued)	 Figure A8.23
A8.4.11 Wrap the insulation around the lower Tygon hose connecting the oil separator to the rocker cover blow-by gas outlet and secure the assembly using Zip Ties as shown. (Refer to fig. A8.24)	 Figure A8.24

ANNEX A9
List of Engine and Stand Parts

Engine and Stand Parts supplied by OH Technologies INC.

Item	Description
IVB001-3	SHAFT, OUTPUT, TOYOTA, 1.5L, SEQ. IVB
IVB001-5	GUARD, FLYWHEEL, BELL HOUSING, SEQ. IVB (YELLOW)
IVB001-11	BEARING, PILOT, FLYWHEEL, SEQ. IVB
IVB001-12	CLUTCH ASSY., (INCLUDES COVER, PRESSURE PLATE AND BOLTS)
IVB002-11	ASSEMBLY, SEAL INSERT TOOL
IVB002-12	STUD, SHOULDER, FOR USE WITH OHTIVB-002-2
IVB002-5	BAFFLE, ROCKER COVER
IVB002-6	CAP, OIL FILL, ASSY.
IVB003-100	KIT, FRONT COVER O-RINGS, SEALS AND CORD FOR MOUNTING TO OIL PAN
IVB003-2	CORD (O-RING), FRONT COVER, SEQ. IVB
IVB003-3	PLATE, ACCESS (INCLUDING STUDS, NUTS & LOCK WASHERS)
IVB003-4	GASKET, ACCESS PLATE, OHTIVB-003-1, COVER, FRONT
IVB004-1	GASKET, WATER PUMP PLATE, OHTIVB-003-1 COVER, FRONT
IVB005-1	GASKET, COOLANT OUT ADAPTER, SEQ. IVB
IVB007-1	GASKET, WATER PUMP, IN, ADAPTER, SEQ. IVB
IVB022-12	PLUG, DRAIN, MODIFIED, SEQ. IVB
IVB022-14	PLUG, DRAIN, ASSY, IVB
IVB022-20	O-RING, OIL PAN, FILTER CIRCUIT, BLOCK MATING SURFACE
IVB022-21	CORD (O-RING), OIL PAN (2 EACH PER PKG.)
IVB022-3	DIPSTICK, ASSEMBLY, SEQ. IVB
IVB022-23	KIT, GASKET/O-RING, OIL PAN, BLOCK MATING SURFACE - INCLUDES: T
IVB13751-KEY	FIXTURE, LIFTER, KEYENCE, SEQ. IVB
IVB13751-SPACER	SPACER, FIXTURE, KEYENCE (REQUIRES 2 EACH PER FIXTURE ASSY.)
VH006-3	RING, RETAINER
VH006-6	BEARING, BALL, OUTPUT SHAFT
OHTIVB-001-1	BELL HOUSING, ASSEMBLY, SEQUENCE IVB, TOYOTA
OHTIVB-002-2	COVER, ROCKER, WATER COOLED, SEQ. IVB
OHTIVB-003-1	COVER, FRONT, MODIFIED, ASSY.
OHTIVB-004-1	PLATE, WATER PUMP BLOCK-OFF
OHTIVB-005-1	PLATE, COOLANT OUT ADAPTER, SEQ. IVB
OHTIVB-007-1	PLATE, WATER PUMP, IN, ADAPTER, SEQ. IVB
OHTIVB-008-1	TOOL, CLUTCH ALIGNMENT TOOL
OHTIVB-012-3	HOUSING, OBERG, 28 MICRON (2 PORTS)
OHTIVB-01258-1	PLUG, SPARK
OHTIVB-020-1	CYLINDER, RETURN, OIL, ASSEMBLY, SEQ. IVB
OHTIVB-021-1	COOLANT, INLET TUBE, MODIFIED

OHTIVB-02101-1	SEAL, VALVE STEM
OHTIVB-02112-1	SEAL, VALVE STEM
OHTIVB-022-2	PAN, OIL MODIFIED, WITH MODIFIED PICKUP TUBE AND DIPSTICK, SEQ. IVB
OHTIVB-03028-1	LOCK, VALVE SPRING RETAINER,
OHTIVB-050-1	3,000ml ERLENMEYER FLASK, AMBER FILLED, ETCHED RING @ 2,400ml, CALIBRATED
OHTIVB-051-1	4,000ml ERLENMEYER FLASK, AMBER FILLED, ETCHED RING @ 3,000ml, CALIBRATED
OHTIVB-06997-1	BOLT, W/ WASHER
OHTIVB-06998-1	BOLT, W/ WASHER
OHTIVB-07033-1	O-RING, INJECTOR
OHTIVB-080-1	16000-47A70, ENGINE ASSY W/CLUTCH
OHTIVB-08026-1	BOLT, W/ WASHER, COVER, CLUTCH
OHTIVB-08052-1	STUD, HEX,
OHTIVB-08060-1	STUD, HEX,
OHTIVB-08146-1	NUT, STARTER
OHTIVB-08228-1	NUT, CYLINDER HEAD AND EXHAUST PIPE
OHTIVB-09031-1	O-RING, FRONT COVER
OHTIVB-100-1	KIT, GOLDEN STAND SETUP
OHTIVB-10010-1	TOOL, CRANKSHAFT PULLEY
OHTIVB-10016-1	NUT, FRONT/ INTAKE MOUNT
OHTIVB-101-1	KIT, CYLINDER HEAD REPLACEMENT AND MAINTENANCE (6 RUNS PER KIT)
OHTIVB-102-1	KIT, ENGINE, CAMSHAFT, TEST (SINGLE RUN PER KIT)
OHTIVB-103-1	KIT, ENGINE ASSEMBLY AND INITIAL INSTALLATION
OHTIVB-10426-1	BOLT, WASHER BASED HEX, FRONT/INTAKE MOUNT
OHTIVB-10469-1	BOLT, FLANGE, RH ENGINE MOUNT & T/M HOUSING
OHTIVB-10889-1	BOLT, W/ WASHER,
OHTIVB-11101-1	HEAD SUB-ASSY, CYLINDER, SEQ. IVB
OHTIVB-11115-1	GASKET, CYLINDER HEAD, SEQ. IVB
OHTIVB-11191-1	TUBE, SPARK PLUG SEQ. IVB
OHTIVB-11193-1	GASKET, SPARK PLUG TUBE, SEQ. IVB
OHTIVB-11213-1	GASKET, CYLINDER HEAD COVER
OHTIVB-11310-1	COVER, FRONT OEM
OHTIVB-12031-1	GASKET, DRAIN PLUG
OHTIVB-12054-1	BOLT, WASHER BASED HEX, REAR/EXHAUST MOUNT
OHTIVB-12160-1	BOLT, WASHER BASED HEX HEAD
OHTIVB-12221-1	GASKET, WATER TEMP SENSOR
OHTIVB-12262-1	HOSE, VENTILATION NUMBER 2
OHTIVB-12305-1	INSULATOR SUB-ASSY, ENGINE
OHTIVB-12311-1	BRACKET, ENGINE MOUNTING, FRONT/INTAKE

OHTIVB-12321-1	BRACKET, ENGINE MOUNTING, REAR/EXHAUST
OHTIVB-12361-1	INSULATOR, ENGINE MOUNTING, INTAKE SIDE
OHTIVB-12371-1	INSULATOR, ENGINE MOUNTING
OHTIVB-13501-1	CAMSHAFT SUB-ASSY, NO. 1 INTAKE, SPECIAL TEST
OHTIVB-13502-1	CAMSHAFT, EXHAUST
OHTIVB-13506-1	CHAIN, SUB-ASSY,
OHTIVB-13521-1	SPROCKET, CRANKSHAFT TIMING
OHTIVB-13523-1	SPROCKET, CAMSHAFT TIMING
OHTIVB-13540-1	TENSIONER ASSY, CHAIN
OHTIVB-13540-2	TENSIONER ASSY, CHAIN
OHTIVB-13552-1	GASKET, CHAIN TENSIONER
OHTIVB-13566-1	GUIDE, TIMING CHAIN,
OHTIVB-13591-1	ARM, TIMING CHAIN TENSION
OHTIVB-13711-1	VALVE, INTAKE,
OHTIVB-13715-1	VALVE, EXHAUST,
OHTIVB-13734-1	SEAT, VALVE SPRING
OHTIVB-13741-1	RETAINER, VALVE SPRING
OHTIVB-15104-1	STRAINER, SUB ASSY, OIL PAN
OHTIVB-15695-1	BOLT, OIL COOLER UNION
OHTIVB-15710-1	COOLER, OIL
OHTIVB-16000-1	ENGINE, ASSY. 1.5L, L/ CLUTCH, SEQ. IVB
OHTIVB-16000-2	ENGINE, ASSY. 1.5L, L/ CLUTCH, SEQ. IVB
OHTIVB-16268-1	PIPE, COOLANT INLET, MODIFIED
OHTIVB-17173-1	GASKET, EXHAUST MANIFOLD
OHTIVB-17177-1	GASKET, INTAKE MANIFOLD TO HEAD
OHTIVB-17400-1	PIPE ASSY., EXHAUST
OHTIVB-17451-1	GASKET, EXHAUST PIPE
OHTIVB-17568-1	SUPPORT, EXHAUST PIPE, STAY,
OHTIVB-17700-1	CLEANER ASSY., AIR W/ ELEMENT, MODIFIED
OHTIVB-17751-1	PIPE, INLET, AIR CLEANER
OHTIVB-17801-1	FILTER, AIR, ELEMENT (FOR USE IN 17700-0Y060 AIR INLET HOUSING)
OHTIVB-19023-1	O-RING, FRONT COVER
OHTIVB-21041-1	NUT, FLANGE
OHTIVB-22030-1	BODY ASSY., THROTTLE W/ MOTOR
OHTIVB-22210-1	PEDAL, THROTTLE, MODIFIED, SPECIAL TEST, SEQ. IVB
OHTIVB-22271-1	GASKET, THROTTLE BODY
OHTIVB-23030-1	LIFTER, VALVE, GRADE 12
OHTIVB-23040-1	LIFTER, VALVE, GRADE 14
OHTIVB-23050-1	LIFTER, VALVE, GRADE 16
OHTIVB-23060-1	LIFTER, VALVE, GRADE 18
OHTIVB-23070-1	LIFTER, VALVE, GRADE 20

OHTIVB-23080-1	LIFTER, VALVE, GRADE 22
OHTIVB-23090-1	LIFTER, VALVE, GRADE 24
OHTIVB-23100-1	LIFTER, VALVE, GRADE 26
OHTIVB-23110-1	LIFTER, VALVE, GRADE 28
OHTIVB-23120-1	LIFTER, VALVE, GRADE 30
OHTIVB-23130-1	LIFTER, VALVE, GRADE 32
OHTIVB-23140-1	LIFTER, VALVE, GRADE 34
OHTIVB-23150-1	LIFTER, VALVE, GRADE 36
OHTIVB-23160-1	LIFTER, VALVE, GRADE 38
OHTIVB-23170-1	LIFTER, VALVE, GRADE 40
OHTIVB-23180-1	LIFTER, VALVE, GRADE 42
OHTIVB-23190-1	LIFTER, VALVE, GRADE 44
OHTIVB-23200-1	LIFTER, VALVE, GRADE 46
OHTIVB-23210-1	LIFTER, VALVE, GRADE 48
OHTIVB-23220-1	LIFTER, VALVE, GRADE 50
OHTIVB-23230-1	LIFTER, VALVE, GRADE 52
OHTIVB-23240-1	LIFTER, VALVE, GRADE 54
OHTIVB-23250-1	LIFTER, VALVE, GRADE 56
OHTIVB-23260-1	LIFTER, VALVE, GRADE 58
OHTIVB-23270-1	LIFTER, VALVE, GRADE 60
OHTIVB-23291-1	INSULATOR, INJECTOR
OHTIVB-25063-1	SPRING, COMPRESSION,
OHTIVB-27014-1	O-RING, FRONT COVER
OHTIVB-28100-1	STARTER, ASSEMBLY (INCLUDES OHTIVB-91612-1 BOLTS AND OHTIVB-08146-1 NUTS)
OHTIVB-29016-1	O-RING, WATER BYPASS PIPE
OHTIVB-30034-1	SPRING, COMPRESSION, SPECIAL TEST, INTAKE, SEQ. IVB,
OHTIVB-31210-1	CLUTCH COVER, ASSY
OHTIVB-31250-1	DISK ASSY., CLUTCH
OHTIVB-47091-1	PAN SUB-ASSY, OIL
OHTIVB-80630-1	BOLT, FLANGE, CHAIN TENSIONER
OHTIVB-80800-1	NUT, FLANGE
OHTIVB-80825-1	BOLT, FLANGE W/ WASHER
OHTIVB-80835-1	BOLT, FLANGE W/ WASHER
OHTIVB-80841-1	NUT, FLANGE
OHTIVB-81020-1	BOLT, FLANGE, ENGINE MOUNTING, FRONT/REAR
OHTIVB-81025-1	BOLT, FLANGE, ENGINE MOUNTING, FRONT/REAR
OHTIVB-82121-1	HARNESS, ENGINE WIRE, 82121-0DD60
OHTIVB-82122-1	WIRE, DYNO, NO.2

OHTIVB-82123-1	STAND WIRING HARNESS SET, INCLUDES 1 EACH ENGINE (OHTIVB-82121-1) & 1 EACH DYNO (OHTIVB-82122-1), MODIFIED, WITH OBDII CONNECTOR, SEQ. IVB
OHTIVB-89465-1	SENSOR, OXYGEN
OHTIVB-89661-1	COMPUTER, ENGINE CONTROL
OHTIVB-90116-1	BOLT, STUD, RH ENGINE MOUNT
OHTIVB-90311-1	SEAL, TYPE T OIL, FRONT COVER
OHTIVB-90363-1	BEARING, RADIAL BALL, CLUTCH
OHTIVB-90460-1	CLAMP, HOSE
OHTIVB-90466-1	CLIP, HOSE, AIR BOX
OHTIVB-90467-1	CLIP, AIR BOX
OHTIVB-90915-1	FILTER, OIL SEQ. IVB
OHTIVB-91612-1	BOLT, W/ WASHER, STARTER
OHTIVB-91619-1	BOLT, W/ WASHER
OHTIVB-A0822-1	BOLT, FLANGE, W/ WASHER
OHT6A-012-5	HOUSING, OBERG ASSEMBLY, 6" WITH 28 MICRON FILTER AND STEEL CHECK VALVE SEAT, 4 PORT
OHT6A-013-2	FILTER, 6, OBERG, 28 MICRON

Engine and Stand Parts supplied by TEI

Item	Description
251-1061	Heat Sink, Single Phase SSR RHS100 (70014831)
CWD2450	RELAY, SOLID STATE DC-AC 240VAC 50A, DC-AC Solid State RELAY (70130488)
IAC5	OPTO 22 Module, Input (IAC5-70133476)
IDC5	OPTO 22 Module, AC Input (IDC5- 70133482)
OAC5	OPTO 22, Module Digital (OAC5-70133487)
ODC5	OPTO 22, Module 5-60 VDC (ODC5-70133495)
PB-16H	PB-16, PB-16 I/O BACKPLANE
70001027	Power Supply, AC to DC, 5V@3A, DIN Rail Mount
70000974	SUPPLY-24VDC@3A
KRPA-11DN-12	RELAY- PB- KRPA-SERIES
MG17416	CIRCUIT BREAKER 1P 15A
MG17456	CIRCUIT BREAKER 2P 15A
MG24456	CIRCUIT BREAKER 2P 50A
LC1D32G7	CONTACTOR- non reversing, 600vac, 32a, 3-pole, 120vac coil, FOR COOLANT PUMPS
27E891	Socket, Relay, Screw Term, Snap-Mount (70199345)
C2-G20X-024VDC	RELAY R4157
SSRT-240D25	RELAY, SOLID STATE DC-AC 240VAC 25A, DC-AC Solid State (70199305)
DLS30	BATTERY CHARGER
9003GCW36SV3A29L36	RESEARCH VALVE, COOLANT
1002GCN36SVCSCLN36	RESEARCH VALVE, TOWER WATER
1001GCN36SVCSFLN36	RESEARCH VALVE
1003GCN36SVCS40L36	RESEARCH VALVE, CHILLED WATER
4270061	GAUGE, 60PSI, 2.5" DIAL, BOTTOM 1/4 NPTM (Liquid Filled)
5020	ELEPHANT FEET
5100	SIDEWINDERS
969-710-201	I/P TRANSDUCER - T1500
010-606-002	I/P Manifold - 10 port
PR7L-1A11D5D111	GO REGULATOR VALVE
BL122CR, 1A	Load cell- 500 lbs
FPG1AP 1AJ 2U 5B 6M	P-XDUCER-FP2000-1PSIG
FPA BL 1AK 2U 5B 6M	P-XDUCER-FP2000-25PSIA
FPG BR 1AK 2U 5B 6M	P-XDUCER-FP2000-100PSIG
1410_SERIES_FLANGE	Driveshaft 20" Collapsed Length 2.75" pilot 3.75" bolt circle
21671	1014A 60 TOOTH GEAR
20015	1014A TACH HOUSING & COVER
31145/31146	REAR SHAFT GUARD – 2 PIECE
10005	DYNO TORQUE ARM
10132	1014A ACTUATOR BAR

10131	BACK KNIFE EDGE ASSEMBLY
10035	MAGNETIC PICK-UP
20029	LOAD CELL CLEVIS BRACKET
ACTUATOR-05	ACTUATOR ASSEMBLY WITH MOUNTING PLATE, ARM, STOP COLLAR
DTC REMOTE-02	DTC REMOTE / OTPUAU REMOTE-02 / Throttle Remote with 40 Feet of Shielded cable and 15 Pin Transform
T/SGS3.5FY-0	TRANSFORMER, 3.5KVA TRANSFORMERS, 208V PRIMARY/250V SECONDARY
T/SGS1.0FY-0	TRANSFORMER, 1.0KVA TRANSFORMERS, 208V PRIMARY/220V SECONDARY
NIL5-ECTPAU-R01	DS820 POWER AMPLIFIER & THROTTLE PAU, 15 AMP RACK MOUNT
1TDT2	EXHAUST COOLING FAN
2ZWT2	PUMP/MOTOR (1.5 HP)
1219-440A3	1/4" OD FLAME RETARDANT TUBING, WHITE STRIP, 250 ft
1219-440B3	1/4" OD FLAME RETARDANT TUBING, RED STRIPE, 250 ft
1219-440C3	1/4" OD FLAME RETARDANT TUBING, ORANGE STRIPE, 250 ft
1219-440D3	1/4" OD FLAME RETARDANT TUBING, YELLOW STRIPE, 250 ft
1219-440E3	1/4" OD FLAME RETARDANT TUBING, GREEN STRIPE, 250 ft
1219-440F3	1/4" OD FLAME RETARDANT TUBING, BLUE STRIPE, 250 ft
1219-440G3	1/4" OD FLAME RETARDANT TUBING, VIOLET STRIPE, 250 ft
1219-44003	1/4" OD FLAME RETARDANT TUBING, NO STRIPE, 250 ft
5100270606	HORIBA MEXA-730, A/F Ratio Analyzer
3200199647	HORIBA SENSOR CABLE, 10 M
3200202803	HORIBA SENSOR
HW111 2024E	MULTICONDUCTOR THERMOCOUPLE CABLE. 24 PAIR, 50 FT, ANSI TYPE EX, 20 AWG
E40107	DYNO FLOW SWITCH ADAPTER
SI5000	DYNO FLOW SWITCH
SM9000	Large flow meter with calibration
E40229	Adaptor for large flow meter
SM8000	Small flow meter with calibration
US0041	Adaptor for small flow meter
EVC006	Cord set, Micro DC-4 wire
5-160-02-008-002	HEAT EXCHANGER - Oil and Blowby
5-160-03-024-002	HEAT EXCHANGER
5-030-06-048-002	HEAT EXCHANGER
5-160-02-008-001	HEAT EXCHANGER- - Fuel
CSMN37MM-50	37 PIN D-SUB CABLE, 50 FT
60745K471	ROD END, 5/8" FEMALE
4213K146	FLOW SIGHT GAGE
60645K421	BALL JOINT ROD END, 1/4" W/ STUD
60645K321	BALL JOINT ROD END, 1/4"
93013A813	SPACER, 1/2" OD, 1/4" ID, 7/8" LENGTH
91465A110	SQUARE HEAD BOLT, 1/4-20, 2" LENGTH

3131T58	HOSE HANGER
289-624	WAGO Break Out Module-37 Pin female
281-901	WAGO, 2 Wire
281-402	WAGO-JMPR
280-833	WAGO-AC-3-STACK
281-652	WAGO-4 Hole
282-698/281-434	WAGO-Fuse Holder
281-302	WAGO-End Cap
280-547	WAGO-AC-3-STACK
284-601	WAGO - Large Gauge
CMFS010M335N2BAE2ZZ	FLOWMETER
2500D3ABBAEZZZ	FLOWMETER TRANSMITTER
VAS 3-A544-2M	DIN CABLE
960-068-003	AIR REGULATOR (SOLD IN TWO PIECES) (REGULATOR 960-068-003) (ADJ KNOB 82510)
F74G-4AN-QP3	MOISTURE TRAP/FILTER
4338-05	ELEMENT, 40
4380-700	SERVICE KIT, F74
JWS300-15	SUPPLY-15VDC@16.5A
51-902	CUTOFF DISCONNECT SWITCH
EZ-202	DRAIN VALVE
SJP4-24-E	Omega T/C Panel
730-N2-1-E0-PV1-V4-0	SIERRA FLOWMETER
BVR	OVERFLOW RESERVOIR
E7T2-9C407-BA	FUEL PUMP
16321-1	PDB (G), Power Distribution Block
16321-3	PDB (L1/L2/N), Power Distribution Block
9001SKR9R	E-Stop, Actuator
9001KA1	E-Stop, Contactor - NC
050200C1-0001B	SILICON RUBBER HEATER
L21EX1A	WATLOW FIREROD CARTRIDGE
X27620-652-00	TYPE E SERIALIZED THERMOCOUPLE 1/8"X2"
X27621-652-00	TYPE E SERIALIZED THERMOCOUPLE 1/8"X3"
X27622-652-00	TYPE E SERIALIZED THERMOCOUPLE 1/8"X4"
X27623-652-00	TYPE E SERIALIZED THERMOCOUPLE 1/4"X4"
13301	FUEL PRESSURE REGULATOR
HPG1	FILTER, Fuel, With Mount Housing
TEI-HPG1-ALT	TEI-HPG1-ALT: FUEL FILTER CANISTER (Replaces FRAM HPG1)
HPGC1	FRAM Replacement Fuel Filter Elements
23682	REMOTE OIL FILTER ADAPTER
SEQIVB-02-02-03	EXHAUST TURN-DOWN PIPE
SEQIVB-02-02-05	EXHAUST BRASS GASKET

SEQIVB-02-02-04	EXHAUST INSULATION WRAP (2 PIECES)
SEQIVB-02-03-01	EXHAUST SAMPLE TUBE
SEQIVB-03-03-02	LOAD CELL ADAPTER
BRD7	SwRI Interface Board Digital, 8Ch Interface Board
PB-16H	SwRI 16 Channel I/O board
SEQIVB-CABLE-01	ACTUATOR ENCODER CABLE
SEQIVB-CABLE-02	AUXILIARY CABLE
SEQIVB-CABLE-03	DYNO CONTROL CABLE
SEQIVB-CABLE-04	THROTTLE CONTROL CABLE
SEQIVB-CABLE-05	ACTUATOR MOTOR CABLE
SEQIVB-CABLE-06	ECPAU POWER CABLE
SEQIVB-CABLE-07	RECEPTACLE BOX CABLE
SEQIVB-CABLE-08	REMOTE BASIC PLUG
SEQIVB-CABLE-09	THROTTLE ACTUATOR CABLE
SEQIVB-CABLE-10	SIERRA FLOW METER CABLE
SEQIVB-CABLE-11	LOAD CELL CABLE
SEQIVB-CABLE-12	MAGNETIC RPM PICK-UP CABLE
SEQIVB-TBC-004	THROTTLE ACTUATOR COVER
SEQIVB-CABLE-13	MICRO-MOTION CABLE
SEQIVB-05-03	ACTUATOR MOUNTING PLATE MOD
ARTHR-2149	1/4" SWGLK QC4 with 1/4" Male End Connector
SS-QC4-B2-4PF	SS, QUICK CONNECT BLKHEAD 1/4'FNPT W/2 Panel Nut**
SS-QC4-B2-400	1/4 SWGLK W/TWO PANEL NUTS (standard config)
329920HPIW	EXHAUST BOLTED CLAMP 2"
E40107	DYNO FLOW SWITCH ADAPTER
E40229	Adaptor for large flow meter SM9000
US0041	Adaptor for small flow meter SM8000
EVC006	CABLE
SM9000	Large flow meter with calibration
SM8000	Small flow meter with calibration
IVB001-5	FLYWHEEL GUARD
08F23C6240A3FPH7	FUEL SOLENOID VALVE
SEQIVB-HOSE-08-01	Crankcase Ventilation to Flowmeter, 3/8" Tygon S3 B-44-3, 7.25" long, (connects with 3/8" ID Hose Barb, SS, not included)
SEQIVB-HOSE-08-02	Crankcase Ventilation to Trap, 5/8" Tygon S3 B-44, 60" long, (connects with 5/8" ID Hose Barb, SS, not included)
SEQIVB-HOSE-01-01	Chilled Water Return Oil Cooler, Gates LOL, 1/2" ID, Black, 149" long, (connects with 08 Push On / Female 37° Swivel, Brass, not included)
SEQIVB-HOSE-01-02	Chilled Water Supply Oil Cooler, Gates LOL, 1/2" ID, Black, 120" long, (connects with 08 Push On / Female 37° Swivel, Brass, not included)
SEQIVB-HOSE-01-03	Chilled Water Supply, RAC Research Valve, Gates LOL, 1/2" ID, Black, 60" long, (connects with 08 Push On / Female 37° Swivel, Brass, not included)
SEQIVB-HOSE-01-04	Chilled Water Supply, Fuel Research Valve, Gates LOL, 1/2" ID, Black, 60" long, (connects with 08 Push On / Female 37° Swivel, Brass, not included)

SEQIVB-HOSE-01-05	Chilled Water Return, RAC Research Valve, Gates LOL, 1/2" ID, Black, 48" long, (connects with 08 Push On / Female 37° Swivel, Brass, not included)
SEQIVB-HOSE-01-06	Chilled Water Return, Fuel Research Valve, Gates LOL, 1/2" ID, Black, 48" long, (connects with 08 Push On / Female 37° Swivel, Brass, not included)
SEQIVB-HOSE-01-07	Chilled Water Supply, Oil Research Valve, Gates LOL, 1/2" ID, Black, 48" long, (connects with 08 Push On / Female 37° Swivel, Brass, not included)
SEQIVB-HOSE-01-08	Chilled Water Return, Oil Research Valve, Gates LOL, 1/2" ID, Black, 30" long, (connects with 08 Push On / Female 37° Swivel, Brass, not included)
SEQIVB-HOSE-02-01	RAC Coolant Supply B, Gates LOL, 3/4" ID, Black, 168" long, (connects with -12 Push On / Female 37° Swivel, Brass, not included)
SEQIVB-HOSE-02-02	RAC Coolant Supply A, Gates LOL, 3/4" ID, Black, 162" long, (connects with -12 Push On / Female 37° Swivel, Brass, not included)
SEQIVB-HOSE-02-03	RAC Coolant Return B, Gates LOL, 3/4" ID, Black, 144" long, (connects with -12 Push On / Female 37° Swivel, Brass, not included)
SEQIVB-HOSE-02-04	RAC Coolant Return A, Gates LOL, 3/4" ID, Black, 138" long, (connects with -12 Push On / Female 37° Swivel, Brass, not included)
SEQIVB-HOSE-02-05	Dyno Water Supply, Manifold, Gates LOL, 3/4" ID, Black, 30" long, (connects with -12 Push On / Female 37° Swivel, Brass, not included)
SEQIVB-HOSE-02-06	Dyno Water Return, Manifold, Gates LOL, 3/4" ID, Black, 30" long, (connects with -12 Push On / Female 37° Swivel, Brass, not included))
SEQIVB-HOSE-04-01	Fuel Return, Gates PTFE 1/4" ID, SS Braided, 102" long with 04-04 PTFE Crimp, SAE 37° (JIC) swivels, SS
SEQIVB-HOSE-04-02	Exhaust B/P, PEX, Gates PTFE 1/4" ID, SS Braided, 48 " long with 04-04 PTFE Crimp, SAE 37° (JIC) swivels, SS
SEQIVB-HOSE-04-03	Oil Gallery, PLG, Gates PTFE 1/4" ID, SS Braided, 42" long with 04-04 PTFE Crimp, SAE 37° (JIC) swivels, SS
SEQIVB-HOSE-04-04	Crankcase, PCK, Gates PTFE 1/4" ID, SS Braided, 36" long with 04-04 PTFE Crimp, SAE 37° (JIC) swivels, SS
SEQIVB-HOSE-04-05	Exhaust A, Gates PTFE 1/4" ID, SS Braided, 33" long with 04-04 PTFE Crimp, SAE 37° (JIC) swivels, SS
SEQIVB-HOSE-04-06	Exhaust B, Gates PTFE 1/4" ID, SS Braided, 24" long with 04-04 PTFE Crimp, SAE 37° (JIC) swivels, SS
SEQIVB-HOSE-04-07	Intake Manifold, PIM, Gates PTFE 1/4" ID, SS Braided, 24" long with 04-04 PTFE Crimp, SAE 37° (JIC) swivels, SS
SEQIVB-HOSE-04-08	Intake Air, PIA, Gates PTFE 1/4" ID, SS Braided, 18" long with 04-04 PTFE Crimp, SAE 37° (JIC) swivels, SS
SEQIVB-HOSE-04-09	Fuel Rail, PFL, Gates PTFE 1/4" ID, SS Braided, 18" long with 04-04 PTFE Crimp, SAE 37° (JIC) swivels, SS
SEQIVB-HOSE-04-10	Fuel Return, Panel, Gates PTFE 1/4" ID, SS Braided, 15" long with 04-04 PTFE Crimp, SAE 37° (JIC) swivels, SS
SEQIVB-HOSE-04-11	Oil Sampling, Gates PTFE 1/4" ID, SS Braided, 15" long with 04-04 PTFE Crimp, SAE 37° (JIC) swivels, SS
SEQIVB-HOSE-05-01	Fuel Supply, Gates PTFE 3/8" ID, SS Braided, 102" long with 06-06 PTFE Crimp, SAE 37° (JIC) swivels, SS
SEQIVB-HOSE-05-02	Fuel Rail, Gates PTFE 3/8" ID, SS Braided, 24" long with 06-06 PTFE Crimp, SAE 37° (JIC) swivels, SS
SEQIVB-HOSE-05-03	Fuel Supply, Panel, Gates PTFE 3/8" ID, SS Braided, 15" long with 06-06 PTFE Crimp, SAE 37° (JIC) swivels, SS
SEQIVB-HOSE-06-01	Oil from Filter, Gates PTFE 1/2" ID, SS Braided, 14" long with 08-08 PTFE Crimp, SAE 37° (JIC) swivels, SS
SEQIVB-HOSE-06-02	Oil In, Gates PTFE 1/2" ID, SS Braided, 11" long with 08-08 PTFE Crimp, SAE 37° (JIC) swivels, SS
SEQIVB-HOSE-06-03	Oil Out, Gates PTFE 1/2" ID, SS Braided, 9.5" long with 08-08 PTFE Crimp, SAE 37° (JIC) swivels, SS

SEQIVB-HOSE-07-01	Engine Coolant Supply, Eaton Class A Heater hose 1”ID Blue, 144" long, (conects with 1" ID Hose Barb, SS, not included)
SEQIVB-HOSE-07-02	Engine Coolant Return, Eaton Class A Heater hose 1”ID Blue, 132" long, (conects with 1" ID Hose Barb, SS, not included)
SEQIVB-HOSE-07-03	Dyno Water Supply, Eaton Class A Heater hose 1”ID Blue, 16" long, (conects with 1" ID Hose Barb, SS, not included)
SEQIVB-HOSE-07-04	Dyno Water Return, Eaton Class A Heater hose 1”ID Blue, 16" long, (conects with 1" ID Hose Barb, SS, not included)
T-Couple Extension #1	Thermal Couple Extension Cable, 84 inches long, Type E with male and female connectors
T-Couple Extension #2	Thermal Couple Extension Cable, 86 inches long, Type E with male and female connectors
T-Couple Extension #3	Thermal Couple Extension Cable, 64 inches long, Type E with male and female connectors
T-Couple Extension #4	Thermal Couple Extension Cable, 61 inches long, Type E with male and female connectors
T-Couple Extension #5	Thermal Couple Extension Cable, 84 inches long, Type E with male and female connectors
T-Couple Extension #7	Thermal Couple Extension Cable, 86 inches long, Type E with male and female connectors
T-Couple Extension #8	Thermal Couple Extension Cable, 67 inches long, Type E with male and female connectors
T-Couple Extension #11	Thermal Couple Extension Cable, 100 inches long, Type E with male and female connectors
T-Couple Extension #12	Thermal Couple Extension Cable, 100 inches long, Type E with male and female connectors
T-Couple Extension #13	Thermal Couple Extension Cable, 86 inches long, Type E with male and female connectors
T-Couple Extension #15	Thermal Couple Extension Cable, 65 inches long, Type E with male and female connectors
BPO-2288-08-08	1/2" ID, -08 Push On / Female 37° Swivel, Brass
BPO-2288-12-12	3/4" ID, -12 Push On / Female 37° Swivel, Brass
SEQIVB-RCT01	Rocker Cover Table
SMN-5250-U	Flow Switch
B70227	O-Ring for oil filter adaptor (Buna A70)
SEQIVB-02-10-02	Oil Filter Adapter Sleeve Nut
SEQIVB-02-10-01	Oil Filter Adaptor
85472	Oil Separator

ANNEX A10

TEST FUEL CHEMICAL SPECIFICATIONS

A10.1 CERTIFICATE OF ANALYSIS:

PRODUCT: **KA24E TEST FUEL**

PRODUCT CODE: **HF0008**

Batch No.: ______________
TMO No.: ______________
Tank No.: ______________
Date: ______________

TEST	METHOD	UNITS	SPECIFICATIONS			RESULTS
			MIN	TARGET	MAX	
Distillation, % Evap - IBP	ASTM D86[1]	°F	75		95	
5%		°F				
10%		°F	120		135	
20%		°F				
30%		°F				
40%		°F				
50%		°F	200		230	
60%		°F				
70%		°F				
80%		°F				
90%		°F	300		325	
95%		°F				
Distillation - EP		°F	385		415	
Recovery		vol %		Report		
Residue		vol %		Report		
Loss		vol %		Report		
Gravity @ 60 °F	ASTM D4052	°API	58.7		61.2	
Density @ 15 °C	ASTM D4052	kg/l	0.734		0.744	
Reid Vapor Pressure	ASTM D5191	psi	8.8		9.2	
Carbon	ASTM D5291	wt fraction	0.8580		0.8667	
Carbon	ASTM D3343	wt fraction		Report		
Sulfur	ASTM D2622	wt %	0.0120		0.0140	
Lead	ASTM D3237	g/gal			0.05	
Oxygen	ASTM D4815	wt %			0.2	
Composition, aromatics	ASTM D5769	vol %			35.0	
Composition, olefins	ASTM D6550	vol %	5.0		10.0	
Composition, saturates	Calc	vol %		Report		
Oxidation Stability	ASTM D525	minutes	1440			
Copper Corrosion, 3 hr @ 50° C	ASTM D130	Class			1	
Gum content, unwashed	ASTM D381	mg/100ml			10	
Gum content, washed	ASTM D381	mg/100ml			5	
Research Octane Number	ASTM D2699	Rating	96.0		97.5	
Motor Octane Number	ASTM D2700	Rating		Report		
R+M/2	D2699/2700	---		Report		
Sensitivity	D2699/2700	---	7.5			
Net Heat of Combustion	ASTM D240	btu/lb		Report		
Color	Visual			Green		

Quality Assurance Technician ______________________________

ANNEX A11

IVB Extended Shutdown Oxidation Protection Procedure.

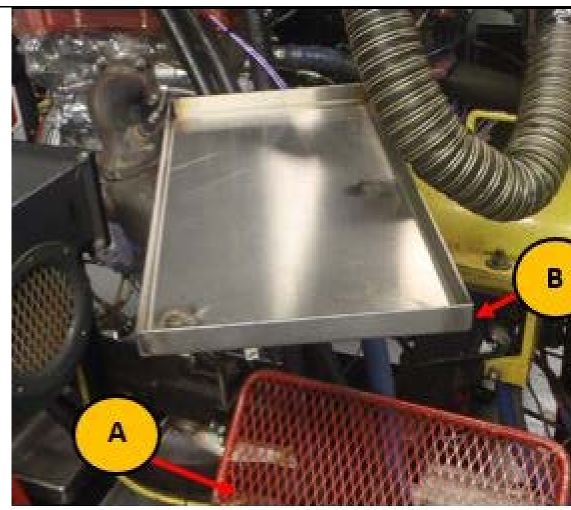
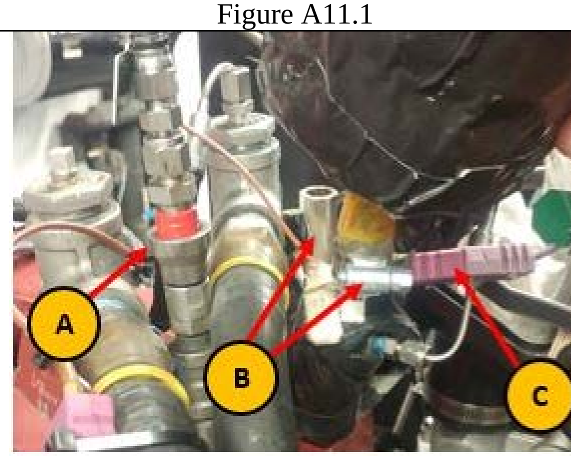
A11.1 This section outlines the procedure for an IVB test which has accumulated test time and is experiencing a shutdown where the engine and test parts are static and cannot be protected by the normal oiling that occurs in a running engine.

A11.2 If a test experiences an unscheduled shutdown that exceeds 2.0 hours, or if a test has reached end of test and the camshafts and lifters cannot be removed within 2.0 hours of EOT, then this procedure shall be performed within 2.0 hours.

A11.3 Use the proper Personal Protection Equipment (PPE) to accomplish this procedure.

A11.4 *Procedure*

A11.4.1 Ensure the test stand that has been shut down properly, so the engine cannot be cranked.

A11.4.2 Remove the exhaust safety guard (A) and install the jacketed rocker cover table (B). (Refer to Fig A11.1) 1) Rocker cover table is TEI part# - SEQIVB-RCT-01. 2) Clean the surface of the jacketed rocker cover table to ensure that the valve cover is not contaminated.	 Figure A11.1
A11.4.3 Jacketed rocker cover disconnect. (Refer to Fig. A11.2) 1) Remove the crankcase pressure transducer line (A) 2) Remove the oil separator (B) from the OHT jacketed rocker cover and swing it out of position for clearance. 3) Disconnect the blow-by gas out thermocouple (C)	 Figure A11.2

A11.4.4 Coil pack removal. (Refer to Fig. A11.3)

1) Using a 5 mm Allen drive socket wrench, remove the bolts securing each of the four (4) coil packs.
2) Keep the coil packs connected to the harness.
3) The spaces between the intake manifold runners (B) are a good location to place the coil packs once removed.

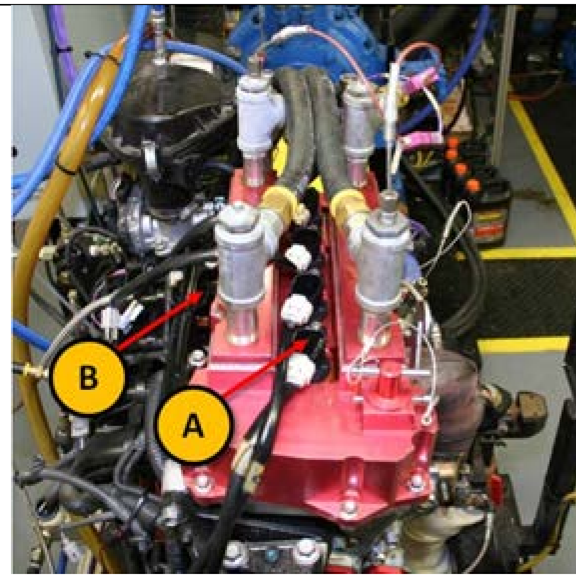


Figure A11.3

A11.4.5 Jacketed rocker cover removal.
(Refer to Fig. A11.4)

1) Starting with #1 in Fig. A11.4 loosen the bolts in the order shown.
2) Remove all fasteners and prepare to lift cover off engine.

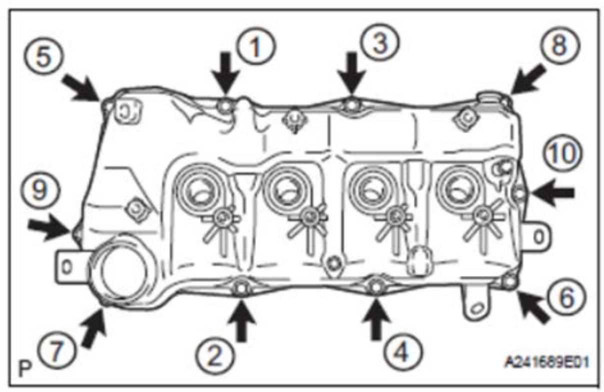


Figure A11.4

A11.4.5 Jacketed rocker cover removal to support tray.
(Refer to fig. A11.5)

1) Carefully lift the jacketed rocker cover up over the valve train components and position the assembly on the rocker cover table.

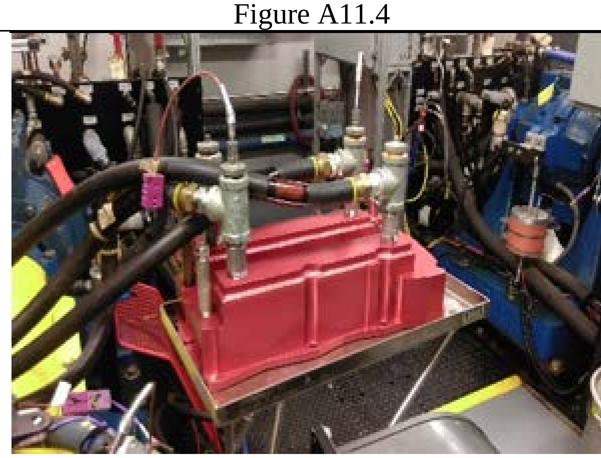
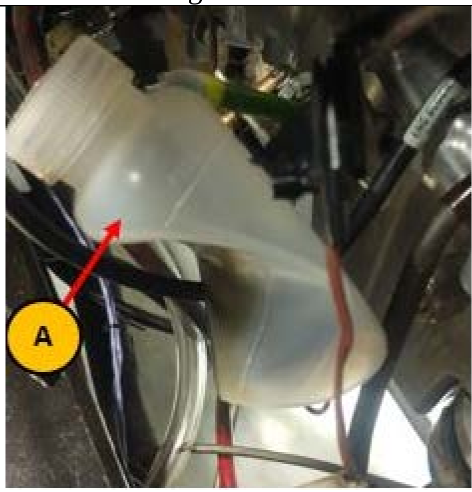


Figure A11.5

<table>
<tr><td>A11.4.6 Remove the oil dipstick plug from the intake side of the OHT modified oil pan (A) (Refer to Fig. A11.6)</td><td>
Figure A11.6</td></tr>
<tr><td>A11.4.7 Oil extraction for valve train oiling.
(Refer to Fig. A11.7)

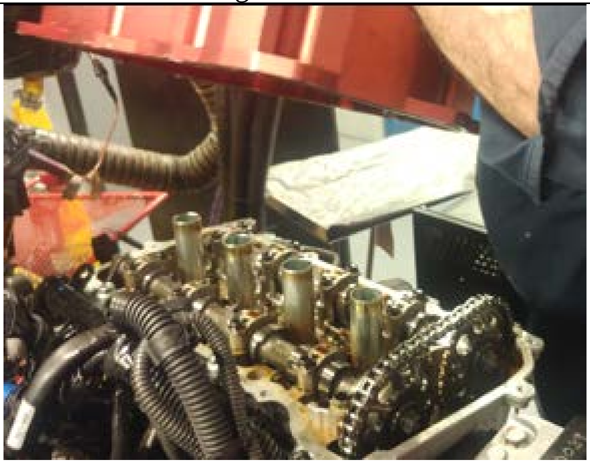
1) Use a clean Thermo Scientific Nalgene 2402-0250 Unitary Wide-Mouth Wash Bottle, 250 ml (A) with an 12” length of Tygon F-4040-A, 1/4" ID X 3/8" OD. Hose.
2) Position the bottle so the Tygon hose can be extended into the oil through the oil dipstick access hole.
3) Squeeze the clean empty bottle then insert the hose into the oil and let the bottle extract the test oil until the bottle is approximately ¼ full.

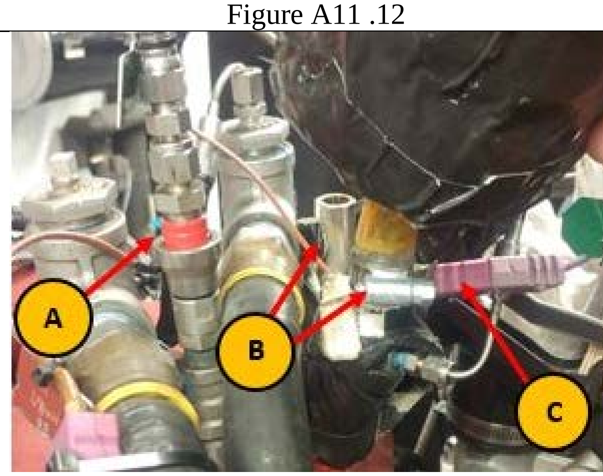
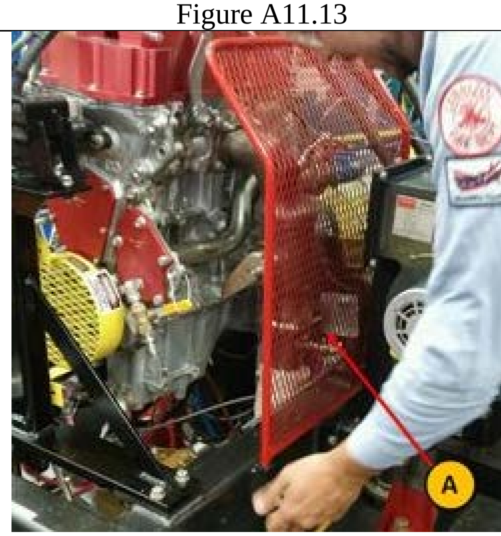
Note - Use caution not to spill any of the test oil.</td><td>
Figure A11.7</td></tr>
<tr><td>A11.4.8 Lubricating the valve train components.
(Refer to Fig. A11.8)

1) Carefully remove the hose and bottle from under the intake manifold and position over the valve deck.
2) Thoroughly coat the camshafts and bucket lifters with the test oil that was obtained from the test oil pan.
3) Completely dispense the test oil, to ensure there is no excess oil left in the bottle.</td><td>
Figure A11.8</td></tr>
</table>

<table>
<tr><td>A11.4.9 Reinsert the oil dipstick plug from the intake side of the OHT modified oil pan (A). (Refer to Fig. A11.9)</td><td>Figure A11.9</td></tr>
<tr><td>A11.4.10 Valve train component protection.
(Refer to Fig. A11.10)

1) Place a clean stock valve cover over the valve deck to prevent contamination of the test engine and or oil.
2) Identify the bottle with the test number and oil code so it is not used on a different test.
3) Keep the bottle and hose at the test stand until the EOT test parts have been removed or engine is ready for re-start.
4) The bottle can be cleaned and reused or properly disposed of after the test cams have been removed.</td><td>Figure A11.10</td></tr>
<tr><td>A11.4.11 Engine re-assembly after extended shut-down.
(Refer to Fig. A11.11)

1) Remove the stock plastic valve cover.
2) Carefully swing the jacketed rocker cover back over the cylinder head and carefully position on the engine.
3) Ensure the spark plug oil seals are in position and the jacketed cover oil seal between the cover and cylinder head are in the correct positions.
4) Insert the fasteners and hand tighten following the sequence shown in Figure A11.4.
5) Torque the fasteners in sequence to 10 N·m (88 lbf-in)</td><td>Figure A11.11</td></tr>
</table>

A11.4.12 Coil pack installation. (Refer to Fig. A11.12) 1) Install the four (4) coil packs and fasteners. 2) Using a 5 mm Allen socket, torque the coil pack fasteners to 5 N·m (44 lbf-in).	 Figure A11 .12
A11.4.13 Reconnecting the jacketed rocker cover components. (Refer to Fig. A11.13) 1) Reconnect the crankcase pressure transducer line (A). 2) Reinstall the Oil separator (B) to the blow-by hose nipple and hand tighten the hose clamp. 3) Replace the insulation on the blow-by hose. 4) Reconnect the blow-by gas out thermocouple (C).	 Figure A11.13
A11.4.14 Exhaust Guard. (Refer to Fig. A11.14) 1) Remove the jacketed rocker cover table. 2) Reinstall the exhaust guard (A). 3) Proceed to the engine startup procedure.	 Figure A11.14

ANNEX A12

Stand Maintenance Procedure after a Camshaft Lobe Failure

A12.1 Annex A12 is written to provide clarity on cleaning the external oil and blow-by systems after a test which experienced camshaft lobe failure.

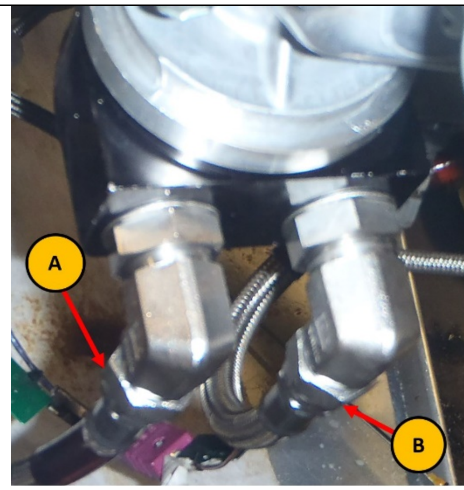
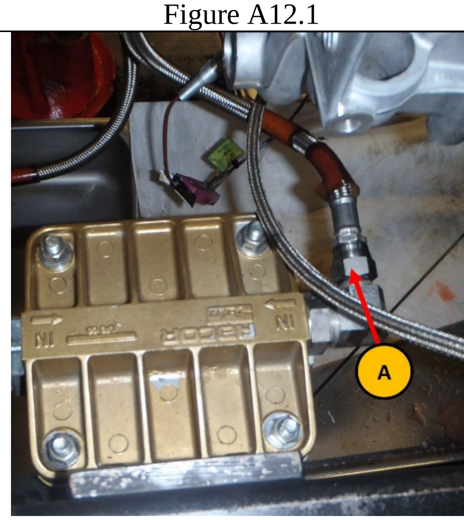
A12.1.2 Ensure that the external oil system has been drained.

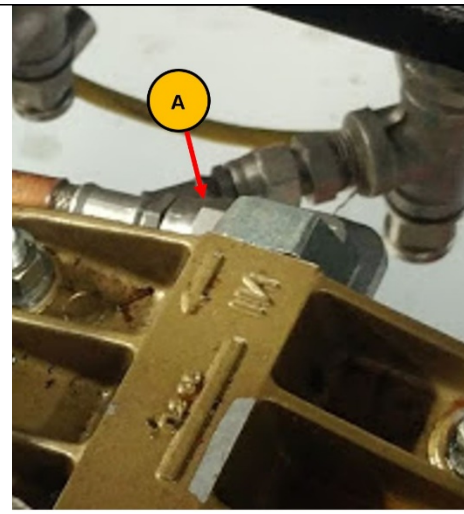
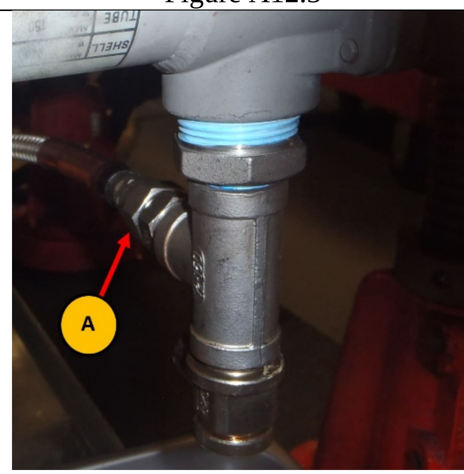
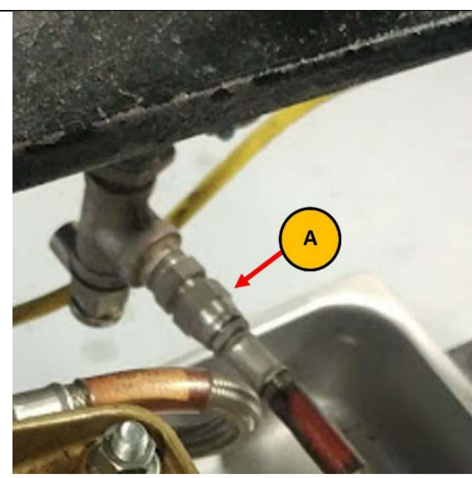
A12.1.3 To prevent contamination of the Portable Oil Cleaning Flush Cart with metal particles, do not perform the external oil system solvent flush procedure as outlined in section 11.3.1.3 on tests that experience camshaft lobe failures.

A12.1.4 Remove and clean the engine which is outlined in a separate procedure.

Note 1 – Use proper Personal Protection Equipment when performing the tasks outlined in these instructions. Follow Federal, State, local and company environmental and safety regulations, guidelines and policies while performing these procedures.

A12.2 Disassembling the external oil system for cleaning after a lobe failure.

A12.2.1 Removal of external oil lines from the remote oil filter adapter. (Refer to fig. A12.1) 1) Turn off the facility chilled water supply and return. 2) With a 7/8” wrench, remove the oil hose that is connected to the “oil in” fitting on the remote oil filter adapter (A). 3) With a 7/8” wrench, remove the oil hose that is connected to the “oil out” fitting on the remote oil filter adapter (B).	 Figure A12.1
A12.2.2 Removal of external oil lines from the remote oil filter housing. (Refer to fig. A12.2) 1) With a 7/8” wrench, remove the oil hose that is connected to the “IN” fitting on the oil filter housing (A).	 Figure A12.2

A12.2.2 Removal of external oil lines from the remote oil filter housing. (Continued) (Refer to fig. A12.3) 2) With a 7/8” wrench, remove the oil hose that is connected to the oil filter housing “OUT” fitting (A). Note—Under side of housing will be marked “OUT”	 Figure A12.3
A12.2.3 Removal of external oil lines from the oil heat exchanger. (Refer to fig. A12.4) 1) With a 7/8” wrench, remove the oil hose that is connected to the heat exchanger “IN” fitting (A).	 Figure A12.4
A12.2.3 Removal of external oil lines from the oil heat exchanger. (Continued) (Refer to fig. A12.5) 2) With a 7/8” wrench, remove the oil hose that is connected to the heat exchanger “OUT” fitting (A).	 Figure A12.5

A12.2.4 Remote oil filter screen housing, fittings, and oil filter screen by-pass component disassembly.
(Refer to figures A12.6 – A12.10)

1) Using a 3/16” Allen wrench remove the two oil filter bracket bolts.

2) Place the filter in an area where it can be disassembled.

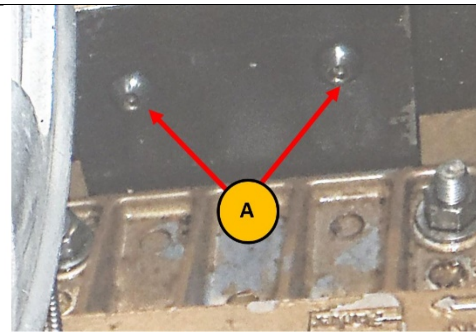


Figure A12.6

A12.2.4.1 Remote oil filter screen housing, fittings, and oil filter screen by-pass component disassembly.
(Continued) (Refer to fig. A12.7)

1) Identify proper orientation scribe marks on the filter housing for the oil filter “In” and “Out” 90° hose fittings and remove (A).
2) Remove the four (4) 3/8 x 24 oil filter housing bolts, nuts, and washers (B).
3) Separate the two housings to expose the internal oil filter screen.

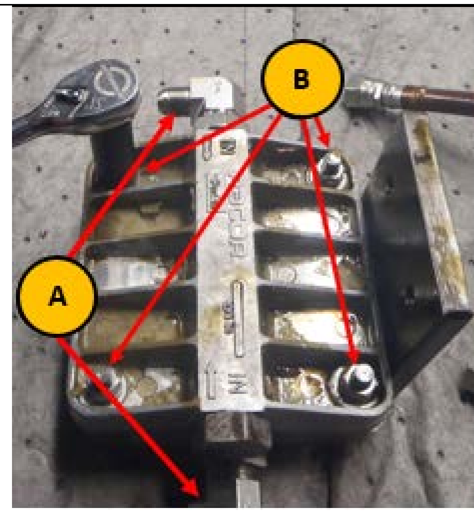


Figure A12.7

A12.2.4.2 Remote oil filter screen housing, fittings, and oil filter screen by-pass component disassembly.
(Continued) (Refer to fig. A12.8)

1) Position the out side of the filter housing up to gain access to the bypass theaded plug (A).
2) Remove the Bypass check ball (B), spring (C), sealing ring (D) and threaded plug (E).
3) Clean all components using degreasing solvent and inspect for debris.
4) Remove all evidence of Teflon Tape from threaded holes in the housings and re-clean as necessary.

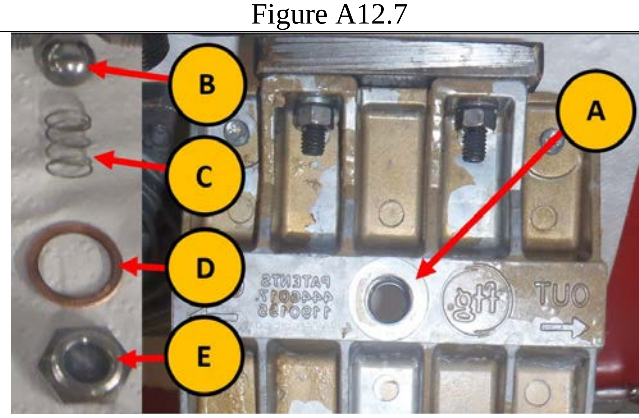
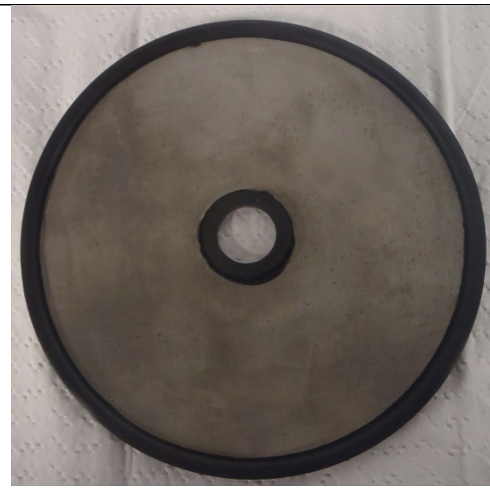
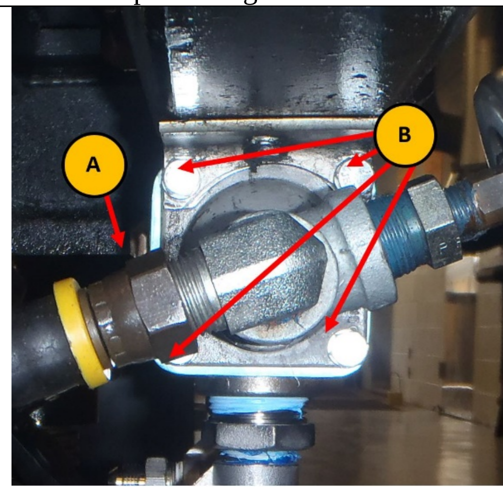
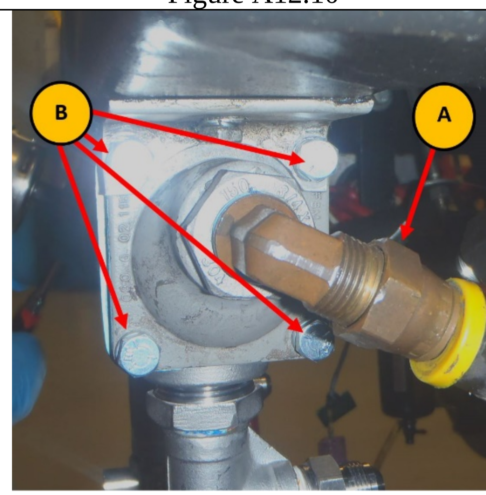
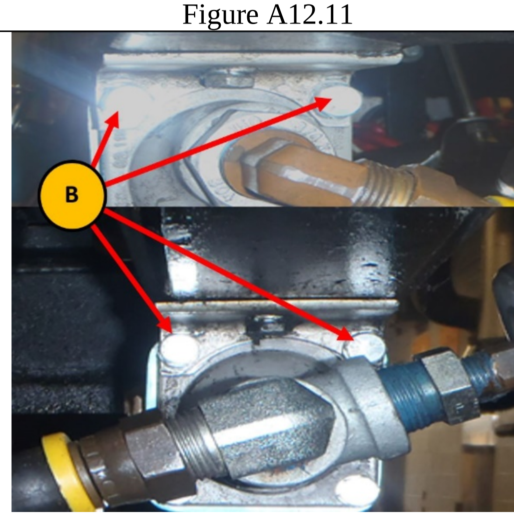


Figure A12.8

A12.2.4.3 Oil filter screen cleaning and inspection. (Refer to fig. A12.9) 1) Using degreasing solvent, wash the 28-micron filter screen and air dry using clean compressed shop air not exceeding 138kpa. (20 psi.). 2) Hold the filter up to a light and inspect the filter after cleaning. 3) Inspect the rubber seals for damage or debris. 4) Look for staining or fine metallic particles from a lobe failure that gets trapped between the screen layers. 5) Discard the filter screen if it has any staining or material between the screen layers.	 Figure A12.9

A12.2.5 External oil heat exchanger disassembly and cleaning procedure after experiencing a camshaft lobe failure.

A12.2.5.1External heat exchanger disassembly. (Refer to fig. A12.10) 1) Place a pan directly under the heat exchanger to catch any fluid that will leak out after the “chilled supply” hose is removed. 2) With a 7/8” wrench, remove the “chilled supply” hose connected to the heat exchanger “IN” fitting (A). 3) Using a 7/16” socket, long extension and ratchet loosen all four of the bolts holding down the heat exchanger cap (B). Note: optional chilled water supply pressure gauge is shown.	 Figure A12.10
A12.2.5.1External heat exchanger disassembly. (Continued) (Refer to fig. A12.11) 1) Place a pan directly under the heat exchanger to catch any fluid that will leak out after the chilled return hose is removed. 2) With a 7/8” wrench, remove the “chilled return” hose connected to the heat exchanger “OUT” fitting (A). 3) Using a 7/16” socket, long extension and ratchet loosen all four of the bolts holding down the heat exchanger cap (B).	 Figure A12.11
A12.2.5.1External heat exchanger disassembly. (Continued) (Refer to fig. A12.12) 1) Hold the heat exchanger to prevent it from falling while removing the stand mounting bolts. 2) Using a 7/16” socket, long extension and ratchet remove the four of the bolts holding the heat exchanger caps to the stand mounts (B). 3) Place the heat exchanger in an area where it can be disassembled. The top stand mount bolts are 1/4” x 20NC x 1”long.	 Figure A12.12

A12.2.6 External oil heat exchanger layout view.
(Refer to fig. A12.13)

1) Scribe marks on the caps and heat exchanger to insure proper reassembly.
2) Using a 7/16" socket, long extension and ratchet remove the four (4) bolts holding the heat exchanger caps to the heat exchanger (A).
3) Discard the gaskets (B).
4) Remove the oil "IN" and "OUT" plumbing assemblies (C).

The top stand mount bolts are 1/4" x 20NC x 3/4" length.

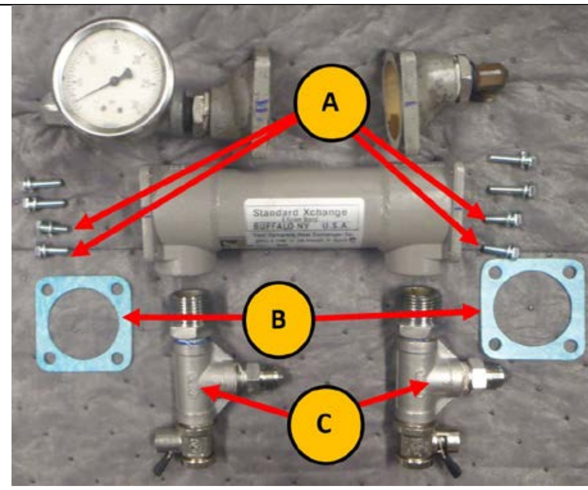


Figure A12.13

A12.2.6 External oil filter housing and heat exchanger layout view. (Refer to fig. A12.14)

1) Parts may be cleaned using degreasing solvent and air dry using clean compressed shop air not exceeding 138kpa. (20 psi.).
2) Parts may also be cleaned using the Ultrasonic cleaner for 1 hour.
    a. Rinse with hot water after cleaning to remove any soap residue.
    b. Solvent wash then let dry before reassembly.


Figure A12.14

A12.2.7 Remote oil filter adapter layout view.
(Refer to fig. A12.15)

1) Using a 1 ½" socket and ratchet remove, then solvent wash and air dry the remote oil filter adapter.

ID	TEI p/n	Description
A	Monroe p/n 4.00 x 62 x 4 B70	4 mm x 62 mm OD O-ring
B	SEQIVB-02-10-01	Oil filter adapter ring
C	Monroe p/n 4.00 x 72 x 4 B70	4 mm x 72 mm OD O-ring
D	MOROSO 23682	Remote oil filter adapter
E	SEQIVB-02-10-02	Oil filter adapter sleeve nut

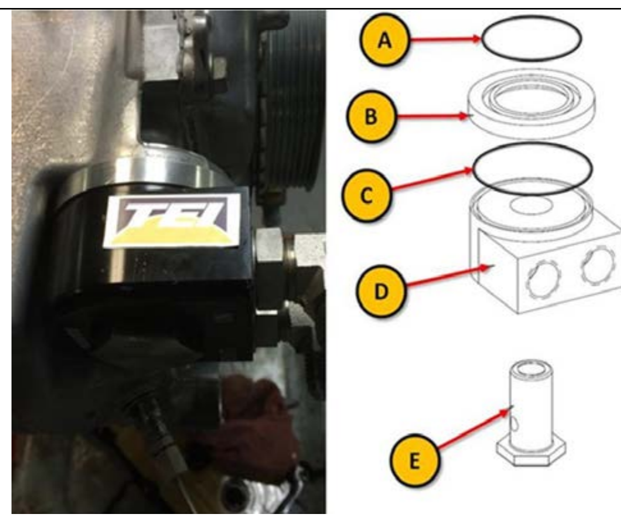


Figure A12.15

<table>
<tr>
<td>
A12.2.8 Oil gallery thermocouple and pressure adapter fitting disassembly. (Refer to fig. A12.16)

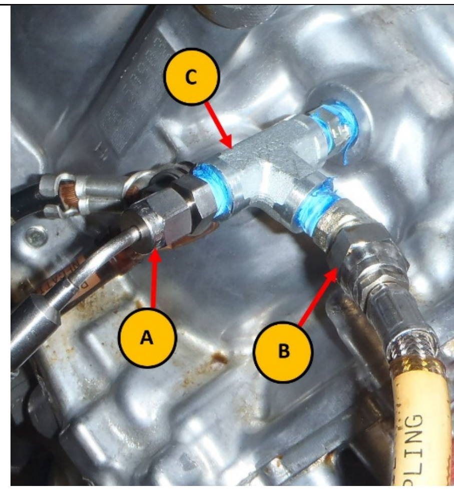
1) Remove the oil gallery thermocouple and wipe clean with degreasing solvent and a suitable cloth (A).
2) Remove the oil sample line from the oil pressure adaptor (B).
3) Remove the oil temperature and pressure adaptor plumbing (C).
</td>
<td>


Figure A12.16
</td>
</tr>
<tr>
<td>
A12.2.9 Oil pressure transducer, and oil sampling system disassembly. (Refer to fig. A12.17)

1) Remove the oil pressure transducer line (A).
2) Remove the oil sampling line from the engine (B).
3) Remove the oil sampling plumbing and gauge (C).
4) Remove the oil sample valve (D).

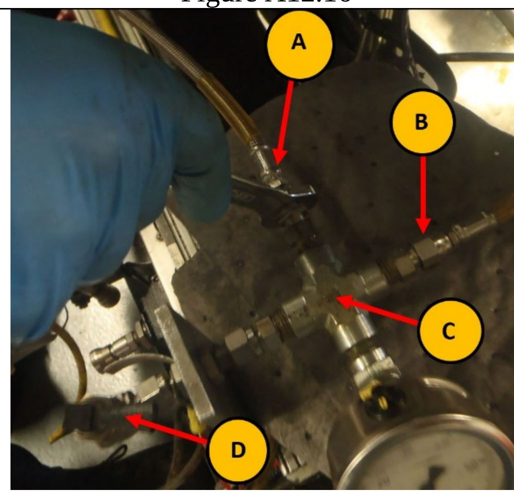
Note—Optional oil pressure gauge is shown.
</td>
<td>


Figure A12.17
</td>
</tr>
<tr>
<td>
A12.2.9 Oil pressure transducer, and oil sampling system disassembly. (Continued) (Refer to fig. A12.18)

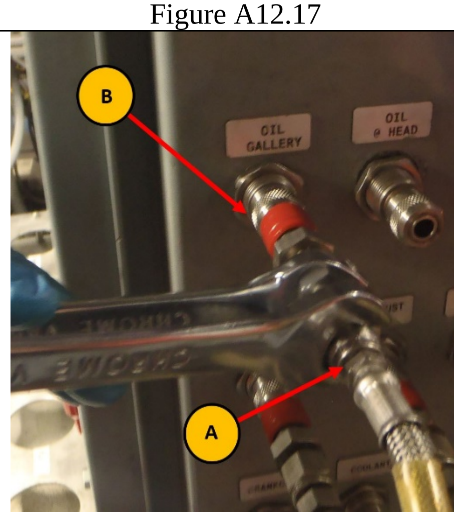
1) Disconnect the oil pressure transducer line (B) from the male ¼” quick connect (A).
2) Remove the male ¼” Quick connect (B).
</td>
<td>


Figure A12.18
</td>
</tr>
</table>

A12.2.10 Oil system, sampling valve, fittings, and hoses layout view. (Refer to fig. A12.19)

1) Clean using degreasing solvent wash to remove any metal debris and oil residues.
2) Dry using clean compressed shop air not exceeding 138kpa. (20 psi.).

Note—Optional oil pressure gauge is shown.

Figure A12.19

A12.2.11 Reference view of the external oil sampling system. (Refer to Fig. 20)

1) Oil sample valve (1)
2) Oil sample valve cap (2)
3) Bulk head fitting adaptor (3)
4) Oil pressure transducer line attached to Pipe tee (4)
5) Engine oil gallery pressure line connection (5)

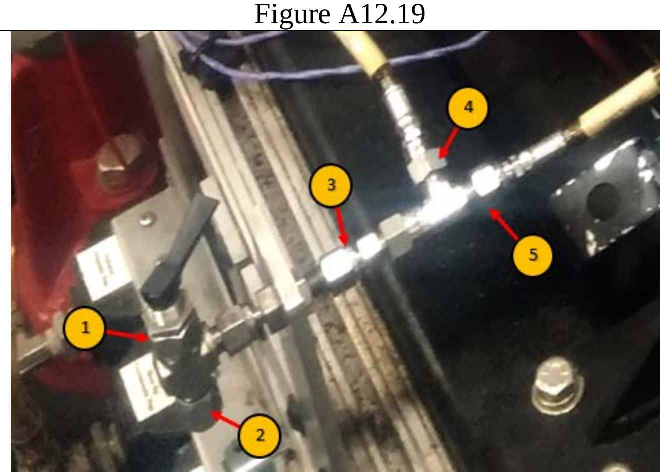


Figure A12.20

A12.2.12 Reference view of external oil sampling system with optional pressure gage. (Refer to Fig. A12.21)

1) Oil sample valve (1)
2) Oil sample valve cap (2)
3) Bulk head fitting adaptor (3)
4) 4-way pipe tee (4)
5) Optional pressure gage (5)

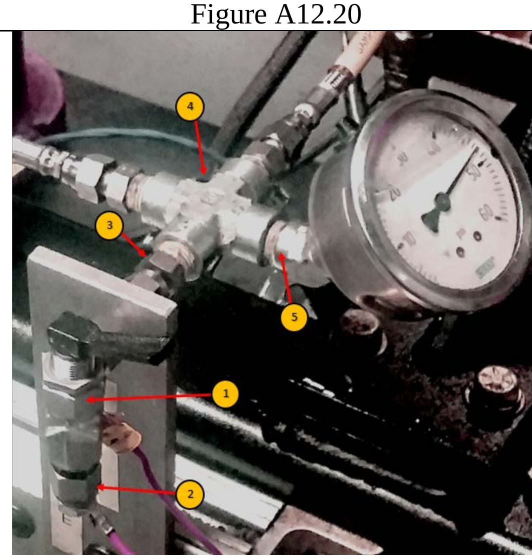
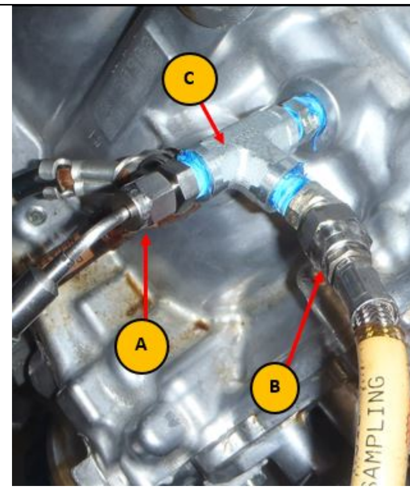
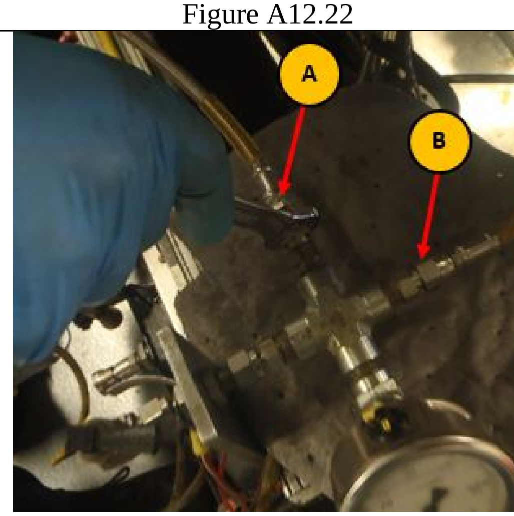
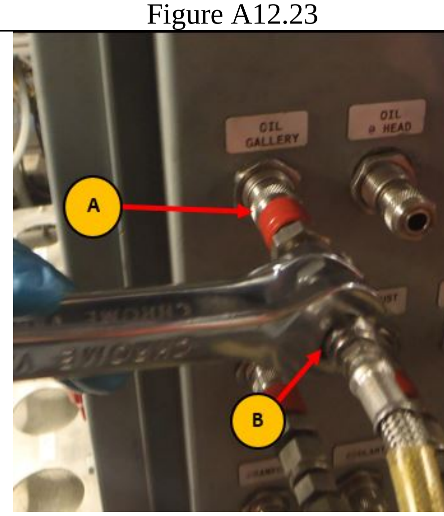


Figure A12.21

A12.3 Reassembly process of the external oil system after cleaning from a lobe failure.

A12.3.1 Reinstall the oil temperature and pressure adapter plumbing. (Refer to fig. A12.22) 1) Reinstall the oil temperature and pressure adaptor plumbing (C). 2) Reinstall the oil gallery thermocouple (A). 3) Reinstall the oil sample line from the oil pressure adaptor (B).	 Figure A12.22
A12.3.2 Reinstall the oil pressure transducer and oil sampling lines. (Refer to fig. A12.23) 1) Reinstall the oil pressure transducer line (A). 2) Reinstall the oil sampling line from the engine (B). Note—Optional oil pressure gauge is shown.	 Figure A12.23
A12.3.2 Reinstall the oil pressure transducer and oil sampling lines. (Continued) (Refer to fig. A12.24) 1) Reconnect the male ¼" quick connect (A). 2) Reinstall the oil pressure transducer line (B) to the male ¼" Quick connect (A).	 Figure A12.24

<table>
<tr>
<td>A12.3.3 Reassembly of the External Oil Cooler. (Refer to fig. A12.25)

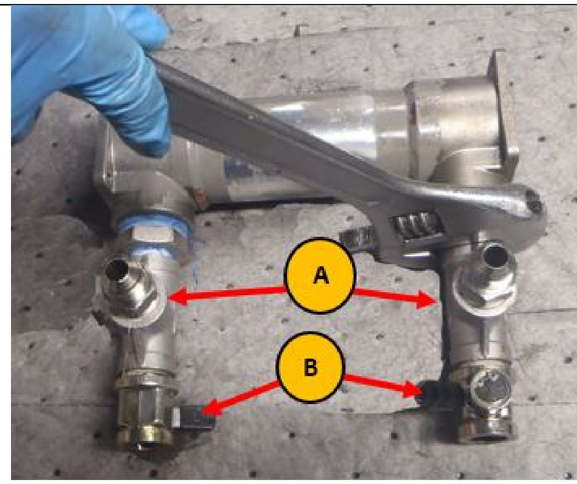
1) Wrap the threaded bushings with five wraps of Teflon Tape.
2) To ensure oil does not come in contact with the Teflon Tape, do not wrap tape past the first set of threads.
3) Reinstall the oil “In” and “Out” assemblies in the proper orientation (A).
4) Close the oil drain valves.</td>
<td>

Figure A12.25</td>
</tr>
<tr>
<td>A12.3.3 Reassembly of the External Oil Cooler. (Continued) (Refer to fig. A12.26)

1) Locate the scribe marks to ensure proper heat exchanger cap orientation (A).
2) Install new gaskets and caps in the correct orientation.
3) Only install and hand tighten the lower bolts (B).

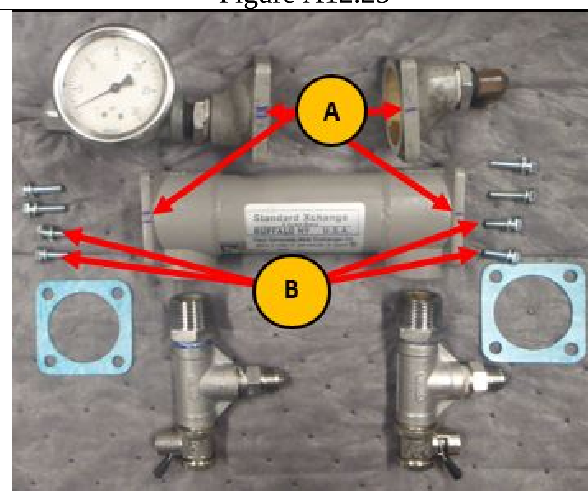
Note—Optional chilled water supply pressure gauge is shown.</td>
<td>

Figure A12.26</td>
</tr>
<tr>
<td>A12.3.3 Reassembly of the External Oil Cooler. (Continued) (Refer to fig. A12.27)

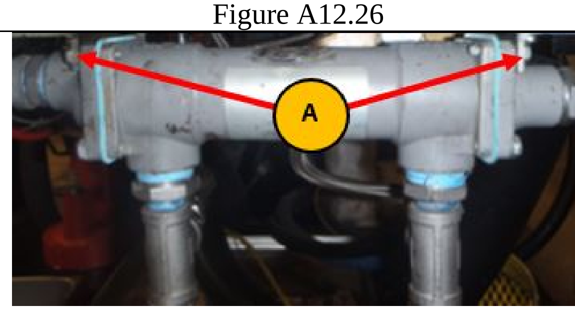
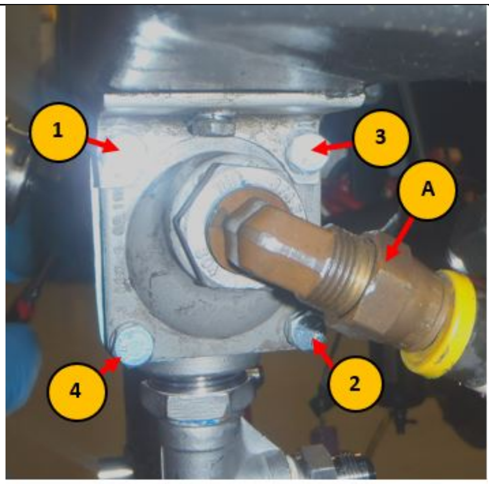
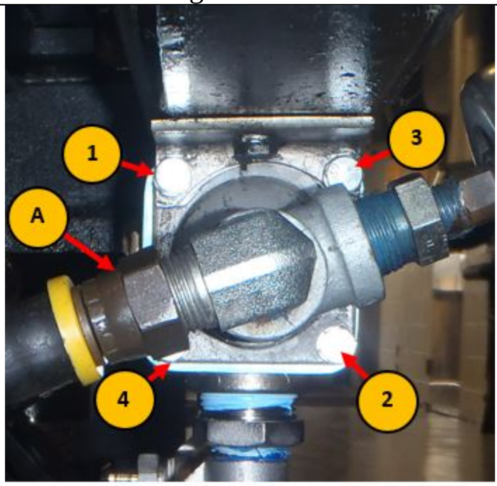
1) Position the oil heat exchanger assembly between the brackets mounts, then install the cap head screws hand tight (A).</td>
<td>

Figure A12.27</td>
</tr>
</table>

A12.3.3 Reassembly of the External Oil Cooler. (Continued) (Refer to fig. A12.28) 1) Using a 7/16" socket, long extension and ratchet tighten all four of the bolts holding down the heat exchanger cap in order from (1) to (4). Torque bolts to 8 lbf·ft. 2) Carefully thread the "chilled return" hose onto the fitting (A). 3) With a 7/8" wrench, tighten the "chilled return" hose that is connected to the heat exchanger "OUT" fitting (A).	 Figure A12.28
A12.3.3 Reassembly of the External Oil Cooler. (Continued) (Refer to fig. A12.29) 1) Using a 7/16" socket, long extension and ratchet tighten all four of the bolts holding down the heat exchanger cap in order from (1) to (4). Torque bolts to 8 lbf·ft. 2) Carefully thread the "chilled supply" hose onto the fitting. 3) With a 7/8" wrench, tighten the "chilled supply" hose that is connected to the heat exchanger "IN" fitting (A).	 Figure A12.29

A12.3.4 Reassembly and mounting of the external oil filter components. (Refer to fig. A12.30)

1) Layout and inspect the cleaned oil filter parts.
2) Replace the O-rings (qty. 4) on all fittings (A).

The O-ring size is 0.139” W x 1 1/8” O.D x 7/8” I.D.
O-ring trade number is 212.
O-ring material is oil resistant Buna.

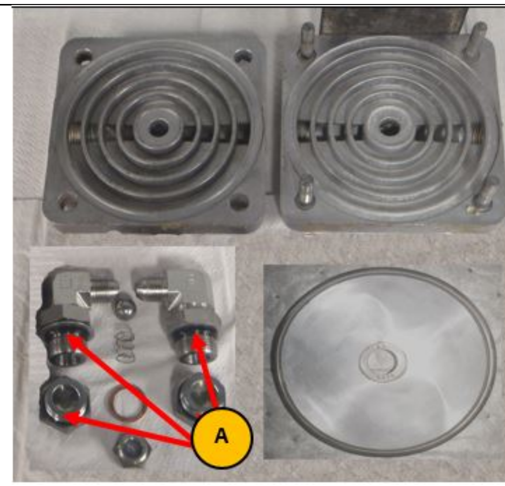


Figure A12.30

A12.3.4 Reassembly and mounting of the external oil filter components. (Continued) (Refer to fig. A12.31)

1) Inspect the oil filter by-pass check ball and seat (A).
2) Check spring uncompressed length it should be 17mm +/- 1mm (B).
3) Replace the Teflon washer with a new copper washer (C).
4) Tighten the Check Ball Assembly retaining plug to 30 lbf·ft. (D).

Copper crush washer size is 18.2 mm I.D x 23.9 mm O.D x 1.7 mm thick.

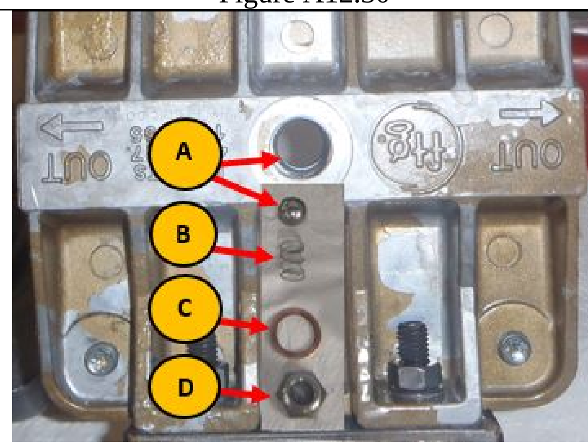


Figure A12.31

A12.3.4 Reassembly and mounting of the external oil filter components. (Continued) (Refer to fig. A12.32)

1) Install the 28-micron filter screen into the lower filter housing. (Identified with “OUT” on the housing)
2) Ensure the letters “IN” are facing up as shown at (A).

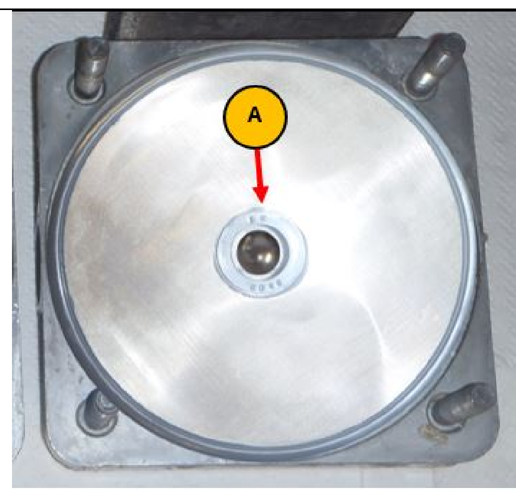


Figure A12.32

A12.3.4 Reassembly and mounting of the external oil filter components. (Continued) (Refer to fig. A12.33)

1) Carefully install the upper filter housing to insure the filter screen does not become misaligned.
2) Install (4) 3/8 washers on the lower housing studs.
3) Install (4) 3/8 x 24 NC nuts on the lower housing studs.
4) Hand tighten the (4) nuts then torque in sequence from (1) to (4), to 20 lbf·ft.

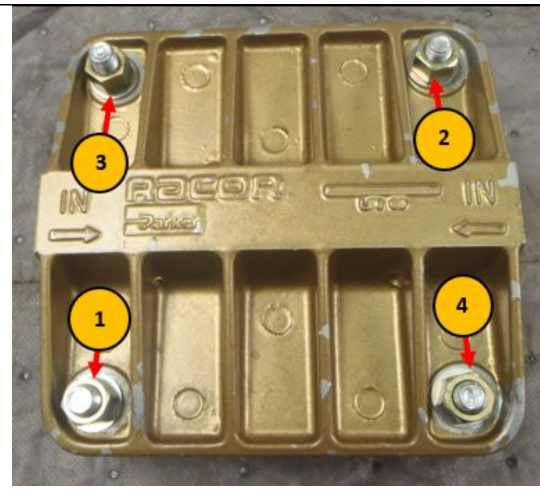


Figure A12.33

A12.3.4 Reassembly and mounting of the external oil filter components. (Continued) (Refer to fig. A12.34)

1) Install the 90° hose fittings in their proper locations.
2) Oil “OUT” hose fitting is in the lower filter housing (A).
3) Oil “IN” hose fitting is in the upper filter housing (B).
4) Plug (C) is in the upper filter housing.
5) Plug (D) is in the lower filter housing.

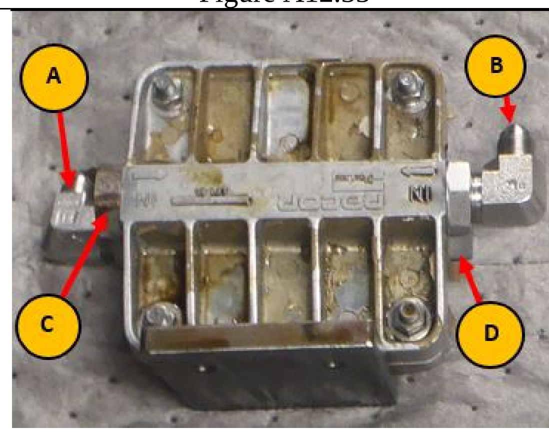


Figure A12.34

A12.3.4 Reassembly and mounting of the external oil filter components. (Continued) (Refer to fig. A12.35)

1) Position the oil filter assembly on the engine cradle then install the cap head screws hand tight.
2) Using a 3/16” Allen wrench install the (20 oil filter bracket bolts. Torque to 10 lbf·ft.

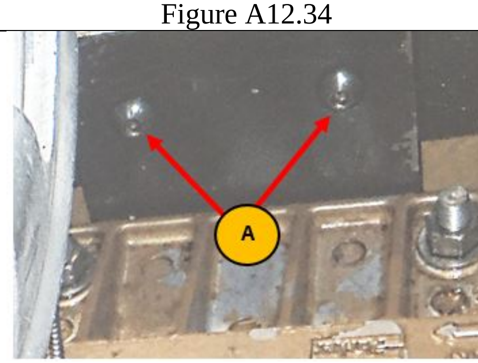


Figure A12.35

A12.3.5 Remote oil filter adapter layout view.
(Refer to fig. A12.36)

1) Using a 1 ½" socket and ratchet attach the remote oil filter adapter assembly to the engine.

ID	TEI p/n	Description
A	Monroe p/n 4.00 x 62 x 4 B70	4 mm x 62 mm OD O-ring
B	SEQIVB-02-10-01	Oil filter adapter ring
C	Monroe p/n 4.00 x 72 x 4 B70	4 mm x 72 mm OD O-ring
D	MOROSO 23682	Remote oil filter adapter
E	SEQIVB-02-10-02	Oil filter adapter sleeve nut

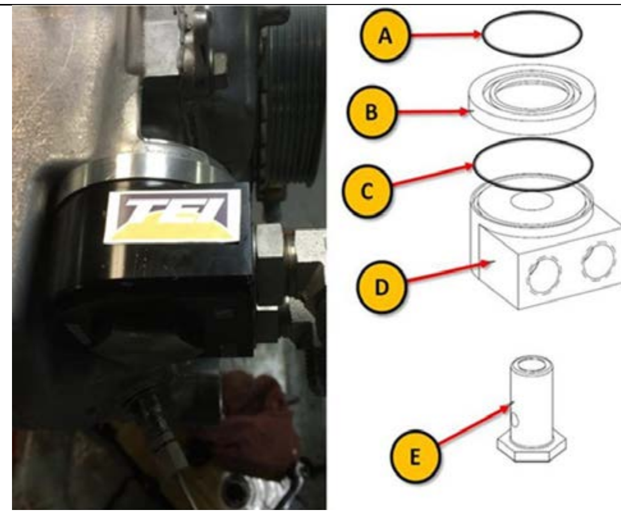


Figure A12.36

A12.3.6 External oil line connections. (Refer to fig. A12.37)

1) Solvent wash and air dry the oil hoses.
2) Install the oil hoses as per figure A12.36
3) (A) –TEI - SEQIVB-Hose-06-01. (14 inches long)
4) (B) – TEI - SEQIVB-Hose-06-02. (11 inches long)
5) (C) – TEI - SEQIVB-Hose-06-03. (9 inches long)

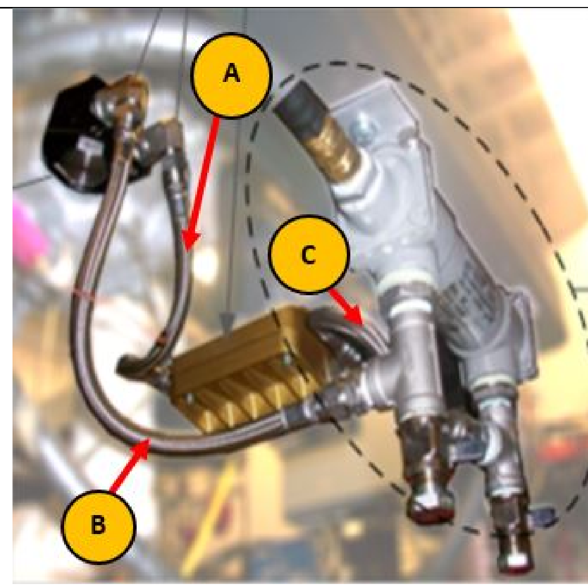


Figure A12.37

A12.4 Removal and cleaning process for the external breather and oil separator assemblies after completion of a test that experienced a camshaft lobe failure.

A12.4.1 Disassembly of the Air Box and Oil Seperator.
(Refer to Fig. A12.38)

1) Remove the 2 hitch pins (A) that attach the box to the heat exchanger bracket.
2) Remove the hose from the combustion air tube.
3) Lift the box off of the bracket to gain acess to the heat exchanger.
4) Remove the insulation from the oil seperator “IN” hose then loosen the hose clamp.
5) After the clamp has been loosened separate the oil “IN” hose from the valve cover (B).

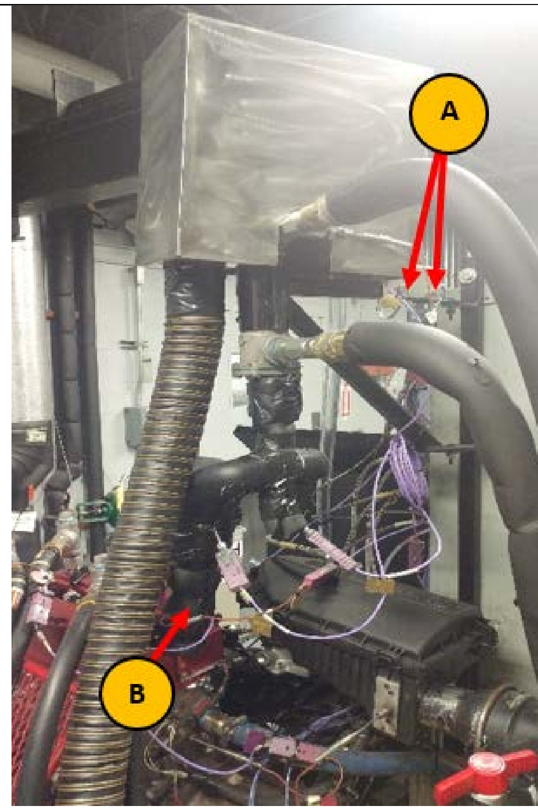


Figure A12.38

A12.4.2 Breather system coolant connections and thermocouple disconnect.
(Refer to Fig. A12.39)

1) Remove the blow-by hose (A) from the top of the heat exchanger.
2) With the system drained, disconnect the quick connectors (B) for the coolant “IN” and “OUT” hoses.
3) Remove the thermocouples;
   a.) Blowby Gas temperature (C)
   b.) Blowby coolant Tempature “OUT” (D)
   c.) Blow-by coolant “IN” (E) (optional T/C)
   d.) Blow-by heat exchanger “IN” (F) (optional T/C)
   e.) Blow-by oil seperator (G) (optional T/C)
4) Remove the insulation then loosen the oil seperator hose clamp (H).

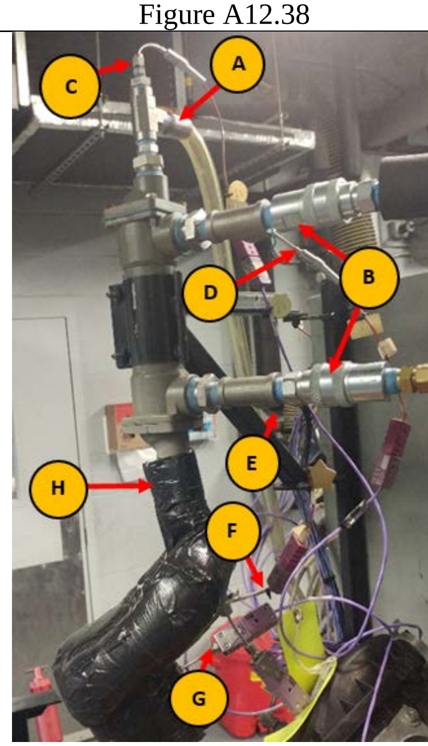
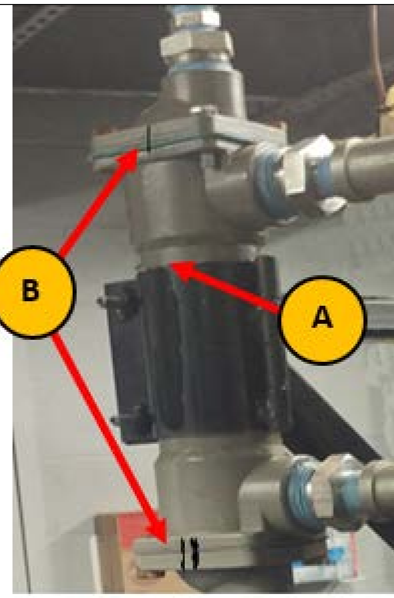
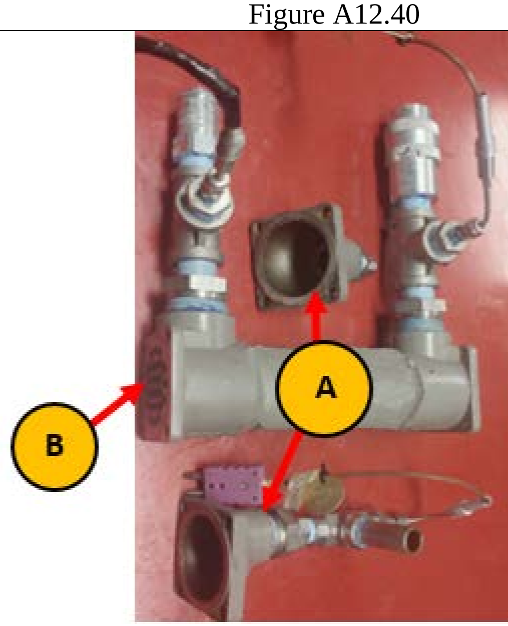


Figure A12.39

<table>
<tr>
<td>A12.4.3 Blow-by heat exchanger marking and removal.
(Refer to Fig. A12.40)

1) Scribe the heat exchanger and clamp to ease reinstallation (A).
2) Mark the blow-by heat exchanger end caps to ease in reassembly (B).
3) Remove the two ¼” x 20NC x 1 “ bolts to release the heat exchanger clamp.
4) Place the blow-by heat exchanger in an area where it can be disassembled.</td>
<td>
Figure A12.40</td>
</tr>
<tr>
<td>A12.4.4 Blow-by heat exchanger disassembly and cleaning. (Refer to Fig. A12.41)

1) Remove the 8 - ¼” x 20NC x ¾” “ end cap bolts then remove the blow-by heat exchanger end caps (A).
2) Discard the end cap gaskets.
3) Solvent wash the end caps and blow-by heat exchanger tubes (B) to remove any oil or metal particles.
4) Dry using clean compressed shop air that does not exceed 138 kPa (20 psi.)

(optional Thermocouple tap shown in figure)</td>
<td>
Figure A12.41</td>
</tr>
</table>

A12.4.5 Blow-by heat exchanger assembly.
(Refer to Fig. A12.42)

1) Reassemble the blow-by heat exchanger using new gaskets.
2) Ensure that the caps are oriented in the correct position.
3) Install the 8 - ¼” x 20NC x ¾” “ end cap bolts.
4) Tighten the bolts in an “X” pattern.
5) Torque to 11 N·m (8 lbf.ft) in an “X” pattern.

(optional Thermocouple tap shown in figure)

Figure A12.42

A12.4.6 Blow-by heat exchanger test stand installation.
(Refer to Fig. A12.43)

1) Align the scribe marks on the heat exchanger and clamp (A).
2) Install the two ¼” x 20NC x 1“ bolts to secure the heat exchanger.

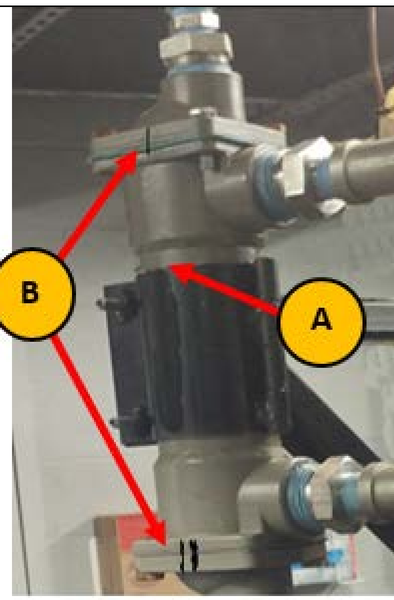


Figure A12.43

A12.4.7 Oil seperator assembly.
(Refer to Fig. A12.44)

1) Remove oil seperator assembly and remove the insulation, hoses and hose clamps.
2) Top plumbing without Thermocouple (A).
3) Top plumbing with Thermocouple (B).
4) Oil seperator with optional Thermocouple (C).

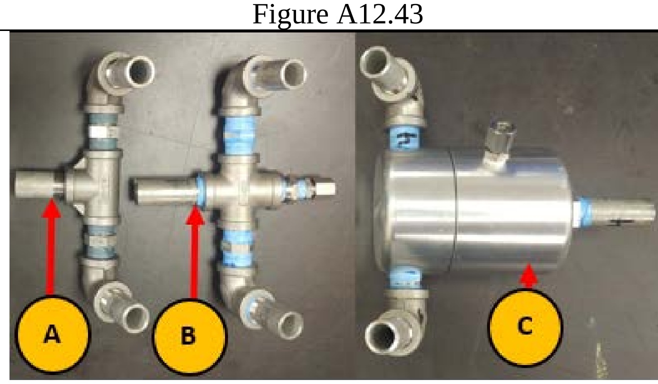


Figure A12.44

A12.4.8 Oil seperator cleaning.
(Refer to Fig. A12.45)

1) Disassemble the oil seperator.
2) Solvent wash the oil seperator and top plumbing (A, B, and C refer to figure 43) to remove any heavy fouling.
3) Ultrasonic clean the oil seperator and top plumbing (A, B, and C refer to figure 43) for 20 minutes then wash with hot water to remove the all soapy residue.
4) Reassemble the oil seperator using a new O-ring.
5) Solvent washed seperator example (A).
6) Ultrasonic washed oil seperator example (B).

Figure A12.5
O-ring is VITON, dash number 038.
1/16 W x 2 ¾ O.D. X 2 5/8 I.D.

See Annex A8 for additional detailed instructions on oil separator final assembly and foam insulation requirements.

ANNEX A13

Oxidation and Nitration Measurement Technique

A13. Integrated and Peak Method Techniques.

A13.1 Utilize a nominally 0.1 mm path length cell. BaF_2, KBr and ZnSe cells have been found suitable. Measured units are absorbance per centimeter (Abs/cm). The FTIR device is not specified, any commercially available device maybe used.

A13.2 Obtain the spectra of the fresh oil and corresponding used oils. Subtract the new oil spectra from the used oil and perform the analysis on the differential spectra. If oxidation or nitration absorbance, or both exceeds the linear range of the detector, oxidation or nitration measurements, or both, are not required.

A13.3 Peak area integration, oxidation—Determine area under the curve between baseline endpoints. Draw baseline endpoints in a subjective manner, at the discretion of the operator. Typical endpoints will be the left at around 1800 cm^{-1} (1780 - 1820 cm^{-1}) and the right around 1650 cm^{-1} (1640-1660 cm^{-1}) (See Fig A13.1). Typical peak will fall around 1710 cm^{-1}. If the instrument does not correct to a specific path length in the subtraction process, conversion from the actual path length to a 1 cm path length is required to report the final result. Convert to a 1 cm path length using the following:

$$A_F = 10 \, (A_R / PL_A) \qquad \text{(A13.1)}$$

where:

A_F = final area, Abs/cm,
A_R = raw area = the area determined by the device at the end points and peak, Absorbance units
PL_A = actual path length = the cell path length, mm.

If the instrument does correct to 0.1mm path length during the subtraction process use the following to calculate the final result:

$$A_F = 100 \, A_R \qquad \text{(A13.2)}$$

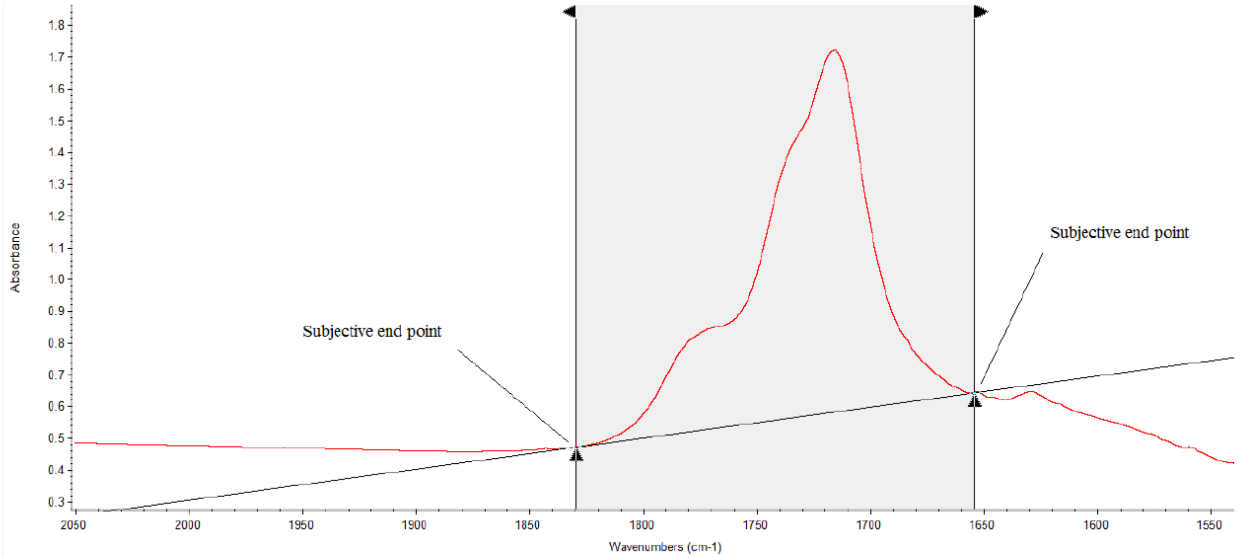


Fig. A13.1

A13.4 Peak area integration, nitration— Determine area under the curve between baseline endpoints. Draw baseline endpoints in a subjective manner, at the discretion of the operator. Typical endpoints will be the left at around 1640 cm^{-1} (1635 - 1645 cm^{-1}) and the right around 1620 cm^{-1} (1615 - 1625 cm^{-1}) (See Fig A13.2). Typical peak will fall around 1633 cm^{-1}. If the instrument does not correct to a specific path length in the subtraction process, conversion from the actual path length to a 1 cm path length is required to report the final result. Convert to a 1 cm path length using equation 13.1.

If the instrument does correct to 0.1mm path length during the subtraction process, convert to 0.1 mm process using equation 13.2.

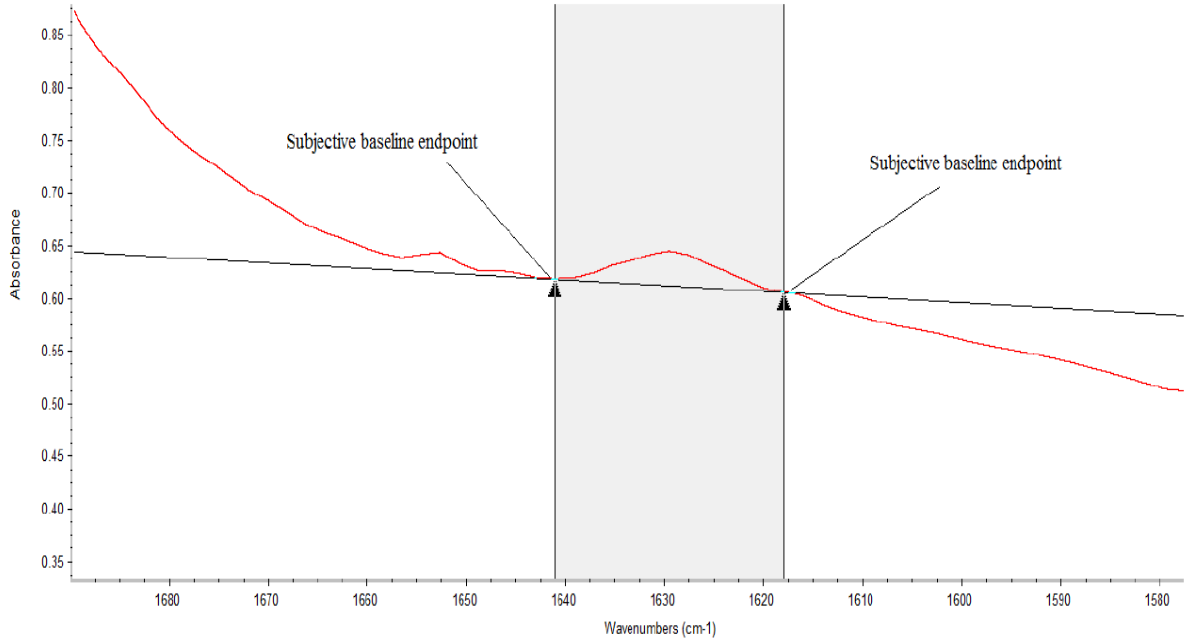

Subjective baseline endpoint
Subjective baseline endpoint
Absorbance
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
1680
1670
1660
1650
1640
1630
1620
1610
1600
1590
1580
Wavenumbers (cm-1)

Fig. A13.2

Appendix X1
Sequence IVB Engine Health Checklist

X1.1 Explanation of Document**:**

X1.1.2 This checklist is to be used at the end of a test to ensure that the engine is suitable for additional testing.

X1.1.3 The items on this checklist are meant to supplement the pre-test and post-test measurements currently being taken (i.e. camshaft end-play, cylinder compression, etc.).

X1.1.4 The items on this checklist are intended to be completed by a mechanic without having to remove the front cover, oil pan or cylinder head.

X1.2 CHECKLIST:

X1.2.1 Hardware Inspection**:**

X1.2.1.2 Measure crankshaft thrust/end play**:**

X1.2.1.3 Place a dial indicator against the front harmonic balancer.

X1.2.1.4 Manually apply force (pushing and pulling) to the balancer and measure its displacement with the dial indicator. (See Fig. X1.1)

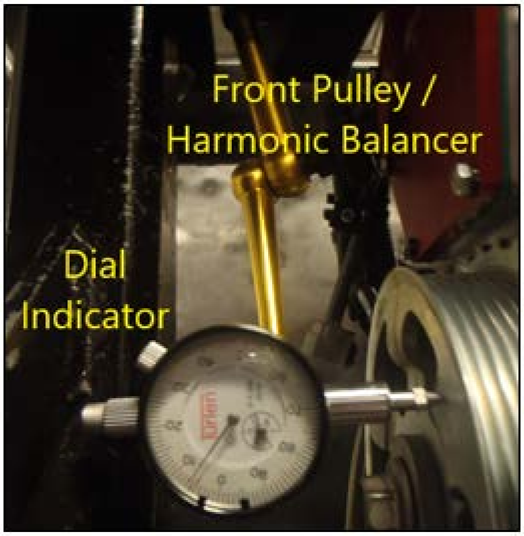


Fig. X1.1

X1.2.2 Inspect Timing Chain and Sprockets**:**

X1.2.2.1 Visually inspect the timing chain links for abnormal or excessive wear.

X1.2.2.2 Check the slack in the chain while the tensioner is pinned to ensure that it cannot jump a tooth on one of the camshaft sprockets. (See Fig. X1.2)

Fig. X1.2

X1.2.2.3 Visually inspect the sprocket teeth for deep scratches or excessive polishing from the timing chain.

X1.2.3 Inspect Valve Stem Tips**:**

X1.2.3.1 Visually inspect the valve stem tips for rounded edges or mushrooming. (See Fig. X1.3)

Fig. X1.3

X1.2.3.2 It may also be useful to inspect the shims from the previous test's lifters.
X1.2.3.3 A deep, round groove in a shim is an indication that the associated valve stem has become deformed. (See Fig. X1.4)

Fig. X1.4

X1.2.4 Inspect Valve Springs and Retainers**:**

X1.2.4.1 Inspect the valve springs and retainers for damage or excessive polishing.

X1.2.5 Rocker Arm Cover**:**

X1.2.5.1 Confirm that none of the bolt holes that connect the OHT rocker arm cover to the front cover have become stripped or elongated.
X1.2.5.2 Stripped threads must be repaired (stainless steel inserts) before the engine can resume operation.

X1.2.6 *Front Cover**:***

X1.2.6.1 Confirm that there is no oil seepage around the mating surfaces between the front cover, oil pan, and engine block.
X1.2.6.2 Small leaks can be repaired externally with an application of silicone over the affected area.

X1.2.7 Spark Plug Isolation Tubes**:**

X1.2.7.1 Shine a light inside of each tube to confirm that there is no oil residue in the bottom.
X1.2.7.2 This can be done just before the spark plugs are removed for end-of-test compression and leak down measurements.

X1.3 Borescope:

X1.3.1 The engine only needs to be inspected with a borescope if the previous test encountered excessive end-of-test iron or oil consumption.

Note – These iron (Fe) and oil consumption thresholds have not yet been established.

X1.3.2 With the borescope inserted through the spark plug hole, inspect the cylinder bores and pistons for signs of damage, scoring, or excessive polishing.

Note **-** A qualitative acceptability limit for bore polishing has not yet been established.

Appendix X2

(Non-mandatory Information)

X2. Useful Information

X2.1 General Communications Concerning Sequence IVB Reference Tests, Procedural Questions and Non-Reference Tests:

ASTM Test Monitoring Center
Attention: Administrator
6555 Penn Avenue
Pittsburgh, PA 15206-4489
Telephone: (412) 365-1030

X2.2 Reference Oils and Calibration Oils:

Purchase reference oils and calibration oils by contacting:
ASTM Test Monitoring Center
Attention: Operations Manager
6555 Penn Avenue
Pittsburgh, PA 15206-4489
Telephone: (412) 365-1031

X2.3 Test Stand:

Purchase Sequence IVB golden test stand and hardware by contacting:
TEST ENGINEERING, INC. (TEI)
12718 Cimarron Path
San Antonio, TX 78249
Telephone: (210) 690-1958
Fax: (210) 690-1959

X2.4 Test Engine:

Purchase Sequence IVB test engines and hardware by contacting:
OH Technologies, Inc.
9300 Progress Parkway
P.O. Box 5039
Mentor, OH 44061-5039
Telephone: (440) 354-7007
Fax: (440) 354-7080

X2.5 Dynamometer:

A Midwest Model 1014A (175-hp) dry gap dynamometer may be ordered from:
DyneSystems Inc.
3602 West Wheelhouse Road
Milwaukee, WI 53208
Telephone: (414) 755-0040

X2.6 Test Fuel:

Purchase Sequence IVB test fuel by contacting:
Haltermann Solutions
15600 West Hardy Rd.
Houston, TX 77060
Telephone: (800) 969-2542

X2.7 Coolant & Rocker Cover Flow Meters: SM8000 SM9000

ifm efector, inc.
1100 Atwater Dr.
Malvern, PA. 19355
Telephone: 800-441-8246

X2.8 Brulin 815 QR-NF and 815 GD

BHC, Inc.
P.O. Box 270
Indianapolis, IN. 46206
Telephone: 317-923-3211