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

This standard is issued under the fixed designation D7320; 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

The test method described in this standard can be used by any properly equipped laboratory; it does not require the assistance of anyone outside that laboratory. However, the ASTM Test Monitoring Center (TMC)[2] provides reference oils and an assessment of the test results obtained on those oils by the laboratory (see Annex A1). By these means, the laboratory will know whether their use of the test method gives results statistically similar to those obtained by other laboratories. Furthermore, various agencies require that a laboratory utilize the TMC services in seeking qualification of oils against specifications. For example, the U.S. Army imposes such a requirement in connection with several Army engine lubricating oil specifications.

Accordingly, this test method is written for use by laboratories that utilize the TMC services. Laboratories that choose not to use those services may simply ignore those portions of the test method that refer to the TMC.

This test method may be modified by means of Information Letters issued by the TMC. In addition, the TMC may issue supplementary memoranda related to the test method (see A1.8).

1. Scope

1.1 This test method covers an engine test procedure for evaluating automotive engine oils for certain high-temperature performance characteristics, including oil thickening, varnish deposition, oil consumption, as well as engine wear. Such oils include both single viscosity grade and multiviscosity grade oils that are used in both spark-ignition, gasoline-fueled engines, as well as in diesel engines.

1.1.1 Additionally, with nonmandatory supplemental requirements, a IIIGA Test (Mini Rotary Viscometer and Cold Cranking Simulator measurements), a IIIGVS Test (EOT viscosity increase measurement), or a IIIGB Test (phosphorous retention measurement) can be conducted. These supplemental test procedures are contained in Appendixes Appendix X1, Appendix X2, and Appendix X3, respectively.

NOTE 1—Companion test methods used to evaluate engine oil performance for specification requirements are discussed in SAE J304.

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 *Exception*—Where there is no direct SI equivalent such as screw threads, national pipe threads/diameters, and tubing size.

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 in 6.14.1.1 and 7.1.

1.4 This test method is arranged as follows:

[1] This test method is under the jurisdiction of ASTM Committee D02 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.B0.01 on Passenger Car Engine Oils.

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[2] Until the next revision of this test method, the ASTM Test Monitoring Center will update changes in the test method by means of information letters. Information letters may be obtained from the ASTM Test Monitoring Center, 6555 Penn Avenue, Pittsburgh, PA 15206-4489. Attention: Administrator. This edition incorporates revisions in all information letters through No. 11–1.

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D86 Test Method for Distillation of Petroleum Products at Atmospheric Pressure
D130 Test Method for Corrosiveness to Copper from Petroleum Products by Copper Strip Test
D235 Specification for Mineral Spirits (Petroleum Spirits) (Hydrocarbon Dry Cleaning Solvent)
D240 Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter
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)
D1319 Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption
D2699 Test Method for Research Octane Number of Spark-Ignition Engine Fuel
D2700 Test Method for Motor Octane Number of Spark-Ignition Engine Fuel
D3231 Test Method for Phosphorus in Gasoline
D3237 Test Method for Lead in Gasoline by Atomic Absorption Spectroscopy
D3244 Practice for Utilization of Test Data to Determine Conformance with Specifications
D3338 Test Method for Estimation of Net Heat of Combustion of Aviation Fuels
D3343 Test Method for Estimation of Hydrogen Content of Aviation Fuels
D4052 Test Method for Density, Relative Density, and API Gravity of Liquids by Digital Density Meter
D4175 Terminology Relating to Petroleum, Petroleum Products, and Lubricants
D4485 Specification for Performance of Active API Service Category Engine Oils
D4684 Test Method for Determination of Yield Stress and Apparent Viscosity of Engine Oils at Low Temperature
D4815 Test Method for Determination of MTBE, ETBE, TAME, DIPE, tertiary-Amyl Alcohol and C_1 to C_4 Alcohols in Gasoline by Gas Chromatography
D5185 Test Method for Determination of Additive Elements, Wear Metals, and Contaminants in Used Lubricating Oils and Determination of Selected Elements in Base Oils by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES)
D5191 Test Method for Vapor Pressure of Petroleum Products (Mini Method)
D5293 Test Method for Apparent Viscosity of Engine Oils and Base Stocks Between –5 and –35°C Using Cold-Cranking Simulator
D5452 Test Method for Particulate Contamination in Aviation Fuels by Laboratory Filtration
D5453 Test Method for Determination of Total Sulfur in Light Hydrocarbons, Spark Ignition Engine Fuel, Diesel Engine Fuel, and Engine Oil by Ultraviolet Fluorescence
D5862 Test Method for Evaluation of Engine Oils in Two-Stroke Cycle Turbo-Supercharged 6V92TA Diesel Engine[4]
D6593 Test Method for Evaluation of Automotive Engine Oils for Inhibition of Deposit Formation in a Spark-Ignition Internal Combustion Engine Fueled with Gasoline and Operated Under Low-Temperature, Light-Duty Conditions
D6750 Test Methods for Evaluation of Engine Oils in a High-Speed, Single-Cylinder Diesel Engine—1K Procedure (0.4 % Fuel Sulfur) and 1N Procedure (0.04 % Fuel Sulfur)
D6984 Test Method for Evaluation of Automotive Engine Oils in the Sequence IIIF, Spark-Ignition Engine
D7422 Test Method for Evaluation of Diesel Engine Oils in T-12 Exhaust Gas Recirculation Diesel Engine
E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
E191 Specification for Apparatus For Microdetermination of Carbon and Hydrogen in Organic and Organo-Metallic Compounds
E608/E608M Specification for Mineral-Insulated, Metal-Sheathed Base Metal Thermocouples
E1119 Specification for Industrial Grade Ethylene Glycol
IEEE/ASTM SI 10 Standard for Use of the International System of Units (SI): The Modern Metric System[3]

2.2 *Military Specification:*[5]

MIL-PRF-2104, Lubricating Oil, Internal Combustion Engine, Tactical Service

2.3 *SAE Standards:*[6]

J183, Engine Oil Performance and Engine Service Classification (Other Than "Energy-Conserving")
J300, Engine Oil Viscosity Classification *HS-23/00
J304, Engine Oil Tests

2.4 *Other ASTM Documents:*

Guidelines for Calibration[7]

[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.

[4] Withdrawn. The last approved version of this historical standard is referenced on www.astm.org.

[5] Hardcopy available from Document Automation and Production Service, Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094. Also, can be downloaded from internet address: http://assist2.daps.dla.mil/quicksearch/.

[6] Available from Society of Automotive Engineers, 400 Commonwealth Dr., Warrendale, PA 15096-0001. These standards are not available separately. Order either *SAE Handbook*, Vol. 3, or *SAE Fuels and Lubricants Standards Manual*, HS-23.

[7] Guidelines for Calibration can be found in the Lubricant Test Monitoring System, available from the Test Monitoring Center, http ://www. astmtmc. cmu.edu/

The Lubricant Test Monitoring System, Sequence IIIG Test Control Chart Technique for Developing and Applying Severity Adjustments (SA)[8]

3. Terminology

3.1 *Definitions:*

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

3.1.2 *BTDC (before top dead center)*, *n*—used with the degree symbol to indicate the angular position of the crankshaft relative to its position at the point of uppermost travel of the piston in the cylinder. **D4175**

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

3.1.4 *clogging*, *n*—the restriction of a flow path due to the accumulation of material along the flow path boundaries. **D4175**

3.1.5 *cold-stuck piston ring*, *n—in internal combustion engines*, a piston ring that is stuck when the piston and ring are at room temperature, but inspection shows that it was free during engine operation.

3.1.5.1 *Discussion*—A cold-stuck piston ring cannot be moved with moderate finger pressure. It is characterized by a polished face over its entire circumference, indicating essentially no blowby passed over the outside of the ring during operation. **D6593**

3.1.6 *correction factor*, *n*—a mathematical adjustment to a test result to compensate for industry wide shifts in severity.

3.1.7 *corrosion*, *n*—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. **D4175**

3.1.8 *debris*, *n—in internal combustion engines*, solid contaminant materials unintentionally introduced into the engine or resulting from wear. **D5862**

3.1.9 *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.

3.1.9.1 *Discussion*—It may contain additives to enhance certain properties. Inhibition of engine rusting, deposit formation, valve train wear, oil oxidation, and foaming are examples. **D6750**

3.1.10 *EWMA*, *n*—abbreviation for exponentially-weighted moving average.

3.1.11 *free piston ring*, *n—in internal combustion engines*, a piston ring that will fall in its groove under the force of its own weight when the piston with the ring in a horizontal plane, is turned 90° (putting the ring in a vertical plane). **D4175**

3.1.11.1 *Discussion*—In determination of this condition, the ring may be touched slightly to overcome static friction.

3.1.12 *hot-stuck piston ring*, *n—in internal combustion engines*, a piston ring that is stuck when the piston and ring are at room temperature, and inspection shows that it was stuck during engine operation.

3.1.12.1 *Discussion*—The portion of the ring that is stuck cannot be moved with moderate finger pressure. A hot-stuck ring is characterized by varnish or carbon across a portion of its face, indicating that portion of the ring was not contacting the cylinder wall during engine operation. **D4175**

3.1.13 *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).

3.1.14 *LTMS date*, *n*—the date the test was completed unless a different date is assigned by the TMC.

3.1.15 *LTMS time*, *n*—the time the test was completed unless a different time is assigned by the TMC.

3.1.16 *lubricant*, *n*—any material interposed between two surfaces that reduces the friction or wear, or both, between them. **D4175**

3.1.17 *lubricating oil*, *n*—a liquid lubricant, usually comprising several ingredients, including a major portion of base oil and minor portions of various additives. **D4175**

3.1.18 *Material Safety Data Sheet, (MSDS)*, *n*—a fact sheet summarizing information about material identification; hazardous ingredients; health, physical, and fire hazards; first aid; chemical reactivities and incompatibilities; spill, leak, and disposal procedures; and protective measures required for safe handling and storage. **http://www.msdssearch.com**

3.1.19 *non-compounded engine oil*, *n*—a lubricating oil having a viscosity within the range of viscosities of oils normally used in engines, and that may contain anti-foam agents or pour depressants, or both, but not other additives. **D4175**

3.1.20 *non-reference oil*, *n*—any oil, other than a reference oil; such as a research formulation, commercial oil, or candidate oil. **D4175**

3.1.21 *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.

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

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

3.1.23.1 *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. **D4175**

3.1.24 *rust (coatings)*, *n—of iron or its alloys*, a corrosion product consisting of hydrated iron oxides, usually reddish in color, but can also be brown-to-black.

3.1.25 *SA*, *n*—abbreviation for severity adjustment.

3.1.26 *scoring*, *n—in tribology*, a severe form of wear characterized by the formation of extensive grooves and scratches in the direction of sliding. **D4175**

[8] Sequence IIIG Test Control Chart Technique For Developing And Applying Severity Adjustments (SA), available at internet address: ftp://ftp.astmtmc.cmu.edu/docs/ltms/ltms.pdf

3.1.27 *scuffing*, *n—in lubrication*, damage caused by instantaneous localized welding between surfaces in relative motion that does not result in immobilization of the parts. **D6593**

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

3.1.28.1 *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.).

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

3.1.30 *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. **D4175**

3.1.31 *varnish*, *n—in internal combustion engines*, a hard, dry, generally lustrous, deposit that can be removed by solvents but not by wiping with a cloth. **D4175**

3.1.32 *wear*, *n*—the loss of material from a surface, generally occurring between two surfaces in relative motion, and resulting from mechanical or chemical action or a combination of both. **D7422**

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *build-up oil*, *n*—EF-411, non-compounded, ISO VG 32 (SAE 10) oil used in lubricating some of the Sequence IIIG parts during engine assembly.

3.2.2 *calibrated test stand*, *n*—a test stand on which Sequence IIIG engine oil tests are conducted within the LTMS as administered by the TMC. (See 10.1.)

3.2.3 *central parts distributor (CPD)*, *n*—the manufacturer and supplier of many of the parts and fixtures used in this test method.

3.2.3.1 *Discussion*—Because of the need for rigorous inspection and control of many of the parts used in this test method, and because of the need for careful manufacture of special parts and fixtures used, companies having the capabilities to provide the needed services have been selected as the official suppliers for the Sequence IIIG test method. These companies work closely with the original parts suppliers, with the Test Procedure Developer, and with the ASTM groups associated with the test method to help ensure that the equipment and materials used in the method function satisfactorily.

3.2.4 *special test parts (STP)*, *n*—parts that do not meet all the definitions of critical parts, non-production parts, or SPO parts, but shall be obtained only from the specified distributor.

3.2.5 *critical parts (CP)*, *n*—those components used in the test, which are known to affect test severity.

3.2.5.1 *Discussion*—Critical parts shall be obtained from the Central Parts Distributor or Special Parts Supplier, who will identify them with either a serial number or a batch/ lot control number.

3.2.6 *EOT time (end of test time)*, *n*—20 min after the engine reaches 100 test h of operation, which allows 120 s for ramp-down/idle, a 15-min wait for oil to drain into the sump, and allows the operator 3.0 min to measure oil level.

3.2.7 *non-production parts (NP)*, *n*—components used in the test, which are available only through the Central Parts Distributor, Special Parts Supplier, or the Test Procedure Developer.

3.2.8 *participating laboratory*, *n*—a laboratory equipped to conduct Sequence IIIG tests, which conducts reference oil tests in cooperation with the TMC, in order to have calibrated test stands available for non-reference oil testing.

3.2.9 *pinched piston ring*, *n*—an installed piston ring which will not move in its groove under moderate finger pressure, but which has a polished face over its entire circumference indicating that it was free during engine operation; The ring may be restricted over varying degrees of its circumference.

3.2.10 *reference oil test*, *n*—a standard Sequence IIIG engine oil test of a reference oil designated by the TMC.

3.2.11 *service parts operations parts (SPO)*, *n*—these test components are obtained from Service Parts Operations a division of General Motors Corporation.

3.2.12 *sluggish piston ring*, *n*—an installed piston ring which it offers resistance to movement in its groove, but it can be pressed into or out of the groove under moderate finger pressure; when so moved, it does not spring back (one that is neither free nor stuck).

3.2.13 *special parts supplier, (SPS)*, *n*—the manufacturer and supplier of many of the parts and fixtures used in this test method.

3.2.14 *special test parts*, *n*—parts that do not meet all the definitions of critical parts, non-production parts, or SPO parts, but shall be obtained from the Special Parts Supplier.

3.2.15 *standard test, (valid test)*, *n*—an operationally valid, full-length Sequence IIIG test conducted on a calibrated test stand in accordance with the conditions listed in this standard.

3.2.16 *stuck piston ring*, *n*—one that is either partially or completely bound in its groove and cannot be readily moved with moderate finger pressure.

3.2.17 *test procedure developer*, *n*—the group or agency which developed the Sequence IIIG test procedure before its standardization by ASTM, and which continues to be involved with the test in respect to modifications in the test method, development of Information Letters, supply of test parts, and so forth.

3.2.17.1 *Discussion*—In the case of the Sequence IIIG test, the Test Procedure Developer is General Motors Research and Development Center.

3.2.18 *test full mark*, *n*—the oil level established after the 10-min initial run-in.

3.2.19 *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 IIIG engine oil test.

3.2.20 *test start*, *n*—introduction of test oil into the engine after the final assembly and mounting in the test stand.

3.2.21 *test start time*, *n*—the time that test oil was introduced into the engine on the test stand.

4. Summary of Test Method

4.1 A 3800 series II V-6 test engine block with a displacement of 3.8 L is solvent-cleaned, measured, and rebuilt; using new parts installed as specified in this test method.

4.2 The engine is installed on a test stand equipped with an appropriate data acquisition system, the required fluids process control system, and all necessary accessories for controlling speed, load, and various other operating parameters.

4.3 The engine is charged with the test oil.

4.4 The engine is operated for an initial run-in period of 10 min to check all test stand operating systems and to establish a zero hour oil level reading and initial oil viscosity sample.

4.5 Following the run-in and oil leveling period of 10 min, the engine is ramped up to test conditions over a 15 min period then operated under non-cyclic, moderately high speed, load, and temperature conditions for 100 h, in 20 h segments.

4.6 The initial oil level in the oil pan is determined after the 10 min initial run-in, and subsequent oil level calculations are determined during the oil leveling period at the end of each 20 h segment.

4.7 Used oil samples are taken after the 10 min initial run-in and after each 20 h test segment; kinematic viscosity at 40 °C is determined for each of the seven samples; the percentage change in viscosity of the five latter samples is determined relative to the viscosity of the first used oil sample (10 min initial run-in).

4.8 At the conclusion of the test, the engine is disassembled and the parts are visually rated to determine the extent of deposits formed. In addition, wear measurements are obtained.

5. Significance and Use

5.1 This test method was developed to evaluate automotive engine oils for protection against oil thickening and engine wear during moderately high-speed, high-temperature service.

5.2 The increase in oil viscosity obtained in this test indicates the tendency of an oil to thicken because of oxidation. In automotive service, such thickening can cause oil pump starvation and resultant catastrophic engine failures.

5.3 The deposit ratings for an oil indicate the tendency for the formation of deposits throughout the engine, including those that can cause sticking of the piston rings in their grooves. This can be involved in the loss of compression pressures in the engine.

5.4 The camshaft and lifter wear values obtained in this test provide a measure of the anti-wear quality of an oil under conditions of high unit pressure mechanical contact.

5.5 The test method was developed to correlate with oils of known good and poor protection against oil thickening and engine wear. Specially formulated oils that produce less than desirable results with unleaded fuels were also used during the development of this test.

5.6 The Sequence IIIG engine oil test has replaced the Sequence IIIF test and can be used in specifications and classifications of engine lubricating oils, such as the following:

5.6.1 Specification D4485,

5.6.2 Military Specification MIL-PRF-2104, and

5.6.3 SAE Classification J183.

6. Apparatus

6.1 *Laboratory*—Observe the following laboratory conditions to ensure good control of test operations, and good repeatability:

6.1.1 Maintain the ambient laboratory atmosphere relatively free of dirt, dust, and other contaminants.

6.1.2 Control the temperature of the room in which parts measurements are made so that the temperature for after-test measurements is within a range of ± 3 °C relative to the temperature for the before-test measurements. If difficulties with parts fits are encountered, consider the effects of temperature coefficient of expansion. See 6.2.

6.1.3 Filter the air in the engine build-up area, and control its temperature and humidity to prevent accumulation of dirt or rust on engine parts.

6.1.4 If an engine is assembled in an area of controlled environment and moved to a non-controlled area, provide suitable protection of the engine so that moist air cannot enter the engine and promote rusting before the test.

6.1.5 Do not permit air from fans or ventilation systems to blow directly on an engine mounted on a test stand during test operation.

6.2 *Drawings*—Obtain the equipment drawings referenced in Annex A12 of this test method from the TMC. Because the drawings may not be to scale or may not contain dimensions, when using them to fabricate special parts, do not use a dimensionless drawing as a pattern. Drawings supplied with dimensions are considered to be correct when the temperature of the equipment is (22 ± 3) °C, unless otherwise specified.

6.3 *Specified Equipment*—Use the equipment specified in the procedure whenever possible. Substitution of equivalent equipment is allowed, but only after equivalency has been proven to the satisfaction of the TMC, the Test Procedure Developer, and the ASTM Sequence IIIG Surveillance Panel.

6.3.1 Do not use heat lamps or fans directed at the engine, and do not use insulation on the engine, for oil or coolant temperature control.

6.3.1.1 *Discussion*—For operator safety and the protection of test components, the use of shielding and insulation on the exhaust system may be incorporated downstream of the oxygen sensor elbow.

6.4 *Test Engine*—The test engine is based on a 1996-97 L36 3800 series II V-6 engine with a displacement of 3.8 L, a compression ratio of 9.0:1, equipped with a production fuel injection system, a retrofit flat-tappet valvetrain, and a special Powertrain Control Module (PCM) for test specific dynamometer operation. Rebuild the engine as specified in this test method.

NOTE 2—Complete test engines are not available for purchase. Test engines can be rebuilt using parts and test kits. See *Sequence IIIG Engine Assembly Manual*.[9] See Annex A2 and Annex A12 for listings of parts and related equipment.

6.4.1 *Engine Parts*—Use the engine parts specified in the Sequence IIIG Engine Assembly Manual.

[9] Sequence IIIG Engine Assembly Manual is available at internet address: ftp://ftp.astmtmc.cmu.edu/docs/gas/sequenceiii/procedure and ils/IIIF-EAM.pdf

6.4.1.1 Use all engine parts as received from the supplier, Central Parts Distributor, Special Parts Supplier, or original equipment manufacturer, unless modifications are specified in this test method or the Sequence IIIG Engine Assembly Manual.[9]

6.4.1.2 Any parts obtained for use in Sequence IIIG testing shall not be diverted to other applications.

6.4.1.3 Before disposing of any Sequence IIIG engine parts, destroy or otherwise render them useless for automotive engine applications.

6.5 *Engine Speed and Load Control*—Use dynamometer speed and load control systems that are capable of controlling the speed and load as specified in Section 11 of this procedure under Data Acquisition and Control.

6.6 *Fluid Conditioning Module*[10,11]—To control the following parameters: engine coolant, condenser coolant, oil cooler coolant, exhaust manifold coolant, and the test fuel supply. The system incorporates the following features: pumps, flow meters, flow control and three-way control valves, external heating and cooling systems, pressure regulator and low-point drains. The system integrates with the test stand data acquisition and control computer for process control. If a test laboratory wishes to build it's own fluid conditioning module, a list of suitable equipment can be found in Annex A13.

6.6.1 *Engine Cooling System*—The Fluid Conditioning Module system supplies non-pressurized coolant at a flow rate of 160 L/min and controls temperature at 115 °C at the engine coolant outlet. The system incorporates the following features: pump, vortex-type flow meter, flow control and three-way control valves, external heating and cooling systems, and low-point drains. The system integrates with the test stand data acquisition and control computer for process control and maintains the specified engine coolant temperature and flow. The system should be flushed with clean water at least once each reference period.

6.7 *Flushing Tank*—Use a flushing tank such as that shown in drawings RX-116924-C, RX-117230-E, and RX-117231-C to circulate the cleaning agents. Use plumbing materials that are impervious to the acidic cleaning agents (stainless steel is satisfactory).

6.8 *Coolant Mixing Tank*—Use a mixing tank such as that shown in drawing RX-117350-D to premix the engine coolant.

6.9 *Condenser Cooling System*—This system, contained in the Fluid Conditioning Module, supplies non-pressurized coolant at a flow rate of (10 ± 2) L/min and temperature controlled at 40 °C (see Annex A8) at the condenser outlet. The system incorporates the following features: condenser heat exchanger, BX-212-1 or OHT3F-075-1:[11,12] condenser adapter fitting, pump, magnetic-type flow meter, flow control and three-way control valves, external heating and cooling systems, and low-point drains. The system integrates with the test stand data acquisition and control computer for process control and maintains the specified coolant temperature and flow.

6.10 *Engine Oil-Cooling System*—The system consists of an oil filter adapter, fitting adapter, oil cooler, and gaskets specified in the Sequence IIIG Engine Assembly Manual, Section 8 Sheet 3. The system uses engine coolant provided through the Fluid Conditioning Module and through a three-way valve as necessary to control the engine oil temperature at a flow rate of approximately 12.0 L/min. When testing high-oxidation sensitive oils, the oil cooling system may go into a by-pass mode, causing the oil cooler to be by-passed. In this condition, the TMC may allow engineering judgment for the oil temperature Quality Index on reference oil tests.

6.10.1 Replace the oil cooler after every test.

6.10.2 Do not use cuprous lines or fittings in the oil system.

6.10.3 Do not use magnetic plugs in the oil system.

6.10.4 Use suitable hose and fittings when plumbing the oil-cooling system.

6.10.5 The oil cooler or oil filter, or both, can be replaced once each test if *(a)* the oil filter pressure differential during test operations is greater than 100 kPa, if *(b)* bypass operation is detected, or if *(c)* the oil pressure delta slowly climbs as test hours are accumulated and decreases by more than 10 kPa in less than 1 min. If the real-time oil delta pressure value exceeds the average of the test's first hour delta pressure by 10 kPa, the oil filter can be replaced.

6.10.5.1 The oil cooler and oil filter can be replaced at the same time only once each test.

6.10.5.2 If the oil filter is replaced during the test, place a pan underneath it to catch any oil lost from the system or filter, or both. Invert the oil filter and allow the filter to drain any oil contained in the old oil filter. Allow the filter to drain for a minimum of 15 min. Add the captured oil to the new oil filter before installing it on the test engine.

6.10.5.3 Do not add new test oil to the engine as a result of oil filter or oil cooler replacement. Consider as oil consumption any oil lost as a result of oil filter or oil cooler replacement.

6.10.5.4 If the oil cooler or oil filter, or both are replaced during a test, place a note in the test report detailing what components were replaced and when they were replaced.

6.11 *Fuel System*—The Fluid Conditioning Module system contains a pressurized, recirculation fuel system, including a pressure regulator to provide (377.5 ± 12.5) kPa fuel pressure. The system should be switched off so no fuel pressure is present at the injector rail during engine shutdowns.

6.12 *Induction Air Supply Humidity, Temperature, and Pressure*—Maintain the throttle body intake air at a moisture content of (11.4 ± 0.7) g/kg of dry air, a dry bulb temperature of (35 ± 2) °C, and a static pressure of 0.050 kPa (see Annex A7). Measure temperature and pressure at the inlet air adapter.

6.13 *Temperature Measurement*—Use 1.6 or 3.2 mm metal-sheathed Specification E608/E608M, iron-constantan (Type J) thermocouples for temperature measurements. Use the shortest possible thermocouples to meet the insertion depth requirements listed in this test method and minimize exposed thermocouple sheathing.

[10] The sole source of supply of the apparatus known to the committee at this time is Kundinger Controls, 1771 Harmon Road, Auburn Hills, MI 48326.

[11] If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

[12] The sole source of supply of the apparatus known to the committee at this time is OH Technologies Inc. P.O. Box 5039, Mentor, OH 44061-5039.

6.13.1 *Thermocouple Location*—Locate the sensing tip of all thermocouples in the center of the stream of the medium involved, unless otherwise specified.

6.13.1.1 *Oil Filter Adapter*—Install the thermocouple in the tapped hole in the oil filter adapter as shown in the Sequence IIIG Engine Assembly Manual, Section 8 Sheet 3.

6.13.1.2 *Oil Pan (Sump)*—Install the thermocouple in the oil sump drain plug OHT3F-063-1 with the tip extending (19 to 25) mm beyond the end of the sump drain plug.

6.13.1.3 *Engine Coolant In*—Install the thermocouple in the coolant inlet adapter OHT3F-031-1 with the sensing tip centered in the coolant flow.

6.13.1.4 *Engine Coolant Out*—Install the thermocouple for the coolant outlet OHT3F-034-1 with the sensing tip centered in the coolant flow.

6.13.1.5 *Condenser Coolant Out*—Locate the thermocouple in the coolant out fitting in the condenser with the sensing tip centered in the coolant flow.

6.13.1.6 *Blowby Gas*—Install the thermocouple at the outlet of the condenser with the sensing tip centered in the blowby gas flow.

6.13.1.7 *Fuel*—Install the thermocouple in the fuel rail fittings on the inlet side of the fuel rail.

6.13.1.8 *Inlet Air*—Install the thermocouple in the inlet air adapter, as shown in the Sequence IIIG Engine Assembly Manual, Section 8 Sheet 4.

6.14 *Air-to-Fuel Ratio Determination*—Determine the engine air-to-fuel ratio (AFR) by measuring the CO, CO_2, and O_2 components of the exhaust gas sample with electronic exhaust gas analysis equipment. When using electronic exhaust gas analyzers, take particular care to dry the exhaust gas sample prior to introducing it into the analyzer. Take the exhaust gas samples from the exhaust manifold exit flanges. See Annex A6. (See Sequence IIIG Engine Assembly Manual, Section 8 Sheet 1.)

6.14.1 *Injector Flow Testing*—Flow test the fuel injectors before each test according to the following procedure:

6.14.1.1 Use aliphatic naphtha (**Warning**—Flammable. Health hazard.) as the calibration fluid.

6.14.1.2 Apply 276 kPa to the fuel rail.

6.14.1.3 Apply 13 V to the injector solenoid continuously.

6.14.1.4 Allow the injector to spray into a graduated cylinder capable of holding at least 250 mL.

6.14.1.5 Volume-check all injectors for 60 s and note the volume produced by each injector.

6.14.1.6 Observe the spray pattern that each injector produces; if the injector has a straight stream or dribbles, it should be discarded.

6.14.1.7 The six injectors that are to be installed on an engine fuel rail shall produce volumes that are within 5 mL of each other.

6.14.2 Remove the solvent that is remaining in the injector from the flow check using compressed air.

6.15 *Exhaust and Exhaust Back Pressure Systems*:

6.15.1 *Exhaust Manifolds and Pipes*—Install water-cooled exhaust manifolds and stainless runners as shown in the Sequence IIIG Engine Assembly Manual, Section 8 Sheet 2.

6.15.2 *Water-Jacketed Exhaust Pipes*—For safety, water-jacketed exhaust pipes or external water spray systems are allowed only when introduced beyond the Y pipe and after the system drops below the bedplate or enters the overhead loft.

6.15.3 *Exhaust Sample Lines*—Install exhaust sample lines in the two exhaust manifold exit flanges. Both left and right banks should use the same sample line location (inboard or outboard), as shown in the Sequence IIIG Engine Assembly Manual, Section 8 Sheet 1. Use good laboratory practice to ensure that water does not accumulate in the lines during engine operation.

6.15.4 *Back-Pressure Lines*—Install exhaust-backpressure lines in the two exhaust manifold exit flanges. Both left and right banks should use the same backpressure measurement location (inboard or outboard), as shown in the Sequence IIIG Engine Assembly Manual, Section 8 Sheet 1. Use good laboratory practice to ensure that water does not accumulate in the lines during engine operation.

6.16 *Blowby Flow Rate Measurement*—Use the sharp-edge orifice meter, part number RX-116169-A1, revision N, to measure engine blowby flow rates. (See 11.11.)

6.17 *Pressure Measurement and Pressure Sensor Location*—Use electronic pressure transducers located as indicated in this test method.

6.17.1 *Intake Manifold Vacuum*—Use a transducer having a range of (0 to 100) kPa. Connect the transducer to the vacuum outlet located on the intake plenum main vacuum port. Tee the transducer, manifold absolute pressure sensor and fuel rail pressure regulator all together from the main port.

6.17.2 *Engine Oil Gallery Pressure*—Use a transducer having a range of (0 to 700) kPa. Connect the transducer to the location shown in the Sequence IIIG Engine Assembly Manual, Section 8 Sheet 3 (OUT Port, oil to block).

6.17.3 *Oil Pump Outlet Pressure*—Use a transducer having a range of (0 to 700) kPa. Connect the transducer to the location shown in the Sequence IIIG Engine Assembly Manual, Section 8 Sheet 3 (IN Port, oil to filter).

6.17.4 *Exhaust Back Pressure*—Use a transducer having a range of (0 to 10) kPa; attach the line to the exhaust end plate as shown in the Sequence IIIG Engine Assembly Manual, Section 8 Sheet 1.

6.17.5 *Inlet Air Pressure*—Use a transducer having a range of (–125 to +125) Pa. Connect the transducer to the air inlet adapter as shown in the Sequence IIIG Engine Assembly Manual, Section 8 Sheet 4.

6.17.6 *Crankcase Pressure*—Use a transducer having a range of (–125 to +125) Pa. Connect the transducer to the front of the lower intake manifold as shown in the Sequence IIIG Engine Assembly Manual, Section 6 Sheet 7.

6.18 *PCV Plug*—Block off the positive crankcase ventilation system during testing using a dummy PCV valve, part number OHT3F-002-1, as shown in the Sequence IIIG Engine Assembly Manual, Section 6 Sheet 11.

6.19 *Parts Modifications*—Modify the following parts according to the instructions listed in the Sequence IIIG Engine Assembly Manual:

6.19.1 Throttle body, Section 7 Sheet 6.

6.19.2 Intake manifold, Section 6 Sheet 7.

6.19.3 Engine block, Section 1 Sheet 2.

7. Reagents and Materials

7.1 *Test Fuel*—Use only EEE unleaded fuel[11,13] (**Warning**—Flammable. Health Hazard.) (see Annex A4, Table A4.1), observing the following:

7.1.1 Make certain that all tanks used for transportation and storage are clean before filling with test fuel.

7.1.2 Verify that there are at least 3030 L of test fuel.

7.1.3 Analyze quarterly the contents of each storage tank that contains fuel used for qualified Sequence IIIG tests to ensure the fuel has not deteriorated or been contaminated in storage. Analyze the fuel for Distillation, Gravity, RVP Sulfur and Gums. Send the results from these analyses to the TMC for inclusion in the Sequence III Test Fuel data base. Conduct a repeat analysis on an additional sample when the fuel analysis is found to be out of specification for any of the above parameters.

7.2 *Engine and Condenser Coolant*—Use ethylene glycol meeting Specification E1119 for Industrial Grade Ethylene Glycol. (**Warning**—Combustible. Health Hazard.)

7.3 *Coolant Additive*—Use Nacool 2000 or Pencool 2000 coolant additive[11,14] for the engine and condenser coolant. (**Warning**—Combustible. Health Hazard. See appropriate MSDS.)

7.4 *Coolant Preparation*—Prepare the coolant blend for the engine coolant system, and for the oil cooler and condenser coolant system, in the following manner:

7.4.1 Do not apply heat either during, or following, the coolant preparation.

7.4.2 Use a container of a size adequate to hold the entire coolant blend required by both systems. See drawing RX-117350-D for an example of a suitable container.

7.4.3 Add the required amount of glycol (**Warning**—Combustible. Health Hazard.) to the container.

7.4.4 Add the required amount of additive concentrate to the container to achieve a concentration of coolant additive to glycol of 15.625 mL/L. (**Warning**—See appropriate MSDS.)

7.4.5 Mix the blend in the container for 30 min.

7.4.6 Add the blend to the engine coolant system and the condenser coolant system.

7.5 *Pre-Test Cleaning Materials*—Use the cleaning materials (**Warning**—See appropriate MSDS.) specified in the following list for cleaning of parts to be used in the test. Do not use unapproved substitutes (see Note 3).

NOTE 3—Only these specific materials and sources have been found satisfactory. If chemicals other than these are proposed for use, equivalency shall be proven and approval obtained from the TMC.

7.5.1 Use Penmul L460 as the parts cleaning agent.[11,15] (**Warning**—Corrosive. Health Hazard.)

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

7.5.3 Sequence IIIG Test Component Cleaner, a mixture (by mass) of:

94 parts oxalic acid[11,16] (**Warning**—Corrosive. Health Hazard.)

6 parts dispersant[11,17] (**Warning**—Corrosive. Health Hazard.)

NOTE 4—If permitted by the hazardous materials disposal practices in a laboratory, sodium carbonate can be used to neutralize the oxalic acid in used Sequence IIIG Test component cleaner.

7.5.4 Use NAT-50 or PDN-50 soap[11,18] in automatic parts washers to clean Sequence IIIG engine parts. See 9.3.

7.6 *Sealing and Anti-seize Compounds*—Use the sealing compounds specified in the following list.

7.6.1 Use Permatex Number 2 non-hardening sealer as the sealing compound for cylinder head bolts.

7.6.2 Use Perfect Seal Number 4 Brush-Type Sealing Compound as the sealing compound for front and rear cover gaskets.[11,19]

7.6.3 Only GM Autocare Adhesive, part number 12346141, or Dow RTV Grade 3154 sealer and Permatex Ultra Black Sealer, part number 24105, are allowable for use on the oil pan gasket and intake manifold gasket only. (See Sequence IIIG Engine Assembly Manual, Section 4 Sheet 12 and Section 6 Sheet 6.)

7.6.4 Teflon tape may be used, provided it does not come into contact with engine oil.

8. Test Oil Sample Requirements

8.1 *Selection*—The supplier of the test oil sample shall determine that the test oil sample is representative of the lubricant formulation to be evaluated and that it is not contaminated.

8.2 *Quantity*—The supplier shall provide the test oil sample of 12 L.

NOTE 5—A Sequence IIIG Test can be conducted with a sample of test oil as little as 10 L, provided that no spillage or leakage occur during test preparation. The greater quantity is specified to accommodate minor spillage and leakage.

8.3 *Storage Prior to Test*—The test laboratory shall store the test oil sample in a covered building to prevent contamination by rainwater.

[13] The sole source of supply of the apparatus known to the committee at this time is Haltermann Products, 1201 Sheldon Road, P.O Box 429, Channelview, TX 77530-0429.

[14] The sole source of supply of the apparatus known to the committee at this time is Penray Companies, Inc., 1801 Estes Ave, Elk Grove, IL 60007.

[15] The sole source of supply of the apparatus known to the committee at this time is Penetone Corporation 74 Hudson Ave. Tenafly, NJ 07670.

[16] The sole source of supply of the apparatus known to the committee at this time is Ashland Chemical Co., P.O. Box 391, Ashland, KY 41114.

[17] The sole source of supply of the apparatus known to the committee at this time is Petro Dispersant Number 425 Powder (50-lb bags) is available from Witco Corp., 3230 Brookfield, Houston, TX 77045.

[18] The sole source of supply of the apparatus known to the committee at this time is Better Engineering Mfg., Inc., 8361 Town Center Court, Baltimore, MD 21236.

[19] The sole source of supply of the product known to the committee at this time is Perfect Seal, 3322 Beekman St., Cincinnati, OH 45223.

9. Preparation of Apparatus

9.1 *Condenser Cleaning*—Immediately after completing a Sequence IIIG test, remove the stainless steel condenser assembly, disassemble it, and soak it in parts cleaning agent. After the soaking, clean the inside of the tube with parts cleaning agent and a non-cuprous bristle brush. Rinse both the blowby gas and coolant sides of the condenser with clean degreasing solvent.

9.1.1 After ten tests, or more frequently if film is present, clean the coolant side of the condenser by flushing it for one half-hour with a solution of Sequence IIIG test component cleaner at 20 g per 1 L of water. (See 7.5.) Rinse it thoroughly with tap water at 60 °C.

9.1.2 After cleaning the coolant side of the condenser, pressure check it for leaks using air at 70 kPa.

9.2 *Intake Manifold Cleaning*—Clean the intake manifold with degreasing solvent.

9.3 *Cleaning of Engine Parts (other than the block and heads)*—Clean all engine parts (other than the connecting rods, block and heads; see 9.4, 9.5 and 9.6) thoroughly prior to engine assembly. Degrease them first, and then brush them with parts cleaning agent. Immediately remove the cleaner by spraying with hot tap water. Blow-dry the parts with clean, dry shop air (**Warning—**For technical use only) and immediately coat them with a 50/50 mixture of build-up oil and degreasing solvent.

9.4 *Connecting Rod Cleaning*—Clean the connecting rods according to the following:

9.4.1 Clean the connecting rods by soaking in degreasing solvent for a mininum of 2 h. Spray the rods with a 50/50 mix of build-up oil and degreasing solvent.

9.5 *Engine Block Cleaning*—Clean the block according to the following:

9.5.1 Remove the debris in the head bolt and main bearing-cap bolt holes using class 2B bottoming taps of the appropriate sizes.

9.5.2 Physically remove all sand and slag deposits, and any other debris, from the water jacket using a sharp-ended drill rod or a long straight slot screwdriver.

9.5.2.1 Check the camshaft tunnel for sharp edges on the front of each bore and along the cross-drilled oil gallery inside each bearing bore. Deburr as necessary. See the Sequence IIIG Engine Assembly Manual, Section 1 Sheet 2.

9.5.3 Thoroughly clean the block prior to honing as follows: In the case of a block used in a previous test, remove the crankshaft, main bearings, and bearing caps. In addition, remove all bushings, bearings, and oil gallery plugs prior to cleaning. With either a new or a used block, prevent cleaner or oil from entering the engine coolant passages. (See Sequence IIIG Engine Assembly Manual, Section 1 Sheet 4.)

9.5.3.1 Clean the block in a heated bath or temperature-controlled automated parts washer before and after honing. Follow these suggested guidelines to ensure there is no rusting of the engine block after this process:

(1) Use only NAT-50 or PDN-50 soap at a concentration of 7.3 kg of soap per 380 L of water. Change the soap and water solution at least every six months.

(2) Set the water temperature to (60 ± 10) °C.

(3) Do not in any manner pre-condition the water that is being used.

(4) Prior to installing the engine in the parts washer, ensure that all coolant passages are blocked off to prevent cleaning solutions from entering the passages.

(5) Allow the block to run through the cleaning cycle for a period of (30 to 40) min.

(6) After the cycle is complete, immediately remove the block from the washer and spray it down with degreasing solvent.

(7) Wipe cylinder bores out with a lint free towel.

(8) Spray engine block with a 50:50 mixture of build-up oil and degreasing solvent.

(9) Do not remove the paint dot from the crankcase area of the block.

(10) Allow the block to cool to room temperature before honing the block.

9.5.3.2 See the Sequence IIIG Engine Assembly Manual, Section 2 for the honing procedure.

9.5.3.3 After honing the cylinder walls, clean the engine block again according to 9.5.3 and spray the engine block (including all oil galleries) first with degreasing solvent followed by a 50:50 mixture of degreasing solvent and build-up oil. Using this 50:50 mixture, wipe out the cylinder bores with clean cloth towels until all honing residue has been removed.

9.5.3.4 Air dry the engine block, using clean dry shop air, and coat the cylinder walls with build-up oil using soft, lint-free, clean cloths.

9.6 *Cylinder Head Cleaning*—Clean the cylinder heads according to the following:

9.6.1 Explore all accessible water passages with a flexible probe to detect any material that would interfere with coolant flow.

9.6.2 Clean the cylinder heads according to the recommended engine block cleaning procedure (see 9.5.3.1) or clean with degreasing solvent. Spray the heads with a 50/50 mix of degreasing solvent and build-up oil. When cleaning the heads, do not remove the paint dot.

9.7 *Engine Build-up Procedure*—Laboratories will maintain engine-build data Sheets as shown in Annex A14. This data shall be available to the TMC and the Test Procedure Developer for investigative studies as deemed necessary for hardware investigations during times of industry severity shifts or other problems.

9.7.1 *General Information*—Use only the listed service parts, special test parts, and special build up procedures specific to this test as outlined in this test method and the Sequence IIIG Engine Assembly Manual. See 6.4. Make and record measurements specified in this test method of the cylinders, pistons, rings, valve train, cam, and lifters. These measurements will provide evidence of conformance to the specifications of the method, and will provide baselines for determining engine wear that occurs during a Sequence IIIG test.

9.7.2 *Special Parts*—Use the special parts listed in the Sequence IIIG Engine Assembly Manual Section 8.

9.7.3 *Hardware Information*—Complete Form 12, Hardware Information, in standardized report form set (see Annex A5).

9.7.4 *Fastener Torque Specifications and Torquing Procedures*—Use the following specifications and torquing procedures when installing bolts in the engine:

9.7.4.1 *Main Bearing Cap Bolts*—Use new main cap bolts on every test, including tests on new engine blocks; do not modify the threads of the bolts. Do not use air tools on bolts to seat the main bearing caps in the engine block. Use a speed handle and socket, in a crisscross pattern to draw down and lightly seat the main cap. Apply build-up oil to the threads and to the surfaces of the bolts that contact the main bearing caps. In order to prevent hydraulic lock, do not apply oil to the tapped holes in the cylinder block. Install the bolts finger-tight and tighten them further with the SPS Torque Sensor I,[11,20] Ingersoll-Rand ETW-E180,[11,21] or Snap-on ATECH3FR250 Torque Wrench[11,22] only, working from the center out in a crisscross pattern. See the Sequence IIIG Engine Assembly Manual for torquing instructions. (See Section 1 Sheet 6 for honing and Section 3 Sheet 6 for final assembly.)

9.7.4.2 *Cylinder Head Bolts*—Install the cylinder head bolts, GM Part No. 25527831 (long) and 25533811 (short), which are of special design for yield applications using the SPS Torque Sensor I, Ingersoll-Rand ETW-E180 Torque Wrench, or Snap-on ATECH3FR250 Torque Wrench. See the Sequence IIIG Engine Assembly Manual for installation instructions. Replace the bolts after each test. (See Section 1 Sheet 7 for honing and Section 5 Sheet 3 for final assembly.)

9.7.4.3 *Torques for Miscellaneous Bolts, Studs, and Nuts*—Use the torques for miscellaneous bolts, studs, and nuts given in the Sequence IIIG Engine Assembly Manual.

9.8 *Parts Replacement*—See 9.8.1 for information regarding parts. Replace test parts as follows:

9.8.1 Install the new parts listed in Annex A2, Table A2.1 for each test.

9.8.2 Install the new parts listed in Annex A2, Table A2.2, only if the used part is no longer suitable for test purposes.

9.9 *Engine Block Preparation*—Prepare the engine block as follows:

9.9.1 Install new engine block freeze plugs; use a driver to facilitate this replacement.

9.9.2 Install the main bearing caps, without the bearings in place. Tighten the retaining bolts using the procedure in 9.7.4.1.

9.9.3 To prevent entry of honing fluid into the coolant passages of the engine block, cover and seal the coolant inlet passages and freeze plug openings. Close the petcocks if previously installed; if not, install ¼-in. NPT pipe plugs.

9.9.4 With a 30 cm smoothing file, deburr the surfaces of the block that mate with the cylinder heads to ensure adequate gasket seating.

9.9.5 Use the honing torque plates B-H-J GM 3.8L/3E-R-s_t-HT[11,23] to pre-stress the engine block for honing. Install the torque plates with the proper hardened washers (supplied with the honing torque plates), single washers on top row and double washers on bottom row, to establish proper bolt depth. Clean the threaded bores for the cylinder head attachment bolts using a bottoming tap before each installation of the torque plates. The torque plates require the use of new head gaskets, SPO Part No. 24503802 left head and 24503801 right head, along with cylinder head, torque-to-yield fasteners, SPO Part No. 25527831 (long). Clean all sealing and thread locking compounds from the fasteners for the torque plate installation. Coat each fastener with build-up oil, and see Section 1 Sheet 7 of the Sequence IIIG Engine Assembly Manual for installation instructions.

9.9.6 Use only the CV-616 honing machine to hone the cylinder walls. See the Sequence IIIG Engine Assembly Manual, Section 2 for all of the proper setup and operational procedures for each specific run on the Sequence IIIG engine block. Have the load output and the current verified by the manufacturer annually.

9.9.7 Replace the honing fluid, filters, and fiber mats used in the honing machine after every 15-h of honing machine operation. Use the honing machine hour meter to determine hours of operation. See the Sequence IIIG Engine Assembly Manual, Section 2 Sheet 8.

9.9.8 The flow rate of the honing lubricant should be approximately 7 L/min. In addition, do not introduce solvents into the honing fluid or use them to clean the honing stones or guides. Use only honing fluid to clean honing stones or guides.

9.9.9 Hone the cylinder walls without the main bearings in place, but with all bearing caps installed.

9.9.10 Clean the engine block following honing according to 9.5.3.1.

9.9.10.1 Allow the cylinder block to cool for a minimum of 10 min before taking final bore measurements. See Section 2, Sheet 9 of the Sequence IIIG Engine Assembly Manual.

9.9.11 If desired (this is not required), check the main bearing bore clearances using a mandrel, part BX-398-1, according to the following procedure:

9.9.11.1 Starting from the front of the block, slide the mandrel through all four main bearing bores. If excessive resistance is encountered while inserting the mandrel, remove the mandrel from the engine block and inspect the main bearing bores for burrs, nicks, dirt, alignment problems, or any abnormalities. Carefully remove any nicks, burrs, scratches, or dirt with 400-grit paper or a fine stone. Then use a clean shop towel with degreasing solvent to wipe the affected surfaces. Reinstall the mandrel to ensure that it can freely pass through all four main bearing bores. If the mandrel still will not clear the bores after completing the above steps, do not use this block and notify the Test Procedure Developer of the problem. After honing, repeat the above procedure prior to final engine build. The mandrel is an alignment and clearance gage only,

[20] The sole source of supply of the apparatus known to the committee at this time is Sunnen Products Co., 7910 Manchester Ave, St. Louis, MO 63143.

[21] The sole source supply of the apparatus known to the committee at this time is Ingersoll-Rand Assembly Solutions, 510 Hester Drive, White House, TN 37188.

[22] Available from local Snap-on dealers. Snap-on is a trademark of Snap-on, Inc., 10801 Corporate Drive, Kenosha, WI 53141–1430.

[23] The sole source of supply of the apparatus known to the committee at this time is B-H-J Products Inc., 37530 Enterprise Court, Newark, CA 94560.

not an assembly tool. The mandrel should not be in the bores when installing the main bearing caps or torquing the main bearing bolts.

9.10 *Piston Fitting and Numbering*—Fit the pistons to the cylinders according to recommendations listed in the Sequence IIIG Engine Assembly Manual for the run sequence of the block. Use only the specified code pistons for each run sequence. Number the pistons with odd numbers in the left bank from front to rear and with even numbers in the right bank from front to rear.

9.10.1 *Piston Rings*—The rings are pre-sized for each run; check the gap in the cylinder bore for each test. The top ring gap shall be (0.635 ± 0.051) mm. The bottom ring gap shall be (1.067 ± 0.051) mm. The top ring gap shall be smaller than the bottom ring gap and the difference between the two ring gaps shall be between 0.330 mm and 0.533 mm. If the ring gap difference is below 0.330 mm, contact the Test Procedure Developer. Check the ring gap with a Starrett Ring Taper Gage No. 270 with the ring positioned in the cylinder bore using a piston ring depth gage (drawing RX-118602-B). Position the rings 23.67 mm below the cylinder-block deck surface during gap measurement. Record the top and bottom ring gaps on Form 12, Hardware Information, in standardized report form set (see Annex A5). Record and report ring gaps in mm.

9.11 *Pre-Test Camshaft and Lifter Measurements*—Measure the camshaft lobe height and lifter lengths, prior to engine assembly, according to the following procedure:

9.11.1 Remove camshaft and lifters from laboratory inventory.

9.11.2 Remove camshaft and lifters from original container and packaging and set container and packaging aside for later use. Clean camshaft with degreasing solvent. Do not clean the lifters; wipe the lifters with a clean cloth or towel.

9.11.3 Make the camshaft measurement using Mitutoyo Snap Gauge, model 201-152, and a Mitutoyo Digital Indicator, model 543-252B, to measure the camshaft lobes. Make the lifter measurement with a digital indicator equipped with a Mitutoyo 4.3 mm flat tip, model 131-259 mounted in a indicator stand. Equip the indicator stand with a V-block that is rigidly mounted to the base and locates the lifter with its center axis in line with the digital indicator. Store the camshaft and lifters in a temperature-controlled room, before making dimensional measurements, for at least 90 min to ensure temperature stabilization.

9.11.3.1 Use dimensional measuring equipment accurate to 0.01 mm. Before each measurement session, use standards traceable to the National Institute of Standards and Technology, to ensure measuring equipment accuracy. Include standards having length values within 1.3 mm of the typical lifter and lobe measurement taken. Use the same equipment and standards post-test measuring as were used for pre-test measuring. If a calibration shift between the pre-test and post-test measurements is detected, evaluate the shift to determine the effect on the wear measurement. Record the results of the evaluation and any corrective action taken.

9.11.4 With the camshaft positioned in a set of V-blocks, remove any burrs around the outer edge of the camshaft thrust surface, if necessary. Thoroughly clean the camshaft with degreasing solvent to remove all rust preventative coatings and blow-dry it with clean, dry shop air.

9.11.5 Measure the maximum pre-test dimension of each camshaft lobe, transverse to the camshaft axis to the nearest 0.001 mm. This dimension is at the rear edge of all lobe positions (lobes are numbered from the front to the rear of the camshaft). Record the measurements and temperature at the time of measurement on internal laboratory forms. See 9.7. After measuring, coat the camshaft with build-up oil. Return the camshaft to its original packaging and container until installed in the engine.

9.11.6 Measure the pre-test length of the lifters at the center of the lifter foot to the nearest 0.001 mm. Record the measurements and temperature at time of measurement on internal laboratory forms. See 9.7.

9.11.7 Record the unique serial number for each lifter on internal laboratory forms. See 9.7. Do not use electromechanical scribing devices. Do not place any marks on the lifter body or foot. Return the lifters to their original packaging until installed in the engine.

9.12 *Camshaft Bearing Installation*—The camshaft tunnel is specially processed and uses oversize bearings provided through the CPD. Install the camshaft bearings according to the Sequence IIIG Engine Assembly Manual Section, 3 Sheet 3. Always inspect the lifter and main bearing oil galleries for splintered babbitt materials that might have been shaved from the outside diameter of the bearings during installation. Remove any materials from the oil galleries with clean dry shop air.

9.13 *Camshaft Installation*—Install the camshaft according to the Sequence IIIG Engine Assembly Manual, Section 3 Sheet 11:

9.13.1 Coat the camshaft lobes and journals with a light film of test oil.

9.13.2 Install the camshaft in the engine block, taking care to avoid damage to the lobes, journals, and bearings.

9.13.3 *Installation of Camshaft Thrust Plate*—Lubricate the thrust plate with build-up oil and install the thrust plate to the front of the engine block using new Torx fasteners.[24]

9.14 *Main Bearings*—Verify that the main bearing bore areas in the engine block and bearing caps are clean. Install new main bearings, part number OHT3F-042-2, in the engine block and main bearing caps, and lightly oil the bearing surfaces with build-up oil. New main bearing cap bolts shall be used for each Sequence IIIG test engine build including a new engine block (discard the bolts the block was machined with).

9.14.1 *Crankshaft*—Install the crankshaft.

9.14.2 *Main Bearing Cap Installation*—Install the main bearing caps using new bolts for each test. Do not use the bolts from the new engine block for the first build; use new fasteners for the first build. Do not remove the phosphate coating from the bolts. Do not use air tools on the main bearing cap bolts to seat the caps. Install the bolts finger-tight, and tighten them according to the procedure in 9.7.4.1. Use the main bearings as received.

[24] Trademark of Textron Fastening Systems, 840 W. Long Lake Road Suite 450 Troy, MI 48098.