



Standard Test Method for Dynamometer Evaluation of Unleaded Spark-Ignition Engine Fuel for Intake Valve Deposit Formation¹

This standard is issued under the fixed designation D6201; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers an engine dynamometer test procedure for evaluation of intake valve deposit formation of unleaded spark-ignition engine fuels.² This test method uses a Ford Ranger 2.3 L four-cylinder engine. This test method includes detailed information regarding the procedure, hardware, and operations.

1.2 The ASTM Test Monitoring Center (TMC)³ is responsible for engine test stand calibration as well as issuance of information letters after test method modifications are approved by Subcommittee D02.A0 and Committee D02. Users of this test method shall request copies of recent information letters from the TMC to ensure proper conduct of the test method.

1.3 The values stated in SI units are to be regarded as standard. The values in parentheses are provided for information only.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.* Specific warning statements are given throughout this test method.

1.5 This test method is arranged as follows:

| Subject | Section |
|--|---------|
| Scope | 1 |
| Referenced Documents | 2 |
| Terminology | 3 |
| Summary of Test Method | 4 |
| Significance and Use | 5 |
| Apparatus | 6 |
| Laboratory Facilities | 6.1 |
| Engine and Cylinder Head Build-Up and Measurement Area | 6.1.1 |
| Engine Operating Area | 6.1.2 |

¹ This test method is under jurisdiction of ASTM Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee D02.A0.01 on Gasoline and Gasoline-Oxygenate Blends.

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² Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D02-1453.

³ ASTM Test Monitoring Center (TMC), 6555 Penn Avenue, Pittsburgh, PA 15206-4489.

| Subject | Section |
|---|---------|
| Fuel Injector Testing Area | 6.1.3 |
| Intake Valve Rinsing and Parts Cleaning Area | 6.1.4 |
| Parts Rating and Intake Valve Weighing Area | 6.1.5 |
| Test Stand Laboratory Equipment | 6.2 |
| Test Stand Configuration | 6.2.1 |
| Dynamometer Speed and Load Control System | 6.2.2 |
| Intake Air Supply System | 6.2.3 |
| Exhaust System | 6.2.4 |
| Fuel Supply System | 6.2.5 |
| Engine Control Calibration | 6.2.6 |
| Ignition System | 6.2.7 |
| Engine Coolant System | 6.2.8 |
| External Oil System | 6.2.9 |
| Temperature Measurement Equipment and Locations | 6.2.10 |
| Pressure Measurement Equipment and Locations | 6.2.11 |
| Flow Measurement Equipment and Locations | 6.2.12 |
| Speed and Load Measurement Equipment and Locations | 6.2.13 |
| Exhaust Emissions Measurement Equipment and Location | 6.2.14 |
| DPFE (EGR) Voltage Measurement Equipment and Location | 6.2.15 |
| Ignition Timing Measurement Equipment and Location | 6.2.16 |
| Test Engine Hardware | 6.3 |
| Test Engine Parts | 6.3.1 |
| New Parts Required | 6.3.2 |
| Reusable Engine Parts | 6.3.3 |
| Special Measurement and Assembly Equipment | 6.4 |
| Reagents and Materials | 7 |
| Hazards | 8 |
| Reference Fuel | 9 |
| Preparation of Apparatus | 10 |
| Test Stand Preparation | 10.1 |
| Engine Block Preparation | 10.2 |
| Preparation of Miscellaneous Engine Components | 10.3 |
| Cylinder Head Preparation | 10.4 |
| Cylinder Head Assembly | 10.5 |
| Cylinder Head Installation | 10.6 |
| Final Engine Assembly | 10.7 |
| Calibration | 11 |
| Test Stand Calibration | 11.1 |
| Instrumentation Calibration | 11.2 |
| Procedure | 12 |
| Pretest Procedure | 12.1 |
| Engine Operating Procedure | 12.2 |
| Periodic Measurements and Functions | 12.3 |
| End of Test Procedures | 12.4 |
| Determination of Test Results | 13 |
| Post-Test Intake Valve Weighing Procedure | 13.1 |
| Photographs of Parts—General | 13.2 |
| Induction System Rating | 13.3 |
| Determination of Test Validity—Engine Conformance | 13.4 |
| Report | 14 |
| Precision and Bias | 15 |
| Keywords | 16 |

Subject
Annexes
Detailed Specifications and Photographs of Apparatus
Engine Part Number Listing
Statistical Equations for Mean and Standard Deviation

Section
Annex A1
Annex A2
Annex A3

2. Referenced Documents

2.1 *ASTM Standards*:⁴

- 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)
- D381** Test Method for Gum Content in Fuels by Jet Evaporation
- D525** Test Method for Oxidation Stability of Gasoline (Induction Period Method)
- D873** Test Method for Oxidation Stability of Aviation Fuels (Potential Residue Method)
- D1266** Test Method for Sulfur in Petroleum Products (Lamp Method)
- D1298** Test Method for Density, Relative Density, or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method
- D1319** Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption
- D1744** Test Method for Determination of Water in Liquid Petroleum Products by Karl Fischer Reagent
- D2427** Test Method for Determination of C₂ through C₅ Hydrocarbons in Gasolines by Gas Chromatography
- D2622** Test Method for Sulfur in Petroleum Products by Wavelength Dispersive X-ray Fluorescence Spectrometry
- D3237** Test Method for Lead in Gasoline by Atomic Absorption Spectroscopy
- D4057** Practice for Manual Sampling of Petroleum and Petroleum Products
- D4294** Test Method for Sulfur in Petroleum and Petroleum Products by Energy Dispersive X-ray Fluorescence Spectrometry
- D4814** Specification for Automotive Spark-Ignition Engine Fuel
- D4953** Test Method for Vapor Pressure of Gasoline and Gasoline-Oxygenate Blends (Dry Method)
- D5059** Test Methods for Lead in Gasoline by X-Ray Spectroscopy
- D5190** Test Method for Vapor Pressure of Petroleum Products (Automatic Method) (Withdrawn 2012)⁵
- D5191** Test Method for Vapor Pressure of Petroleum Products (Mini Method)
- D5302** Test Method for Evaluation of Automotive Engine Oils for Inhibition of Deposit Formation and Wear in a Spark-Ignition Internal Combustion Engine Fueled with

- Gasoline and Operated Under Low-Temperature, Light-Duty Conditions (Withdrawn 2003)⁵
- D5482** Test Method for Vapor Pressure of Petroleum Products (Mini Method—Atmospheric)
- E203** Test Method for Water Using Volumetric Karl Fischer Titration
- E1064** Test Method for Water in Organic Liquids by Coulometric Karl Fischer Titration
- 2.2 *ANSI Standard*:⁶
- MC96.1** Temperature Measurement-Thermocouples
- 2.3 *Coordinating Research Council (CRC)*:⁷
- CRC Manual 16**, Carburetor and Induction System Rating Manual
- 2.4 *SAE Standard*:⁸
- J254** Instrumentation and Techniques for Exhaust Gas Emissions Measurement

3. Terminology

3.1 *Definitions of Terms Specific to This Standard*:

3.1.1 *base fuel, n*—unleaded automotive spark-ignition engine fuel that does not contain a deposit control additive, but may contain antioxidants, corrosion inhibitors, metal deactivators, dyes, or oxygenates, or a combination thereof.

3.1.2 *blowby, n*—the combustion products and unburned air/fuel mixture that enter the crankcase.

3.1.3 *deposit control additive, n*—material added to the base fuel to prevent or remove deposits in the entire engine intake system.

3.1.3.1 *Discussion*—For the purpose of this test method, the performance evaluation of a deposit control additive is limited to the tulip area of intake valves.

3.1.4 *exhaust emissions, n*—combustion products from the test fuel including unburned hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO₂), unreacted oxygen (O₂), and oxides of nitrogen (NO_x).

3.1.5 *intake system, n*—components of the engine whose function it is to prepare and deliver an air/fuel mixture to the combustion chamber and includes the throttle, intake manifold, exhaust gas recirculation (EGR) and positive crankcase ventilation (PCV) ports, cylinder head runners and ports, intake valves, and fuel injectors.

3.1.6 *intake valve deposit, n*—material accumulated on the tulip area of the intake valve, generally composed of carbon, other fuel, lubricant, and additive decomposition products, and atmospheric contaminants.

3.1.7 *test fuel, n*—base fuel with or without the addition of a deposit control additive.

4. Summary of Test Method

4.1 This test method utilizes a 1994 Ford 2.3 L in-line, four cylinder, Ford Ranger truck engine with 49 state emission

⁴ 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.

⁵ The last approved version of this historical standard is referenced on www.astm.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 the Coordinating Research Council, Inc., 3650 Mansell Road, Suite 140, Alpharetta, GA 30022.

⁸ Available from Society of Automotive Engineers (SAE), 400 Commonwealth Dr., Warrendale, PA 15096-0001.

calibration. The cylinder block and cylinder head are constructed of cast iron. The engine features an overhead camshaft, a cross-flow, fast burn cylinder head design, and electronic port fuel injection.

4.2 Each test engine is built to a rigid set of specifications using a specially designated intake valve deposit parts kit produced by the Ford Motor Co. (see [Table A2.3](#)). New, weighed, intake valves are used to rebuild the cylinder head. A standard engine oil is used for each test and a new oil filter is installed. The test engine is subjected to a rigorous quality control procedure to verify proper engine operation. To ensure compliance with the test objective, data acquisition of key parameters is utilized during test operation.

4.3 The complete fuel system is flushed of test fuel from the previous test. The fuel system is then filled with the new test fuel.

4.4 The engine is operated on a cycle consisting of two stages. The first stage comprises operating the engine at 2000 r/min and 30.6 kPa (230 mm Hg) manifold absolute pressure for 4 min. The second stage comprises operating the engine at 2800 r/min and 71.8 kPa (540 mm Hg) manifold absolute pressure for 8 min. Ramp time between each stage is 30 s and is independent of the stage times. The cycle is repeated for 100 h.

5. Significance and Use

5.1 *Test Method*—The Coordinating Research Council sponsored testing to develop this test method to evaluate a fuel's tendency to form intake valve deposits.

5.1.1 *State and Federal Legislative and Regulatory Action*—Regulatory action by California Air Resources Board (CARB)⁹ and the United States Environmental Protection Agency (EPA)¹⁰ necessitate the acceptance of a standardized test method to evaluate the intake system deposit forming tendency of an automotive spark-ignition engine fuel.

5.1.2 *Relevance of Results*—The operating conditions and design of the engine used in this test method are not representative of all engines. These factors shall be considered when interpreting test results.

5.2 Test Validity:

5.2.1 *Procedural Compliance*—The test results are not considered valid unless the test is completed in compliance with all requirements of this test method. Deviations from the parameter limits presented in Sections 12 – 14 will result in an invalid test. Apply engineering judgment during conduct of the test method when assessing any anomalies to ensure validity of the test results.

5.2.2 *Engine Compliance*—A test is not considered valid unless the test engine meets the quality control inspection requirements as described in Sections 10 and 12.

⁹ State of California Air Resources Board—Stationary Source Division, Test Method for Evaluating Intake Valve Deposits (IVDs) in Vehicle Engines (California Code of Regulations, Title 13, Section 2257). Available from the California Air Resources Board, P.O. Box 2815, Sacramento, CA 95812.

¹⁰ Clean Air Act Amendments of 1990. Available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

6. Apparatus

NOTE 1—Photographs are provided in [Annex A1](#) depicting the required apparatus and suggesting appropriate design details.

6.1 Laboratory Facilities:

6.1.1 *Engine and Cylinder Head Build-up and Measurement Area*—The engine and cylinder head build-up and measurement area shall be reasonably free from contaminants and maintained at a uniform temperature $\pm 3^{\circ}\text{C}$ ($\pm 5^{\circ}\text{F}$) between 10 to 27°C (50 to 80°F).

6.1.2 *Engine Operating Area*—The engine operating area should be relatively free from contaminants. The temperature and humidity level of the operating area are not specified. Air from a fan can be routed on to the production air intake system to assist in maintaining intake air temperature control.

6.1.3 *Fuel Injector Testing Area*—The fuel injector testing area shall be reasonably free of contaminants. The humidity should be maintained at a uniform comfortable level. (**Warning**—In addition to other precautions, provide adequate ventilation and fire protection in areas where flammable or volatile liquids and solvents, or both, are used.)

6.1.4 *Intake Valve Rinsing and Parts Cleaning Area*—The intake valve rinsing and parts cleaning area shall be reasonably free of contaminants. The humidity should be maintained at a uniform comfortable level. Because of the delicate nature of the deposits, do not subject the deposits to extreme changes in temperature or humidity. (**Warning**—In addition to other precautions, provide adequate ventilation and fire protection in areas where flammable or volatile liquids and solvents, or both, are used.)

6.1.5 *Parts Rating and Intake Valve Weighing Area*—The parts rating area and the intake valve weighing area shall be reasonably free of contaminants.

6.2 Test Stand Laboratory Equipment:

6.2.1 *Test Stand Configuration*—An example of a similar test stand configuration is described in Test Method [D5302](#) (Sequence VE lubricant test method) since the same Ford 2.3 L base engine is utilized. Mount the engine on the test stand so that the flywheel friction face is $4.0 \pm 0.5^{\circ}$ from the vertical with the front of the engine higher than the rear. The engine shall be coupled directly to the dynamometer through a driveshaft. A test stand set-up kit is detailed in [Table A2.1](#). A special “dynamometer laboratory” wiring harness, Part No. DTSC.260.113.00E is required. Engine driven accessories include engine water pump and alternator or idler pulley configuration as detailed in [10.7.9](#). If an alternator is installed, it is to serve only as an idler pulley; it is not to be energized.

6.2.2 *Dynamometer Speed and Load Control System*—The dynamometer used for this test is the Midwest 1014, 175 horsepower, dry gap dynamometer or equivalent. Equivalency means that the dynamometer and dynamometer control system shall be capable of controlling the procedural specifications as detailed in [Table 1](#) and the stage transitions to the specifications in [13.4.3.1](#) and [13.4.4.1](#).

6.2.3 *Intake Air Supply System*—The intake air supply system shall be capable of controlling moisture content, dry bulb temperature, and inlet air pressure as specified in [Table 1](#). See [10.7.8](#) and [Fig. A1.4](#) for details of connection of the laboratory intake air system to the engine.

TABLE 1 IVD Dynamometer Test Operating Parameters and Specifications^A

| Parameter ^A | | Specification | |
|------------------------|--|---------------|-------------|
| Stage | ... | 1 | 2 |
| Time | Stage length, min | 4 | 8 |
| Engine Loading | Engine speed, r/min | 2000 ± 25 | 2800 ± 15 |
| | Engine load, kW | <5 | record |
| Engine Oil | Inlet temperature, °C | 101 + 3, -5 | 101 ± 3 |
| | Outlet temperature, °C | | record |
| | Inlet pressure, kPa gage | | record |
| Engine Cooling | Outlet temperature, °C | | 90 ± 3 |
| | Inlet temperature, °C | | record |
| | Delta pressure, kPa gage | | <41 |
| | Flowrate, L/min | record | 64.4 ± 1.9 |
| Intake Air | Inlet temperature, °C | | 32 ± 3 |
| | Inlet pressure, kPa gage | | 0.05 ± 0.01 |
| | Inlet humidity (corrected), g/Kg | | 11.4 ± 0.7 |
| Engine Breathing | Manifold absolute pressure, kPa | 30.6 ± 1.3 | 71.8 ± 1.3 |
| | Exhaust back pressure, kPa abs | 102 ± 1 | 105 ± 1 |
| Engine Fueling | Flow—kg/h | | record |
| | Flow—total kg | | record |
| | Inlet temperature, °C | | 28 ± 5 |
| Exhaust Emissions | Equivalence ratio or O ₂ , volume % | 1.00 ± 0.03 | record |
| | CO ₂ , volume % | | 0.5 ± 0.3 |
| | CO, volume % | | record |
| | NO _x , ppm (optional) | | 0.7 ± 0.4 |
| | | | record |
| Other | EGR, voltage | | record |
| | Blowby, corrected rate, L/min | ... | record |
| | Spark advance, ° BTDC | 30 ± 3 | 25 ± 3 |

^A Maintain all parameters as close to midrange as possible. The engine load in Stage 1 should be less than 5 kW. The ramp time between each stage is 30 s. Ramp the speed and manifold absolute pressure linearly and at the same time. Fifteen seconds into each ramp the speed shall be 2400 ± 75 r/min, and the manifold absolute pressure shall be 51.2 ± 6.6 kPa (385 ± 50 mm Hg).

6.2.3.1 *Intake Air Humidity*—Determination of the dew point may be made either in the laboratory main duct system or at the test stand. However, maintain duct surface temperature at all points downstream of the humidity measurement point above the dew point to prevent condensation loss (loss of absolute humidity).

6.2.3.2 Correct each reading for non-standard barometric conditions using the following equation:

$$\text{Humidity (corrected), g/kg} = 621.98 \times (P_{sat} / (P_{bar} - P_{sat})) \quad (1)$$

where:

P_{sat} = saturation pressure, mm Hg, and

P_{bar} = barometric pressure, mm Hg.

6.2.4 *Exhaust System*—The laboratory exhaust system shall have the capability of controlling exhaust back pressure as specified in [Table 1](#). The exhaust system shall include the back pressure control valve, exhaust back pressure probe, exhaust emissions probe or UEGO (Lambda) sensor, and the engine oxygen sensor. The Ford production exhaust manifold is to be used to connect the engine to the laboratory exhaust system. [Fig. A1.6](#) and [6.2.11.5](#) give details regarding the exhaust back pressure probe configuration and location, and [Fig. A1.6](#) and

[6.2.14](#) give details regarding the exhaust emissions probe configuration and location. A catalytic converter may be installed downstream of the exhaust back pressure and air-fuel ratio probes.

6.2.5 *Fuel Supply System*—A schematic diagram of a typical fuel supply system is shown in [Fig. A1.7](#). Supply an excess volume of fuel to the fuel rail at all times. Introduce make-up fuel (fuel used by the engine) into the loop from an external source. Mix the make-up fuel with fuel that is returned from the fuel rail (fuel not used by the engine). Pump the fuel through a mixing chamber, or small heat exchanger, which is used to mix the two streams and provide fuel of consistent temperature to the engine as specified in [Table 1](#). Deliver the fuel to a high-pressure pump that boosts the pressure and supplies the fuel to the fuel rail.

6.2.6 *Engine Control Processor Calibration and Main Engine Wiring Harness*—Two engine control EEC-IV processors are required for use in this test method, one for use during new engine break-in and one for test operation. The processor for new engine break-in, as detailed in [12.1.6](#), shall be the Ford Ranger non-modified manual transmission calibration EEC-IV processor (Part No. F47F-12A650-BGC) which is available from local Ford dealers. The specified engine control calibration for the test operation, as detailed in [Table 1](#), shall be the modified Ford Ranger manual transmission calibration EEC-IV processor (OHTIVD-001-02) available from OH Technologies, Inc.¹¹ See [Annex A2](#) for further details. The system should properly control the air-fuel ratio, the EGR and the ignition timing throughout the test. No other method shall be used in conjunction with or in place of the specified EEC-IV processor to adjust the air-fuel ratio, EGR or ignition timing.

6.2.7 *Ignition System*—See [6.2.6](#) for engine control EEC-IV processors which shall be used for ignition system control. See [Annex A2](#) for a listing of other required ignition system components.

6.2.8 *Engine Coolant System*—A typical cooling system is detailed in [Fig. A1.11](#).

6.2.8.1 Control the coolant outlet temperature and flow rate according to the specifications listed in [Table 1](#). The thermostat is not used. The coolant capacity is 21 ± 4 L.

6.2.9 *External Oil System*—Configure the external oil system in accordance with the photographs shown in [Fig. A1.8](#) and [Fig. A1.9](#). An oil system adapter assembly (OHT6A-007-1¹¹) is required. The heat exchanger should be mounted in a vertical plane. Be sure all hoses and fittings on the oil heat exchanger are properly connected and secure.

6.2.10 *Temperature Measurement Equipment and Locations*—Temperature measurement locations for the procedurally required temperatures are specified. Specific measurement equipment is not specified. This allows reasonable opportunity for adaptation of existing test stand instrumentation. The accuracy and resolution of the temperature measurement sensors and complete temperature measurement system shall follow the guidelines detailed in ASTM Research Report

¹¹ Available from OH Technologies, Inc., P.O. Box 5039, Mentor, OH 44061-5039.

RR:D02-1218.¹² If thermocouples are used, all thermocouples except the intake air thermocouple shall be premium, sheathed types. The intake air thermocouple may be an open-tip type. Thermocouples between 3.0 and 6.5 mm (0.125 and 0.25 in.) diameter may be used. However, minimum diameter thermocouples are recommended at locations which require short immersion depths to prevent undesirable temperature gradients. Thermocouple, wires, and extension wires shall be matched to perform in accordance with the limits of error as defined by ANSI publication MC96.1-1975. Type J (Iron-Constantan), Type T (Copper-Constantan), or Type K (Chromel-Alumel) thermocouples are acceptable and if RTDs are used, they shall be of a quality to give equivalent readings to the specified premium thermocouples. Temperature sensors shall not have greater than 5 cm (2 in.) of sheath exposed to lab ambient. All temperature sensor probe tips shall be located in the center of the stream of the medium being measured unless otherwise specified.

6.2.10.1 *Engine Oil Inlet*—Install the temperature sensor tip at the center of the flow stream through the oil filter adapter housing at the engine (See 6.2.9, Fig. A1.8, and Fig. A1.9).

6.2.10.2 *Engine Oil Outlet*—Install the temperature sensor tip at the center of the flow stream through the cross fitting attached to the bottom of the heat exchanger (see Fig. A1.8).

6.2.10.3 *Engine Coolant Inlet*—Install the temperature sensor tip at the center of the flow stream between the coolant heat exchanger and the engine at a distance of 430 ± 100 mm from the coolant inlet at the engine block.

6.2.10.4 *Engine Coolant Outlet*—Install the temperature sensor tip at the center of the flow stream through the thermostat housing within 50 mm of the coolant exit orifice on the cylinder head.

6.2.10.5 *Intake Air Inlet*—Locate the intake air temperature sensor probe in the production air filter housing between the air filter and the engine intake manifold. Install the temperature sensor probe tip 50 ± 10 mm into the housing and perpendicular to the housing (see Fig. A1.7).

6.2.10.6 *Fuel Temperature*—Install the temperature sensor tip at the center of the flow stream after the high pressure pump and just prior to the engine fuel rail (see Fig. A1.7).

6.2.11 *Pressure Measurement Equipment and Locations*—Pressure measurement locations for the procedurally required pressures are specified. Specific measurement equipment is not specified. This allows reasonable opportunity for adaptation of existing test stand instrumentation. The accuracy and resolution of the pressure measurement sensors and complete pressure measurement system shall follow the guidelines detailed in ASTM Research Report RR:D02-1218.¹²

6.2.11.1 *Oil Inlet*—Measure the oil inlet pressure at the oil filter adapter housing (see Fig. A1.9 and 6.2.9).

6.2.11.2 *Coolant Delta Pressure (outlet–inlet)*—The coolant delta pressure determines the flow restrictions of the external cooling system. The measurement is the resultant of the absolute value of the difference between the pressure measured as the coolant exists the cylinder head and prior to the coolant

entering the water pump. Make pressure measurements within 300 mm of these locations.

6.2.11.3 *Air Inlet*—Locate the intake air pressure probe in the production air filter housing between the air filter and the engine intake manifold. Install the probe 5 ± 3 mm into the housing.

6.2.11.4 *Manifold Absolute Pressure*—Measure manifold absolute pressure between the vacuum tree and the intake manifold (see Fig. A1.5).

6.2.11.5 *Exhaust Back Pressure*—Measure exhaust back pressure downstream of the engine oxygen sensor at a distance no greater than 400 mm and at the center of the exhaust stream. Fig. A1.6 gives details regarding the exhaust back pressure probe configuration and location. A condensate trap should be installed between the probe and sensor to accumulate water present in the exhaust gas.

6.2.11.6 *Crankcase Pressure*—Measure the crankcase pressure at the dipstick tube. The sensor shall be capable of measuring positive and negative pressure.

6.2.12 *Flow Measurement Equipment and Locations*—Flow measurement locations for the procedurally required flows are specified. Specific measurement equipment is not specified. This allows reasonable opportunity for adaptation of existing test stand instrumentation. The accuracy and resolution of the flow measurement sensors and complete flow measurement system shall follow the guidelines detailed in ASTM Research Report RR:D02-1218.¹²

6.2.12.1 *Engine Coolant*—Measure the engine coolant flow rate in an area most applicable to the flow measurement device used so that the most accurate measurement can be taken.

6.2.12.2 *Fuel*—The fuel system shall be configured so that the fuel return line from the fuel rail returns downstream of the fuel flow measurement device so that only the make-up fuel flow is measured (see Fig. A1.7).

6.2.13 *Speed and Load Measurement Equipment and Locations*—Speed and load measurement locations for the procedural required speeds and loads are not specified. Specific measurement equipment is not specified. This allows reasonable opportunity for adaptation of existing test stand instrumentation. The accuracy and resolution of the speed and load measurement sensors and complete speed and load measurement system shall follow the guidelines detailed in ASTM Research Report RR:D02-1218.¹²

6.2.14 *Exhaust Emissions Measurement Equipment and Location*—Engine air-fuel ratio may be monitored either by a “real time” equivalence ratio measurement system or by exhaust gas analysis (measurement of O₂, CO, and CO₂). With either system, measurements are to be made downstream of the engine oxygen sensor at a distance no greater than 400 mm and at the center of the exhaust stream.

6.2.14.1 *Real Time—Equivalence Ratio Measurement System*—It is recommended that a real time equivalence ratio measurement system be utilized. One example of a typical system is the Horiba Model MEXA 110. The system utilizes an extended range exhaust gas oxygen sensor (UEGO) air-fuel sensor that is inserted into the exhaust gas stream. The instrument gives instantaneous equivalence ratio measurement which provides the ability to detect when the engine is not

¹² Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D02-1218.

operating at normal equivalence ratio conditions (usually indicating an engine or engine management system problem), thus allowing for a problem to be addressed as it occurs. If an equivalence ratio system is utilized, the hydrogen/carbon (H/C) ratio for the specific fuel being run shall be input into the analyzer before conducting the engine test.

6.2.14.2 *Exhaust Gas Analysis*—Precision instruments for measurement of O₂, CO, and CO₂ are required if exhaust emissions are measured for air-fuel ratio determination. Measurement of NO_x is optional. Equipment suitable for automobile emission measurements is recommended. Precision non-dispersive infrared instrumentation for CO and polarographic instrumentation for O₂ are suggested (see SAE J254). Response time is an important consideration in the performance of this instrumentation. Fig. A1.6 provides details regarding the exhaust emissions probe configuration and location.

6.2.15 *DPFE (EGR) Voltage Measurement Equipment and Location*—DPFE voltage measurement locations for the procedural requirements shall be measured at Pin 27 of the EEC-IV processor. Pin 46 is signal return (ground). Specific measurement equipment is not specified. This allows reasonable opportunity for adaptation of existing test stand instrumentation. The accuracy and resolution of the DPFE voltage measurement equipment shall follow the guidelines detailed in ASTM Research Report RR:D02-1218.¹²

6.2.16 *Ignition Timing Measurement Equipment and Location*—Specific measurement locations and equipment for the measurement of spark advance are not specified.

6.3 *Test Engine Hardware*—This section specifies the engine hardware required for testing.

6.3.1 *Test Engine Parts*—The test engine parts required are detailed in Annex A2. The Engine Parts Kit in Table A2.3 contains a new cylinder head and the necessary parts for assembling the cylinder head for four tests.

6.3.2 *New Engine Parts Required*—The following table contains those new parts to be used for preparing the engine to run this test method.

| |
|---------------------------------|
| Belt, camshaft drive |
| Bolt, head to block |
| Filter, air |
| Filter, fuel |
| Filter, oil |
| Gasket, EGR valve |
| Gasket, exhaust manifold |
| Gasket, head |
| Gasket, low manifold - head |
| Gasket, plenum manifold |
| Gasket, rocker arm cover |
| Gasket - throttle body |
| Gasket, water outlet connection |
| PCV valve |
| Seal, cam |
| Seal, exhaust valve |
| Seal, intake valve |
| Spark plugs |
| Valve, exhaust |
| Valve, intake |

6.3.3 *Reusable Engine Parts*—The parts listed in the following table may be reused. The replacement frequency is listed in the footnotes. Discard all parts when they become unserviceable.

| |
|--------------------------------|
| Air cleaner tube assembly, out |
|--------------------------------|

| |
|--|
| Air cleaner tube assembly, in |
| Air cleaner assembly |
| Alternator or idler pulley assembly |
| Belt, alternator or idler pulley |
| Bolt, cam sprocket |
| Camshaft |
| Coil |
| Cylinder head ^A |
| EEC-IV processor |
| Engine wire harness |
| Engine assembly ^B |
| Fuel injector ^C |
| Filter, air |
| Guide, timing belt |
| Hose, DPFE |
| Ignition control assembly |
| Ignition wire, LH |
| Ignition wire, RH |
| Key, valve spring retainer |
| Lash adjusters |
| Plate, cam |
| Pulley water pump |
| Regulator, EGR vacuum (EVR) |
| Retainers |
| Rocker arms |
| S&W, cam plate |
| Sensor, air charge temperature (ACT) |
| Sensor, crankshaft timing assembly |
| Sensor, engine coolant temperature (ECT) |
| Sensor, heated exhaust gas O ₂ (HEGO) |
| Sensor, mass air flow (MAF) |
| Sensor, pressure feedback EGR Assembly (PFE) |
| Sensor, throttle position (TPS) |
| Sprocket, cam |
| Valve, EGR |
| Valve spring and damper ^D |
| Washer, cam sprocket |

^A The cylinder head may be reused as long as it meets the procedural requirements for buildup as detailed in 10.4 and 10.5.

^B The engine assembly may be reused depending on the condition of the cylinder head bolt holes, cylinder bore wear, blowby, and oil consumption. Procedural requirements have yet to be determined. Refer to 12.4 for procedural requirements for oil consumption.

^C The fuel injectors may be reused as long as they meet the procedural requirements detailed in 10.3.1.

^D Reuse the valve springs as long as they meet the procedural requirements detailed in 10.4.

6.4 *Special Measurement and Assembly Equipment:*

6.4.1 *Graduated Cylinder*—Blending of the deposit control additive may be required and the concentration may be given as a volumetric ratio. Use a sensible sized container for measuring.

6.4.2 *Analytical Balance*—Blending of the additive may be required and the concentration may be given as a mass ratio. An analytical balance capable of 0.01 g resolution with a maximum capacity of at least 2000 g is recommended. Also, a balance is required to determine intake valve weight, which is approximately 100 g, with accuracy of 0.25 % of full scale and resolution of 0.0001 g. Calibrate the balance following the manufacturer's procedure and frequency recommendations.

6.4.3 *Desiccator*—An airtight chamber with lid shall contain an adequate amount of desiccant to maintain a relatively moisture-free environment for intake valves with deposits. (see 7.8).

6.4.4 *Oven*—Use a natural convection oven that is capable of maintaining 93 ± 5°C (200 ± 9°F) for evaporating the

cleaning solvents from the valves. The oven shall have sufficient dimensions to stand the valve upright. There shall be no arcing contacts in the oven.

6.4.5 *Power Wire Wheel*—Use a power wire wheel (bench grinder fitted with a fine, 150 mm (6 in.) diameter steel wire wheel) to clean the intake valves as specified. See 13.1.

6.4.6 *Walnut Shell Blaster*—Similar to a sand blaster, the walnut shell blaster uses shop air pressure; however, a fine, abrasive media of crushed walnut shells is used instead of sand. The walnut shells are sufficiently abrasive to remove carbon while not removing metal from the surface being cleaned. The walnut shell blaster technique is more effective than solvents and generally preferred over a wire brush for removing carbon deposits from the valves and the cylinder head.

6.4.7 *Valve Stem and Guide Measuring Equipment*—Specific equipment to measure valve stem-to-guide clearances in the cylinder head as required in this test method (see 10.4.6) is not specified. Use any commercially available automotive equipment that is capable of measuring to the specifications and tolerances listed in 10.4.6.

6.4.7.1 Accurate measurements are mandatory to determine stem-to-guide clearance as this parameter can affect oil consumption and intake valve deposit accumulation.

6.4.8 *Vernier Caliper*—A vernier caliper is necessary to measure valve seat width of the cylinder head as required in this test method (see 10.4.7).

6.4.8.1 Accurate measurement of valve seat width is required as this parameter can affect heat transfer from the valves, particularly the intake valve and the surface where deposits may accumulate, ultimately affecting deposit accumulation.

6.4.9 *Valve Spring Compression Testing Machine*—A valve spring compression testing machine capable of assessing valve spring condition as specified in 10.4.9 is required. The device shall have an accuracy of 2 % and a resolution of 0.45 kg (1 lb).

6.4.10 *Valve Lapping Tool*—Use a device to rotate or oscillate the valves on the seat to lap the valves. Suitable valve lapping tools are available from automotive tool supply sources. See 10.4.3.

6.4.11 *Valve and Valve Seat Cutting Equipment*—Equipment may be needed to ensure valve and valve seat mating quality as outlined in 10.4.2. Acceptable equipment is available from automotive tool supply sources.

6.4.12 *Blowby Measurement Apparatus*—The blowby measurement apparatus is a device to measure flow rate of the gas passing the piston rings and entering the crankcase. This flow rate provides an indication of the condition of the piston rings and cylinder bore and, therefore, is used as a quality assurance criteria. The device shall have an accuracy of 5 % full scale and a resolution of 0.3 L/min (0.01 ft³/min).

6.4.13 *Fuel Injector Test Rig*—A suitable device capable of accurate, repeatable flow measurement of port fuel injectors is required. This device shall be capable of performing necessary port fuel injector evaluations as outlined in 10.3.1. No suitable commercially available apparatus has been identified.

6.4.14 *PCV Valve Flow Rate Device*—This device is used to verify the flow rate of the PCV valves. Fabricate the device according to the details shown in Fig. A1.10.

6.4.15 *Timing Light*—An inductive pickup timing light may be used to measure ignition timing.

7. Reagents and Materials

7.1 Fuel:

7.1.1 *Fuel Management*—Fuel management is very critical in this test. The following procedure shall be used each time a new base fuel batch will be used in testing:

7.1.1.1 The base fuel storage container(s) shall be relatively free from all contaminants.

7.1.1.2 Take at least a 900 mL fuel sample of the delivered base fuel before the base fuel is installed into the fuel storage container(s). The fuel sample shall be representative of the overall base fuel.

7.1.1.3 Flush the fuel storage container(s) with the base fuel.

7.1.1.4 Add the base fuel to the storage container(s).

7.1.1.5 Take at least a 900 mL fuel sample after the fuel storage container(s) are flushed with the base fuel and the base fuel has been installed into the fuel storage container(s). The fuel sample shall be representative of the overall base fuel.

7.1.2 *Test Fuel Quantity*—Approximately 950 L (250 gal) of test fuel (including all flushes) is required for the test.

7.1.3 *Additive/Base Fuel*—Some test requesters may require the test fuel be blended at the test laboratory and, therefore, will supply the neat deposit control additive and untreated base fuel. The test requester shall supply the deposit control additive and base fuel in appropriate volumes and packaging to ensure safe and efficient handling. Blending instructions detailing the concentration ratio either volumetric-based or mass-based shall accompany all deposit control additives. Mass-based measurement is preferred. However, it is most desirable to have the additive supplied in premeasured, individual containers. Clearly identify the blended fuel.

7.1.4 *Test Fuel*—Test fuel containing deposit control additive shall be a homogeneous blend of additives and base fuel. Blend sufficient fuel before the start of the test. The fuel may be stored in drums or tankage, and shall be labeled clearly to prevent misfueling. Measure and record quantities of fuel and additive blended and dispensed for use in determining the fuel consumption.

7.1.5 *Engine Break-in Fuel*—The engine break-in fuel shall comply with Specification D4814 requirements or Haltermann EEE¹³ or equivalent. Approximately 380 L (100 gal) are required for engine break-in.

NOTE 2—Consider using a fuel with a minimum octane rating of 92 ((R+M)/2) to avoid detonation in the engine during the break-in period.

7.1.6 *Reference Fuel*—See Section 9 regarding reference fuel requirements and specifications.

7.2 *Engine Oil/Assembly Lubricant*—The standard engine oil and assembly lubricant shall be the IVD Reference Oil

¹³ IVD Reference Base fuel is a product of Haltermann Products, subsidiary of the Dow Chemical Company, 1201 S. Sheldon Rd., P.O. Box 429, Channelview, TX 77530-0429.

(IVD Dynamometer Reference Oil).¹⁴ Approximately 4.7 L (5 qt) are needed for this test method, including engine assembly and initial crankcase fill.

7.3 Engine Coolant—The coolant is a mixture of equal volumes of a commercial ethylene glycol based low-silicate antifreeze and distilled or demineralized water. *Do not use uninhibited ethylene glycol.*

7.4 Solvents and Cleaners:

7.4.1 Normal-Hexane or Cyclohexane —The valves are rinsed with either *n*-hexane or cyclohexane. (**Warning**—In addition to other precautions, provide adequate ventilation and fire protection in areas where flammable or volatile liquids and solvents, or both, are used. Suitable protective clothing is recommended.)

NOTE 3—Reagent-grade chemicals will be used for all test procedures. Unless otherwise noted, it is intended that all reagents conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society,¹⁵ where such specifications are available. Other grades may be used provided it is first ascertained that the reagent is of sufficient purity to permit its use without lessening the accuracy of the determination.

7.4.2 Naphtha Solvent—Stoddard solvent conforming to Type I of Specification **D235** is recommended. Proprietary solvents of this general type may be used. This fluid may be used for cleaning parts (that is, valve train parts, cylinder head, intake manifold, throttle body) and as a fuel injector test fluid.

7.5 Fuel Injector Flow Test Fluid—Use naphtha solvent (see **7.4.2**).

7.6 Valve Lapping Compound—Use Fel Pro Clover 320 Grade 1A silicon carbide grease compound (Part No. 1A51804) valve lapping compound.¹⁶

7.7 Crushed Walnut Shells—A walnut shell blaster may be used to remove carbon and deposits from the head or, if necessary, from the intake valves at end-of-test (see **13.1.6.1**). Use clean, fresh walnut shells which are available commercially from industrial and automotive supply sources.

7.8 Desiccant—Use a granular form of anhydrous calcium sulfate (CaSO₄).¹⁷ When not in use, store the desiccant in an airtight container.

8. Hazards

8.1 Specific Hazards—Personnel are exposed to various hazards while in the testing area. Take appropriate care to ensure the safety of all personnel while in the testing area.

9. Reference Fuel

9.1 Reference Base Fuel Batch Approval Process—Each new batch of IVD reference base fuel¹³ is approved by the following process:

9.1.1 Before initial blending, each of the fuel components is analyzed by the fuel supplier. A small amount of fuel mixture is then blended and analyzed using the methods described in **Table 2** and in **9.2.2** and **9.2.3**. The TMC, in conjunction with the ASTM IVD Dynamometer Test Surveillance Panel, determines the acceptability of the analytical data and authorizes blending of the entire batch for engine testing.

9.1.2 A sample of the IVD reference base fuel is shipped to designated independent laboratories. A program involving more than one calibration test is completed using the IVD reference base fuel and reference fuel additives selected by the TMC. The ASTM IVD Dynamometer Test Surveillance Panel is involved in the design of the program. The TMC reviews the test results and after satisfactory completion of the program, will authorize the fuel supplier to notify potential purchasers of the approval status of the IVD reference base fuel batch.

9.2 Fuel Batch Analysis:

9.2.1 Analyze each IVD reference base fuel shipment upon receipt from the supplier to determine the value of the parameters shown in **Table 2**. Compare the results to the values obtained by the supplier on that particular batch. The results should be within the ranges shown beside each parameter. This provides a method to determine if the fuel batch is as shipped, has been contaminated, or has aged prematurely. If any results fall outside the ranges shown in **Table 2**, the laboratory should contact the TMC for help in resolving the problem. These analyses track parameters easily measured at most locations and are usually successful at detecting either gross fuel contamination or significant deterioration with age, heat, oxidation, or mishandling, when compared with initial analysis

TABLE 2 IVD Reference Base Fuel Typical Batch Properties and Transport and Storage Warning Limits

| Parameter | Typical Batch Initial Analysis Values | Transport and Storage Warning Limits |
|---|---------------------------------------|--------------------------------------|
| API gravity ^A | 59.9 | 58.7–61.2 |
| Vapor pressure ^B | 61.5 kPa | 60–63 kPa |
| Total sulfur ^C | 0.025 mass % | 0.01–0.04 mass %, max |
| Solvent washed gum ^D | 1 mg/100 mL | 5 mg/100 mL, max |
| Distillation ^E | | |
| IBP | 30.1°C | 25–35°C |
| 10 % evaporated | 52.5°C | 50–55°C |
| 50 % evaporated | 102.5°C | 95–110°C |
| 90 % evaporated | 154.9°C | 150–160°C |
| EP | 204.0°C | 196–212°C |
| Hydrocarbon type ^F | | |
| Aromatics | 31.0 volume % | 27–35 volume % |
| Olefins | 7.0 volume % | 5–10 volume % |
| Saturates | 62.0 volume % | 55–68 volume % |
| The following parameters are analyzed on an absolute basis: | | |
| Appearance | clear and bright | clear and bright |
| Water ^G | 0.001 volume % | 0.01 volume %, max |
| Lead ^H | <2.5 mg/L | 13 mg/L, max |
| Oxidation stability ^I | >1440 min | 1440 min, min |

^A In accordance with Test Method **D287** or **D1298**.

^B In accordance with Test Method **D4953**, **D5190**, **D5191**, or **D5482** Vapor Pressure.

^C In accordance with Test Method **D1266**, **D2622**, or **D4294**.

^D In accordance with Test Method **D381**.

^E In accordance with Test Method **D86**.

^F In accordance with Test Method **D1319**.

^G In accordance with Test Method **D1744**, **E203**, or **E1064**.

^H In accordance with Test Method **D3237** or **D5059**.

^I In accordance with Test Method **D525**.

¹⁴ Available from Conoco Oil Co., P.O. Box 80430, Rochester, MI 48308.

¹⁵ *Reagent Chemicals, American Chemical Society Specifications*, American Chemical Society, Washington, DC. For Suggestions on the testing of reagents not listed by the American Chemical Society, see *Annual Standards for Laboratory Chemicals*, BDH Ltd., Poole, Dorset, U.K., and the *United States Pharmacopeia and National Formulary*, U.S. Pharmacopeial Convention, Inc. (USPC), Rockville, MD.

¹⁶ Available from Jacobs Equipment Distributing Company, 729 South Flores, San Antonio, TX 78204.

¹⁷ Drierite has been found to be satisfactory. An equivalent material can be used.

values for the fuel batch. The primary sources of intake valve deposition species within a fuel are imperfectly defined, but are controlled in initial production of the fuel by the manufacturer, and verified by the user group by the process described in 9.1.2.

9.2.2 In addition, the fuel supplier shall analyze the contents of each storage tank that contains IVD reference base fuel used for qualified IVD Dynamometer Tests every two months to ensure the fuel has not deteriorated excessively or been contaminated in storage. Laboratories should take composite samples using Practice D4057 as a guideline. The fuel supplier shall provide an adequate supply of fuel sample containers with packaging and pre-addressed return labels to each dynamometer IVD laboratory. Upon receipt of fuel samples from the laboratories, the fuel supplier will perform the following analyses, report the results to the submitting laboratory, and tabulate the results in a database:

Test Method

D4953, D5190, D5191, or D5482 Vapor Pressure

D287 API Gravity

D86 Distillation

D381 Solvent Washed Gum

D381 Unwashed Gum

D525 Oxidation Stability

9.2.3 In instances where results from the physical and chemical tests listed previously appear to vary significantly from the expected results, a second sample will be analyzed or the following tests will also be conducted, or both:

C₂ through C₅ hydrocarbon determination by gas chromatography, Test Method D2427

Potential Gum, Test Method D873

9.2.4 Forward the results of the analyses performed in 9.2.1 and 9.2.2 to the TMC for inclusion in the appropriate data base.

9.3 *Fuel Batch 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 following all applicable safety and environmental regulations.

10. Preparation of Apparatus

10.1 Test Stand Preparation:

10.1.1 *Instrumentation Calibration*—Calibrate all sensors and indicators as required by the particular types of instrumentation utilized. Section 11 provides details on all calibration requirements.

10.1.2 *Exhaust Back Pressure and Exhaust Emissions Sample Probe Inspection*—The exhaust back pressure and exhaust emission sample probes can be used until they become unserviceable. Inspect probes for wear, cracks, contamination, residue, and so forth, and replace if necessary.

10.1.3 *External Hose Inspection*—Inspect all external hoses for wear, cracks, contamination, unspecified restrictions, and so forth, and replace as necessary.

10.1.4 *Engine Wire Harness Inspection*—Inspect the engine wire harness for broken connectors, broken wires, frayed wires, general integrity, and replace or repair as required.

10.1.5 *EGR Voltage Readout Preparation*—The EGR voltage signal is located at Pin 27 of the Ford EEC-IV Processor. Connect a voltage readout device to Pin 27 (output) and Pin 46 (signal return) of the Ford EEC-IV Processor.

10.2 Engine Block Preparation:

10.2.1 *Piston Top Preparation and Inspection*—Inspect piston tops for integrity. Ensure there are no unusual wear patterns on piston tops (pitting, scratches, and so forth). Make sure piston tops are completely clean of all deposits. Use appropriate solvents (see 7.4), a walnut shell blaster, or other appropriate tools to clean the piston tops. Make sure the tools used do not alter the piston top surface, and the piston-to-cylinder wall crevices are clean of all contaminants.

10.2.2 *Cylinder Bore Inspection*—Inspect cylinder bores for unusual wear (scores, pits, and so forth).

10.2.3 *Engine Block Inspection*—Inspect the integrity of the engine block by monitoring the engine's compression pressure (see 12.3.4), percent leakdown (see 12.3.4), and oil consumption (see 12.3.1). The block should be replaced if unusual wear is detected.

10.2.4 *Cylinder Head-to-Cylinder Block Mating Surface*—Clean the cylinder head-to-cylinder block mating surface of any gasket material or deposit using a gasket scraper, the appropriate solvents (see 7.4), a walnut shell blaster, or other appropriate tools.

10.3 Preparation of Miscellaneous Engine Components:

10.3.1 *Fuel Injector Preparation*—Prior to engine installation, evaluate all injectors (new and used) for spray-pattern and flow-rate using a suitable apparatus as defined in 6.4.13 and Stoddard Solvent (see 7.4.2). The evaluation procedure is outlined in this section. Injectors may be cleaned and reused if the criteria outlined in this section are satisfied.

10.3.1.1 *Flush New Injectors*—Flush new injectors for 30 s to remove any assembly residue before flow testing.

10.3.1.2 *Operating Flow Rig*—Using a rig as described in 6.4.13, turn on the fuel pumps, the flow meter, and the timer. After the pumps are turned on, the test fluid (see 7.5) will start to flow through the slave injector. Maintain the test fluid pressure supplied to injector at 269 ± 3.4 kPa (39 ± 0.5 psi) during the entire test. The maintenance of this pressure is very critical because a small change in pressure will have a dramatic effect on the flow rate and spray pattern.

10.3.1.3 *Flow-test Injectors*—Flow-test each injector for three 60-s periods. Record each of these measurements. The final flow rate of the injector is based on the average of these three, 60-s trials.

10.3.1.4 *Observe Spray Quality*—While the injector is flowing, make a visual observation of the spray pattern quality. Record this observation for each occurrence. Reject any injector that demonstrates an abnormal spray pattern. Injectors shall not leak or drip while under pressure for at least 30 s when the injectors are not open. Replace any injector that drips or leaks.

10.3.1.5 *Acceptance Criteria*—Meet the following guidelines when selecting injectors to be used for this test method. Do not use groups of injectors or individual injectors not meeting the following guidelines.

(1) *Flow Specification-Individual Injectors*—Flow-test individual injectors at 269 ± 3.4 kPa (39 ± 0.5 psi) using Stoddard solvent at 15 to 25°C (59 to 77°F) and specific gravity of 0.754 to 0.82. Adjust flow rates for test conditions of fluid temperature and pressure. Individual injectors shall have flow rates of 1.82 to 2.23 mL/s.

(2) *Flow Specification-Groups*—Groups of four injectors shall not have any one injector deviate from the four injector average by more than 3 %.

10.3.2 *Intake Manifold Preparation*—Make sure the intake manifold is clean before each test. Use an acceptable cleaning agent such as a commercially available carburetor cleaner or Stoddard solvent. Inspect the intake manifold for integrity. The intake manifold can be used in repeated engine builds until it becomes unserviceable.

10.3.3 *PCV Valve Preparation*—Use the PCV flow rate measuring device as detailed in 6.4.14 to measure and verify the flow rates of the PCV valve before and after test; record the flow rates. Measure the flow rate twice and average the readings. Reject any PCV valve that does not adhere to the following specifications:

- 24.1 to 32.6 L/min (0.85 to 1.15 ft³/min) at 60.8 kPa (18 in. Hg) vacuum
- 52.4 to 60.9 L/min (1.85 to 2.15 ft³/min) at 27.0 kPa (8 in. Hg) vacuum

10.4 *Cylinder Head Preparation:*

10.4.1 *Valve Labeling*—Use new intake and exhaust valves for each test. Mark each valve prior to valve weighing. For example, an intake valve that is going to be used in Test No. 5 and inserted into the number one cylinder intake valve position could be marked T5 No.1 In. Place all valve markings on the valve stem between the top of the valve and the valve seal-to-valve stem contact area.

10.4.2 *Valve Seat and Face Cutting*—Cut intake and exhaust valve faces (areas that contact the valve seats) to a 45° angle. Double cut the intake and exhaust valve seats. The first cut should be at a 45° angle. The second cut should be at a 30° angle perpendicular to the axis of the valve guide and located on the outer diameter of the seat. A 60° cut can be utilized to adjust the valve seat to valve face interface as required.

10.4.3 *Valve Seat and Face Lapping*—Lap each intake and exhaust valve using Fel Pro Clover 320 Grade 1A Silicone Carbide Grease Compound (Part No. 1A51804)¹⁶ for 20 s.

10.4.4 *Valve Seat and Face Cleaning*—Clean the valves by dipping in Stoddard solvent and wiping with a soft towel. Clean the seats with Stoddard solvent and wipe dry with a soft towel. Wash valves with n-hexane or cyclohexane. Gently shake off any remaining solvent. Place valves in an oven (see 6.4.4) at 93 ± 5 °C (200 ± 9 °F) for 5 min. Place valves in a desiccant for 1 h.

10.4.5 *Valve Weighing*—Weigh and record the valve weights to the nearest 0.0001 g.

10.4.6 *Valve Stem-to-Guide Clearance Measurements*—Measure and record intake and exhaust valve stem-to-guide clearances at the top, center, and bottom of the guide. Two sets of measurements shall be taken in the guide. The first set of measurements shall be taken 3 mm from the top of the guide, at the center of the guide, and 3 mm from the bottom of the

guide. The second set of measurements shall be taken 90° from the first set of measurements. The valve stem shall be measured in the three locations that correspond to the valve guide measurements. The clearances shall be within the specifications listed below:

10.4.6.1 *Valve Stem-to-Guide Clearance Specifications:* Exhaust: 0.038 to 0.140 mm (0.0015 to 0.0055 in.)

Intake: 0.025 to 0.069 mm (0.0010 to 0.0027 in.)

10.4.7 *Valve Seat Width Measurements*—Measure and record the valve seat widths to the nearest 0.025 mm (0.0009 in.).

10.4.7.1 *Valve Seat Width Specifications:* Intake: 1.524 to 2.032 mm (0.060 to 0.080 in.)

Exhaust: 1.778 to 2.286 mm (0.070 to 0.090 in.)

10.4.8 *Valve Spring Free Length Measurements*—Measure and record the valve spring free length dimensions. Experience has shown that the springs should fall within the specifications shown in 10.4.9.

10.4.9 *Valve Spring Loading Measurements*—If the springs are within the specifications for free length dimensions, measure the load on an unassembled valve spring calibration device. The spring loading is measured at a compressed height of 29.5 mm (1.16 in.). Experience has shown that the valve spring parameters should be within the specifications shown below.

10.4.9.1 *Valve Spring Specifications:* Free length: 50.3 to 53.8 mm (1.98 to 2.12 in.)

Load: 67.3 ± 3.6 kg at 29.5 ± 0.76 mm deflection
(148 ± 8 lb at 1.16 ± 0.03 in.)

10.5 *Cylinder Head Assembly:*

10.5.1 *Valve and Valve Seal Installation*—Lubricate each valve seal and valve stem with the specified test oil. Insert each valve into the cylinder head. Install the valve seal over the end of the valve stem with a plastic installation cap in place. Carefully seat the seals fully on the guides.

10.5.2 *Valve Spring and Retainer Installation*—Install pre-screened valve springs and retainers. When installing the valve springs and retainers, do not compress the springs excessively. *Excessive spring compression can damage the valve seals.*

10.5.3 *Valve Spring Assembled Height Measurements*—Measure and record the assembled height of the valve springs according to the procedure described in the 1994 Ford Aerostar, Ranger, Explorer Service Manual¹⁸. The assembled height shall be between 37.85 mm and 39.37 mm (1.49 in. and 1.55 in.).

10.5.4 *Valve Leak Check*—It is recommended to perform a valve leak check be performed on the cylinder head. Seal off the cylinder head's combustion chambers with a metal plate and a cylinder head gasket. Apply 480 kPa (70 psi) to each combustion chamber through the spark plug hole and record the percent leakdown. The percent leakdown should not be greater than 5 % in any of the combustion chambers. If the percent leakdown is greater than 5 % in any of the combustion chambers, then the suspect valve(s) should be re-cut or re-lapped, or both, as well as reweighed until the percent leakdown is less than 5 %. An alternative leak check method is

¹⁸ Available from Helm, Inc., P.O. Box 07150, Detroit, MI 48207.

to use a vacuum pump and a sealing plate on the combustion side of the cylinder head.

10.6 *Cylinder Head Installation:*

10.6.1 *Cylinder Head Torquing*—Install the assembled test cylinder head on the engine. Do not use any sealing or anti-seizure compound on the cylinder head gasket. Install and torque the head bolts according to the procedure described in the 1994 Ford Aerostar, Ranger, Explorer Service Manual.

10.6.2 *Spark Plug Installation*—Install new Motorcraft F3TE-12405-BA spark plugs into the cylinder head. Gap the spark plugs to 1.06 to 1.17 mm (0.042 to 0.046 in.). Torque the spark plugs to 6.8 to 13.6 N-m (5 to 10 lbf-ft).

10.7 *Final Engine Assembly:*

10.7.1 *Camshaft, Rocker Arms, and Camshaft Drive Sprocket Installation*—Install the camshaft, rocker arms, and camshaft drive sprocket. Collapse all lash adjusters before the rocker arms are installed to prevent potential damage to the valves when the timing belt is installed and tensioned.

10.7.2 *Camshaft Drive Installation*—Install the auxiliary shaft sprocket and align the camshaft drive. Torque the sprockets according to the procedure noted in the 1994 Aerostar, Ranger, Explorer Service manual. Install a camshaft drive belt. Use a new camshaft drive for each test. Tension the camshaft drive belt according to the procedure noted in the 1994 Aerostar, Ranger, Explorer Service Manual.

10.7.3 *Water Pump and Water Pump Pulley Installation*—Install the water pump and water pump pulley.

10.7.4 *Camshaft Drive Belt Cover and Crankshaft Pulley Installation*—Install the camshaft drive belt cover. Install the crankshaft pulley. It is advisable to make a reference mark on the crankshaft pulley corresponding to top dead center of the number one and number two pistons. The reference marks are used for the required percent leakdown test.

10.7.5 *Lower Intake Manifold Runner Installation*—Install the lower intake manifold runner to the test head. The lower intake manifold may be installed onto the cylinder head prior to the cylinder head being installed onto the engine block.

10.7.6 *Fuel Injectors and Fuel Injector Rail Installation*—Install the fuel injectors and the fuel injector rail to the lower intake manifold runner. Install injectors such that the electrical connection is at the topmost (12 o'clock) position. Reference scribe markings should be placed on the fuel injectors and the lower intake manifold runner and the scribe markings should be lined up for each test.

10.7.7 *Rocker Cover and Upper Intake Manifold Installation*—Install the rocker cover and the production upper intake manifold.

10.7.8 *Intake Air System Installation*—Install the specified test intake air system which consists of the production air cleaner housing, air filter, and rubber flexible tube which attaches from the air cleaner housing to the throttle body of the upper intake manifold. Refer to [Fig. A1.4](#) and [Table A2.1](#). Route conditioned intake air per the temperature and humidity specifications dictated in [Table 1](#) to the inlet of the air cleaner housing. Replace the specified test air filter every test.

10.7.9 *Miscellaneous Parts Installation*—Install the exhaust manifold, belt tensioning system, accessory drive belt, ignition coil packs, and spark plug wires.

10.7.9.1 The belt tensioning system shall consist of the water pump pulley and the crankshaft pulley as specified by the test engine parts list detailed in [Annex A2](#). Other parts used in the belt tensioning system shall be certified Ford OEM parts. All parts used in the belt tensioning system shall be *free wheeling* and shall not add any additional load to the engine other than normal frictional load losses.

10.7.10 *Engine Cooling System Installation*—A typical engine cooling system configuration is detailed in [Fig. A1.11](#). Equal volumes of a commercial ethylene glycol-based low-silicate antifreeze and distilled or demineralized water shall be utilized in the cooling system. Coolant capacity is specified in [6.2.8.1](#).

10.7.11 *External Oil System Installation*—Refer to [6.2.9](#) for the proper external oil system configuration and installation.

10.7.12 *Fuel System Installation*—Refer to [6.2.5](#) for the proper fuel system configuration and installation.

10.7.13 *Resistance-Temperature Detector (RTD) or Thermocouple Installation, or both*—Install all RTDs or thermocouples, or both, into their respective locations. Refer to [Section 6](#) for the proper locations.

10.7.14 *Pressure and Vacuum Line Installation*—Install all pressure and vacuum lines into their respective locations. Refer to [Section 6](#) for the proper locations.

10.7.15 *Exhaust Emission and Back Pressure Probe Installation*—Install the exhaust emission probe and exhaust back pressure probe into their respective locations. Refer to [Section 6](#) for the proper locations.

10.7.16 *Engine Wire Harness Installation*—Connect all engine wire harness connectors to their respective locations on the engine and engine components.

11. Calibration

11.1 *Test Stand Calibration:*

11.1.1 *Verification:*

11.1.1.1 Each laboratory will schedule stand calibration tests when reference fuels and additives are available, and when TMC has begun to monitor this procedure. Stand calibration tests are normally conducted upon expiration of the 180 day calibration time period. However, calibration time periods may be adjusted by the TMC. Any deviation from the standard calibration time frequency shall be approved by the TMC and reported on a supplemental operational data sheet of the final test report. Any non-reference test started within 180 days of the completion date of the previous calibration test is considered within the calibration time period.

11.1.1.2 Containers of reference fuel additive are provided by the TMC for each stand calibration test. Each container has the correct amount of reference fuel additive to blend with 300 gal of the IVD Reference Base fuel.

11.1.2 *Unacceptable Calibration Results:*

11.1.2.1 It is recognized that a certain percentage of calibration tests will fall outside the acceptance limits because of the application of statistics in the development of the acceptance limits. Failure of a reference fuel test to meet Shewhart or exponentially weighted moving average EWMA precision control chart limits can be indicative of a false alarm or a stand or industry problem. When this occurs, the laboratory, in

conjunction with the TMC, shall attempt to determine the problem source. The TMC may solicit input from industry expertise (other testing laboratories, the test sponsor, ASTM Technical Guidance Committee, IVD Dynamometer Test Surveillance Panel, IVD Dynamometer Test Operations and Hardware Subpanel, and so forth) to help determine the cause and extent of a problem. Industry problems shall be adjudicated by the IVD Dynamometer Test Surveillance Panel.

11.1.2.2 If the TMC determines the problem is a false alarm, and is stand related, there is no impact on non-reference tests running in other stands within the laboratory.

11.1.2.3 The TMC will reschedule a calibration test once it is satisfied that no particular problem exists or the problem has been resolved. The laboratory shall provide adequate documentation to support the conclusions reached during this process. This documentation shall be attached to the acceptable calibration test report. It shall provide sufficient information to show how the problem related to other tests operated during the same period of time.

11.1.3 *Test Stand Modifications*—Report modification of test stand control systems or completion of any nonstandard test on a calibrated stand to the TMC immediately. A nonstandard test includes any test completed under a modified procedure requiring hardware or controller tuning modifications to the test stand. The TMC will determine whether another calibration test is necessary after the modifications have been completed.

11.1.4 *Reference Fuel Accountability:*

11.1.4.1 Laboratories conducting calibration tests are required to provide a full accounting of the identification and quantities of all reference fuels used.

11.1.4.2 With the exception of the new fuel analysis required in 9.2, no physical or chemical analysis of new reference fuels shall be performed without permission of the TMC. Retain all reference fuel samples for 90 days.

11.1.5 *Test Numbering System:*

11.1.5.1 *Acceptable Tests*—The test number shall follow the format *AA-BB-CCC*, where *AA* represents the stand number, *BB* represents the number of tests since the last reference, and *CCC* represents the total number of tests on the stand.

As an example, 02-15-125 represents the 125th test on Stand No. 2 and the 15th test since the last reference. Consecutively number all tests on a given stand.

11.1.5.2 *Unacceptable or Aborted Tests*—If a calibration test is aborted or the results are outside the acceptance limits, the *CCC* portion of the test number for subsequent calibration test(s) shall include a letter suffix. The suffix shall begin with the letter *A* and continue alphabetically until a calibration test is completed within the acceptance limits. For example, if three consecutive unacceptable calibration tests are completed on the same test stand, and the test number of the first test is 02-0-125, the next two test numbers would be 02-0-125A and 02-0-125B. If the results of the next calibration test are acceptable, the test number 02-0-125C would permanently identify the test and appear on future correspondence. The completion of any amount of operational time on tests other than calibration tests

will cause the test number to be increased by one. No letter suffix will be added to the test number of tests other than calibration tests.

11.2 *Instrumentation Calibration*—Calibrate the instrumentation described below prior to each calibration test or every 180 days or as otherwise indicated.

11.2.1 *Engine Speed Measurement System*—Calibrate the speed measurement system prior to each calibration test. If the test stand has been inactive and the instrumentation has not been calibrated within 180 days, perform a speed measurement system calibration prior to starting a test. Calibrate over the operating range of the test.

11.2.2 *Manifold Absolute Pressure Measurement System*—Calibrate the manifold absolute pressure measurement system prior to each calibration test. If the test stand has been inactive and the instrumentation has not been calibrated within 180 days, perform an engine manifold absolute pressure measurement system calibration prior to starting a test. Calibrate over the operating range of the test.

11.2.3 *Engine Fuel Consumption Measurement System*—Calibrate the fuel consumption measurement system prior to each calibration test. If the test stand has been inactive and the instrumentation has not been calibrated within 180 days, perform a fuel consumption measurement system calibration prior to starting a test. Calibrate over the operating range of the test.

11.2.4 *Engine “Real Time” Equivalence Ratio Measurement System*—Calibrate the equivalence ratio measurement system prior to each calibration test. If the test stand has been inactive and the instrumentation has not been calibrated within 180 days, perform an equivalence ratio measurement system calibration prior to starting a test. Calibrate over the operating range of the test.

11.2.5 *Exhaust Gas Analysis Calibration*—If exhaust gas analysis equipment is used, calibrate the exhaust gas analysis equipment before each set of measurements are taken during the test. The calibration technique should compensate for the flow rate sensitivity of the exhaust gas analysis meters.

11.2.6 *Pressure and Temperature Probe Measurement Systems*—Calibrate the pressure and temperature probe measurement systems used to acquire the pressure and temperature data detailed in Table 1 prior to each calibration test. If the test stand has been inactive and the instrumentation has not been calibrated within 180 days, perform a pressure and temperature probe measurement system calibration prior to starting a test. Calibrate over the operating range of the test.

11.2.7 *Humidity System*—Calibrate the primary measurement system at each test stand on a semi-annual basis.

11.2.7.1 Using a hygrometer with a minimum dew point accuracy of $\pm 0.55^{\circ}\text{C}$ at 16°C ($\pm 1^{\circ}\text{F}$ at 60°F), locate the sample tap on the air supply line to the engine, between the main duct and 0.6 m (2 ft) upstream of the engine intake air filter. The calibration consists of a series of paired humidity measurements comparing the supply system with the calibration hygrometer. The comparison period lasts from 20 min to 2 h with measurements taken at 1 to 6 min intervals, for a total

of 20 paired measurements. The measurement interval shall be appropriate for the time constant of the humidity measurement instruments.

11.2.7.2 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 (29.92 in. Hg), using the appropriate equations (see 6.2.3.2). Compute the difference between each pair of readings and calculate the mean and standard deviation of the twenty paired readings, using equations in Annex A3. The absolute value of the mean difference shall not exceed 1.43 g/kg (10 grains/lb), and the standard deviation shall not be greater than 0.714 g/kg (5 grains/lb). If these conditions are not met, investigate the cause, make repairs, and recalibrate. Maintain calibration records for two years.

12. Procedure

12.1 Pretest Procedure:

12.1.1 *Engine Cooling System Charge*—Add equal volumes of a commercial ethylene glycol-based low-silicate antifreeze and distilled or demineralized water. The cooling system capacity shall be 21 ± 4 L.

12.1.2 *Test Oil Charge*—The test oil charge procedure is as follows:

12.1.2.1 Charge the system with 4.1 ± 0.025 kg (9.0 ± 0.6 lb) of the specified test oil.

12.1.2.2 Prime the oil system by removing the distributor shaft cap and using a drill to turn the engine oil pump.

12.1.2.3 At the 0.6 h compression pressure and percent leakdown inspection (see 12.3.4), drain the oil for 20 min through the oil pan drain plug hole.

12.1.2.4 Add test oil to the oil drain so that the final amount equals 4.1 ± 0.025 kg (9.0 ± 0.06 lb).

12.1.2.5 Charge the system with the 4.1 ± 0.025 kg (9.0 ± 0.06 lb) of oil derived in 12.1.2.4.

12.1.2.6 If the optional oil level check during the test is going to be performed, after 20 min, set the dipstick level to the full mark using an adjustable calibrated dipstick.

12.1.3 *Fuel System Preparation*—Change all system fuel filters before each test. The fuel system run tank/container(s) shall be sufficiently flushed. Purge an appropriate amount of test fuel through the entire fuel system to ensure that the previous test fuel is out of the system and the correct test fuel is in the system. Take a 900 mL fuel sample at the engine stand after the fuel system has been purged and prior to the start of test.

12.1.4 *PCV Valve Installation*—Refer to 10.3.3 for proper PCV valve preparation. Install the PCV valve so that there are no leaks between the hoses and the valve. The PCV valve shall have the same orientation as configured in the engine assembly kit (vertical orientation).

12.1.5 *Keep Alive Memory (KAM) Reset*—Turn off the power to the Keep Alive Memory for a minimum of 5 min before start of test.

12.1.6 *Engine Break-in Procedure*—Use the engine break-in procedure to break in a new engine *short block* (an engine block less the cylinder head, valves, camshaft, and engine

accessories). With the exception of a slave cylinder head and the non-modified Ford Ranger Manual Transmission calibration EEC-IV processor (Part No. F47F-12A650-BGB), utilize all test engine hardware and associated engine stand hardware during the break-in period.

12.1.6.1 The break-in period consists of six, 4-h cycles. Thirteen steps comprise one cycle. The ramp times between each step are 2 min and are not part of step times. The total break-in period is 26 h, 36 min (6 cycles = 24 h; total ramp time = 2 h, 36 min).

12.1.6.2 The operational parameters specified for the break-in period are detailed in Table 3. During the first few steps of the break-in, the coolant out temperature and the oil in temperature may be below specification due to low engine speeds and loads. This is acceptable as long as the coolant and oil heat exchangers are not functioning (that is, no cooling is occurring). *The coolant and the oil shall not be heated to try to meet the specification.*

12.1.6.3 Charge the engine coolant system as described in 12.1.1. Charge the engine oil system with 4.1 ± 0.025 kg (9.0 ± 0.06 lb). Prime the oil system by removing the distributor shaft cap and using a drill to turn the engine oil pump.

12.1.7 After the break-in period is complete, an oil consumption verification test shall be performed.

12.1.7.1 Drain the engine oil from the break-in period for 20 min. Weigh the oil.

12.1.7.2 Add test oil to the oil drain so that the final amount equals 4.1 ± 0.025 kg (9.0 ± 0.06 lb).

12.1.7.3 Charge the system with the 4.1 ± 0.025 kg (9.0 ± 0.06 lb) of oil derived in 12.1.7.2.

12.1.7.4 Operate the engine at test conditions as stated in Table 1 for a period of 24 h.

TABLE 3 IVD Dynamometer Test Break-in Cycle^A

| Step No. | Time Per Step (min) | Total Time (h) | Speed (r/min) | Manifold Absolute Pressure (kPa) |
|----------|---------------------|----------------|---------------|----------------------------------|
| 1 | 15 | 0.25 | 1000 | 35.2 |
| 2 | 15 | 0.50 | 1200 | 36.6 |
| 3 | 15 | 0.75 | 1400 | 38.6 |
| 4 | 15 | 1.00 | 1600 | 40.6 |
| 5 | 15 | 1.25 | 1800 | 43.9 |
| 6 | 30 | 1.75 | 2000 | 47.2 |
| 7 | 15 | 2.00 | 2200 | 50.5 |
| 8 | 15 | 2.25 | 2400 | 53.8 |
| 9 | 15 | 2.50 | 2600 | 57.2 |
| 10 | 15 | 2.75 | 2800 | 60.5 |
| 11 | 45 | 3.50 | 3000 | 67.1 |
| 12 | 15 | 3.75 | 3200 | 70.5 |
| 13 | 15 | 4.00 | 3400 | 73.8 |

^A Oil inlet temperature— $101 \pm 3^\circ\text{C}$
Oil Outlet Temperature—record ($^\circ\text{C}$)
Oil Inlet Pressure—record (kPa)
Coolant out temperature— $90 \pm 3^\circ\text{C}$
Coolant in temperature—record ($^\circ\text{C}$)
Intake air inlet temperature— $32 \pm 3^\circ\text{C}$
Intake air inlet humidity— 11.4 ± 0.7 g/kg
Manifold absolute pressure—as specified (kPa)
Exhaust back pressure— 105 ± 1 kPa abs at 2800 r/min, 71.8 kPa MAP
Fuel flow - total—record (total kg)
Fuel inlet temperature— 32°C , max
Coolant in/out delta pressure— <41 kPa
EGR—record (voltage)
Intake air pressure 0.05 ± 0.01 kPa gage

12.1.7.5 Drain the oil for a period of 20 min and record the weight.

12.1.7.6 Calculate the oil consumption by subtracting the weight of the oil derived in 12.1.7.5 from the oil charge as stated in 12.1.7.3.

12.1.7.7 Unusually high oil consumption is occurring if the oil consumption is greater than 0.4 kg.

12.2 Engine Operating Procedure:

12.2.1 *Engine Operating Parameters and Specifications*—The engine operating parameters and specifications are detailed in Table 1. Monitor the parameters and their specified limits as detailed in 12.3.

12.2.2 *Test Time*—The test time is defined as the time at which the engine is being controlled remotely (when the engine stand controlling system and test timer are functioning). Any time during which the engine is not being controlled remotely (such as an initial engine start-up) does not count toward test time. The maximum amount of time in which an engine can be operating in a non-remote situation is 1 h per test. When an engine is operating in a non-remote situation, operate it either in an idle condition or test condition.

12.2.2.1 At instances just after the engine has been switched over to remote operation and the engine parameters have not reached specification, the time accumulated counts toward test time. During this time, allow the parameters to reach specification limits as quickly as possible. The two exceptions are engine speed and engine manifold absolute pressure where ramp times shall be 30 s; both shall be ramped together and linearly.

12.2.3 *Test Duration*—The test duration is 100 h (approximately 462 cycles).

12.2.4 *Engine Shutdown Duration*—The maximum amount of time an engine can be shut down for unscheduled shutdowns during a test is 10 h (cumulative).

12.2.5 *Maximum Number of Engine Shutdowns*—The maximum number of engine shutdown occurrences during a test is four including all scheduled and unscheduled shutdowns. At most, one of these shutdown occurrences may involve multiple stops and restarts of the engine, within a 1-h period after initially restarting the engine for the purpose of troubleshooting a persistent engine/control system problem.

12.2.6 *Scheduled and Unscheduled Shutdowns*—Unless there is an emergency to shut down the engine, all engine shutdowns shall be done at the beginning of Stage 1. One scheduled shutdown occurs at the 0.6 h compression pressure and percent leakdown check.

12.2.7 *Engine Starts and Restarts*—Engine starts and restarts occur at the beginning of the test, after the 0.6 h compression pressure and percent leakdown check, and after any unscheduled shutdowns. After the engine has been started, it shall be checked for proper operation (correct oil pressure, fuel pressure, and so forth). As stated in 12.2.2, the maximum amount of time in which an engine can be operating in a non-remote situation is 1 h per test. When an engine is operating in a non-remote situation, it shall operate either in an idle condition or test condition. After the engine has been checked for proper operation, it shall be put on test (remote operation) as quickly as possible. The engine shall be put on

remote operation at the same point in test time, as when it was shut down. In most cases, this should be at the beginning of Stage 1.

12.2.8 *Out-Of-Specification Time*—If the exhaust gas analysis (O_2 , CO, or CO_2), the equivalence ratio or the ignition timing is out of specification when a reading is taken (Table 1 and 12.3.3), the time accumulated between that current out of specification reading and when the parameter is back within specification counts toward the out-of-specification time accumulated for the test. The maximum cumulative total out-of-specification time limit for these parameters is 3 h. Any shutdown associated with bringing the parameter back within specification is also counted toward the cumulative number of engine shutdowns limit and the cumulative engine shutdown time limit.

12.3 Periodic Measurements and Functions:

12.3.1 *Oil Level Check Procedure*—Performing an oil level check during the test is optional. If an oil level check is performed, the procedure for performing an oil level check is as follows:

12.3.1.1 Shut down the engine at the beginning of Stage 1.

12.3.1.2 Wait 20 min after engine has been shut down.

12.3.1.3 Perform an oil level dipstick measurement using the calibrated oil dipstick.

12.3.1.4 If the oil level is low by more than 473 mL (16 fl. oz), add 0.41 ± 0.01 kg (0.9 ± 0.02 lb) to the engine and continue the test.

12.3.1.5 If the oil level is low by less than 473 mL, continue the test.

12.3.1.6 Record the oil level and any oil addition quantities.

12.3.2 Unusually high oil consumption is occurring if the oil level reduction exceeds 950 mL per 50 h period. If oil is added, record the weight of the oil added.

12.3.3 *Data Collection Procedure*—Utilize 1-min automated data collection to collect data at 1-min intervals at least three times during each Stage 1 and at least seven times during each Stage 2 for all parameters shown in Table 1 except for the parameters as noted below:

| Parameter | Data Collection Interval |
|--|--|
| Exhaust Emissions or Equivalence Ratio | At least once every 24 h |
| Ignition Timing | At least once every 24 h |
| EGR Voltage | At least once every 24 h |
| Blowby | Once within the first 5 h of test time and once within the last 5 h of test time |
| Fuel Flow | Continuous |

12.3.3.1 Take transition traces of engine speed and manifold absolute pressure (MAP) at least once within the first 15 h of test time and at least once within the last 15 h of test time. The frequency of data collection shall be at least 0.5 Hz.

12.3.4 *Compression Pressure and Percent Leakdown Check*—Perform a compression pressure and percent leakdown check at 0.6 ± 0.2 h into the test. The compression pressure and percent leakdown procedure is as follows:

12.3.4.1 *Compression Pressure Check:*

- (1) Disable the fuel.
- (2) Disconnect the ignition power.
- (3) Remove one spark plug from each cylinder.
- (4) Set the throttle plate to wide open throttle (WOT).

(5) Install compression pressure gage spark plug fitting into spark plug hole.

(6) Crank the engine until compression pressure reading on gage stabilizes. *Do not exceed eight compression strokes.*

(7) Record the reading on the compression pressure and percent leakdown log.

(8) The compression pressure shall be a minimum of 1034 kPa (150 psi) in all cylinders, and the compression pressure in any one cylinder shall not be less than 80 % of the pressure of the cylinder with the highest compression pressure reading.

(9) Repeat for remainder of cylinders.

12.3.4.2 Percent Leakdown Check:

(1) Disable the fuel.

(2) Disconnect the ignition power.

(3) Remove one spark plug from each cylinder.

(4) Rotate crankshaft so that intake and exhaust valves are closed on the cylinder to be leak checked.

(5) Install percent leakdown tester spark plug fitting into spark plug hole.

(6) Charge cylinder with air at 100 psi.

(7) Record percent leakdown on a compression pressure and percent leakdown log.

(8) The percent leakdown shall be less than 15 % in any of the cylinders.

12.3.5 *Blowby Measurement*—When measuring engine blowby, maintain crankcase pressure at 0.0 ± 25 Pa (0.0 ± 0.1 in. H₂O).

12.4 End of Test Procedures:

12.4.1 *Engine Cylinder Head Removal*—Completely drain the coolant system. Drain the oil per 12.4.2. Remove the necessary engine accessories to expose the cylinder head. Remove the cylinder head bolts. Carefully remove the cylinder head from the engine block. Remove the cylinder head gasket. Avoid allowing any coolant or oil, or both, to drip onto piston tops or cylinder head combustion chamber. Wipe away any coolant or oil, or both, that is on the engine block and cylinder head mating surfaces. Cover the engine and cylinder head to protect from contamination.

12.4.1.1 Weigh (see 13.1), photograph (see 13.2), and, if requested, rate (see 13.3) the intake valves within 48 h of test completion. Place the valves in a desiccator while they are not being weighed, photographed, or rated.

12.4.2 *Final Oil Drain*—After test completion, drain the oil from the oil pan for 20 min. Weigh the oil and record the weight.

12.4.3 *Final Oil Consumption*—Oil consumption is derived by calculating the difference between the initial oil charge (4.1 kg) plus any oil additions and the final oil drain (final oil consumption = 4.1 kg + oil additions – final oil drain).

12.4.4 *Final Fuel Consumption*—Final fuel consumption is the total fuel used while the engine was in both manual and remote operation.

12.4.5 *Engine Inspection*—On test completion and after the cylinder head has been removed, visually inspect the cylinder bores for unusual wear. Inspect engine hardware and note necessary hardware replacements.

13. Determination of Test Results

13.1 *Post-Test Intake Valve Weighing Procedure*—Prepare the intake valves for weighing using the following procedure. Remove carbon deposits from the combustion chamber side of the valve (valve face) and the valve margin using a bench grinder fitted with a fine steel brush as stated in 6.4.5. Perform the buffing process by rotating the valve and applying just sufficient pressure against the wire wheel to remove the deposits. Avoid removing deposits from any area not specified above.

13.1.1 *Valve Rinse*—Wash the valves gently with cyclohexane or *n*-hexane. Discharge the solvent from a hand squeeze bottle onto the valve. Gently rinse the valve starting at the top of the stem and proceeding towards the tulip section. While discharging the solvent, rotate the valve (which is held in gloved hand) to ensure removal of all oily residues. Continue the washing process until the solvent running off the valve is clear, but perform this procedure only once. Gently shake off any remaining solvent. (**Warning**—In addition to other precautions, provide adequate ventilation and fire protection in areas where flammable or volatile, or both, liquids and solvents are used. Suitable protective clothing is recommended.)

13.1.2 *Removing the Rinse*—Immediately after the wash is complete, place the intake valves inside an oven (see 6.4.4) for 5 min to remove any remaining solvent through vaporization. The oven temperature shall be $93 \pm 5^\circ\text{C}$ ($200 \pm 9^\circ\text{F}$).

13.1.3 *Warm Valve Handling Technique*—Use tongs to transfer the valves from the oven directly into a desiccator.

13.1.4 *Desiccator*—The valves shall remain in the desiccator (see 6.4.3) for a minimum of 1 h and not more than 48 h while they cool to room temperature. Conduct a periodic check of the desiccant to ensure its proper functioning. Monitoring of color change is usually the method employed.

13.1.5 *Weighing the Valves*—After the valves have been dried and cooled in the desiccator, they are ready to be weighed. When the valves are transferred from the desiccator to the scale, wear clean gloves to eliminate contamination and the addition of weight to the valve due to oil or debris from skin contact. Hold valves by the stems. Weigh the valves to the nearest 0.0001 g using a calibrated balance (see 6.4.2) and record the weights.

13.1.5.1 Confirm the repeatability of the balance between the start and the end of this procedure by weighing and recording the weight of a reference valve before and after weighing the four valves. The *start* and *end* valve weights shall not differ by more than 0.0010 g. If the absolute difference is greater than 0.0010 g, then repeat 13.1.5.

13.1.6 *Calculating Deposit Weight*—Calculate the deposit weight by subtracting the start-of-test clean valve weight (obtained in 10.4.5) from the end-of-test weight (obtained in 13.1.5) for each valve.

13.1.6.1 For deposit weights less than 0.0005 g (including negative values), clean valves as described in 10.4.4 and reweigh as described in 10.4.5. Substitute this end-of-test clean valve weight for start-of-test clean valve weight to calculate the deposit weight on these valves. Take photographs (see 13.2) before the valves are cleaned. Clean valves using a walnut shell blaster. Avoid using a wire brush. Rinse residue from the

cleaning as described in 13.1.1. Place valves in oven as described in 13.1.2, and follow 13.1.3 – 13.1.5.

13.1.6.2 If using the end-of-test clean valve weight to calculate deposit weight (13.1.6.1), and the deposit weight is still found to be less than -0.0010 g, the valve weight will be invalid. Valves that have a deposit weight between -0.0010 g and 0.0000 g shall be noted and 0.0000 g shall be used to calculate average deposit weight. *No negative valve weights may be used to calculate average deposit weight.*

13.1.6.3 Outlier rejection criteria may not be used to omit deposit weights. Four valid intake valve deposit weights are necessary for a valid test.

13.2 *Photographs of Parts—General*—In order to better document the test results, take photographs of engine test parts. Photographs shall be of sufficient clarity to accurately assess the deposit area. Reproduce the photographs in color using standard print sizes. Take appropriate precautions so that the photography does not disrupt the deposits.

13.2.1 *Intake Valves*—Take photographs of valves after obtaining deposit weights. Take a photograph of all four valves grouped sequentially, and take individual photographs of each valve from directly above the valve stem. Mark the valves according to their position in the engine.

13.2.2 *Intake Ports*—Take photographs of all four ports, viewed from the combustion chamber side. Take individual photographs of each port from directly in front of that particular cylinder. Individual port photographs may be combined with the corresponding runner photograph.

13.2.3 *Intake Runners*—Take photographs of the four runners, viewed from the intake manifold side of the cylinder head. Take individual photographs of each runner from directly in front of that particular runner.

13.3 *Induction System Rating*—If requested, rate the intake valves, the manifold intake runners, and cylinder head intake ports visually using the CRC Manual 16. Clarification of the induction system rating procedure is as follows:

13.3.1 *Cylinder Head Intake Ports*—Area defined by a cylindrical projection of the intake seat concentric with the valve guide and extending from valve seat to floor and including walls.

13.3.2 *Cylinder Head Runner Entrances*—Area extending 25 mm into cylinder head runners from manifold to cylinder head interface.

13.3.3 *Valve Tulips*—Area from bottom end of travel to top of wear pattern on valve face. Rate valve tulips after valve faces are buffed.

13.4 *Determination of Test Validity—Engine Conformance*—During each test, strictly adhere to the specified operating conditions of the engine and monitor the conditions with data acquisition equipment capable of recording the following data as indicated in 12.3.3.

13.4.1 *Engine Speed During Stages*

13.4.1.1 *Test Validation Criteria*—For Stage 1, the engine speed averaged over the entire test shall be 2000 ± 25 r/min. For Stage 2, the engine speed averaged over the entire test shall be 2800 ± 10 r/min. If engine operation does not conform to this requirement, the test is invalid.

13.4.2 *Manifold Absolute Pressure During Stages:*

13.4.2.1 *Test Validation Criteria*—For Stage 1, the engine manifold absolute pressure averaged over the entire test shall be 30.6 ± 1.3 kPa (230 ± 10 mm Hg). For Stage 2, the engine manifold absolute pressure averaged over the entire test shall be 71.8 ± 1.3 (540 ± 10 mm Hg). If engine operation does not conform to this requirement, the test is invalid.

13.4.3 *Engine Speed During Transitions:*

13.4.3.1 *Test Validation Criteria*—Engine speed shall be 2400 ± 75 r/min after 15 s into the transition between stabilized stages. If engine operation does not conform to this requirement, the test is invalid.

13.4.4 *Manifold Absolute Pressure During Transition:*

13.4.4.1 *Test Validation Criteria*—Manifold absolute pressure shall be 51.2 ± 6.6 kPa (385 ± 50 mm Hg) after 15 s into the transition between stabilized stages. If engine operation does not conform to this requirement, the test is invalid.

13.4.5 *Total Engine Oil Consumption*—Calculate the engine oil consumed per oil drain interval from the oil fill and drain weights as stated in 12.4.3.

13.4.5.1 *Test Validation Criteria*—If the final total oil consumption for the entire test is greater than 1.0 kg, the test is invalid.

13.4.6 *Total Engine Test Duration:*

13.4.6.1 *Test Validation Criteria*—Operate the engine for 100 h (approximately 462 cycles) using the same batch of test fuel.

13.4.7 *Downtime*—After the 0.6 h compression pressure and percent leakdown check, a maximum of 48 h may elapse before restarting test, at which point the official accrual of engine downtime begins. Once downtime accrual has begun and the engine begins operating according to this test method, complete the test with minimal downtime. Refer to 12.2 for specific downtime requirements.

13.4.7.1 *Test Validation Criteria*—Total engine-off time (or downtime) cannot exceed 10 h during any test. If engine operation does not conform to this requirement, the test is invalid. Four engine shutdowns are the maximum number allowed. If engine operation does not conform to this requirement, the test is invalid.

13.4.8 *Out-of-Specification Time*—Refer to 12.2.8 for specific out-of-specification time limits.

13.4.9 *Engine Disassembly*—Engine disassembly other than specified in the procedure shall not be permitted for a valid test. The engine shall not be disassembled for inspection during this test method.

14. Report

14.1 *Standard Report*—The standard test report shall include the sections listed below. Begin each section on a new page, and insert the sections in the order listed below. Deviations in the format are not permitted. However, additional details and data may be attached as an appendix.

14.1.1 Title page including the name of the testing laboratory, test description, run number, start of test date, end of test date, test oil, test fuel including identification of the test fuel/deposit control additive by (the name of the submitting organization and) its name or code, or both, provided by the

submitting organization, a validity statement which states that the test was conducted in a valid manner, and a signature block referring to the test overseer.

14.1.2 Unscheduled shutdown summary including the test hour the engine was shut down, the amount of time the engine was shut down, and the reason the engine was shut down.

14.1.3 Intake valve deposit weight summary including new valve weights, end-of-test valve weights that have been prepared as stated in 13.1.5, and the difference between the end-of-test valve weights and the new valve weights.

14.1.4 Induction system merit rating summary including the valve tulip, intake port, and cylinder head runner entrance ratings.

14.1.5 Pretest and post test measurement summary including the pretest fuel injector flow analysis, the pretest intake and exhaust valve stem-to-guide clearance measurement summary, the pretest valve seat width measurement summary, the pretest PCV valve flow rate summary, the engine compression pressure and percent leakdown check which is performed 0.6 h into the test, the post test oil consumption data, and the final engine test fuel consumption data.

14.2 *Data Acquisition Summary Report*—The test validation criteria report, derived from the data acquisition equipment, shall include the sections listed below:

14.2.1 Manual data acquisition summary. Report maximum, minimum, and average data of Stage 1 and Stage 2. Omit data gathered for the first 20 min after any start-up due to engine warm-up effects.

14.2.2 Automated data acquisition operational summary as detailed in 12.3.3. Report maximum, minimum, average, and standard deviation of Stage 1 and Stage 2. Omit data gathered for the first 20 min after any start-up due to engine warm-up effects.

14.2.3 Stage transition data summary of engine speed and manifold absolute pressure as detailed in 12.3.3.1.

14.3 *Photographs of Specific Parts*—Include photographs of engine parts in the following order: (Take photographs as specified in 13.2.)

14.3.1 Intake Valves-Group,

14.3.2 Intake Valve-Cylinder 1 and 2,

14.3.3 Intake Valve-Cylinder 3 and 4,

14.3.4 Intake Port and Runner-Cylinder 1 and 2, and

14.3.5 Intake Port and Runner-Cylinder 3 and 4.

15. Precision and Bias

15.1 *Precision*—In 1995, an interlaboratory study (ILS) using Draft 3.1 of this test method was conducted. Sixty tests were conducted by ten laboratories on four fuels. A data analysis panel was appointed by the Coordinating Research Council to analyze the intake valve deposit weight data from the ILS. The CRC Data Analysis Panel developed ASTM repeatability and reproducibility values using the ILS database.¹⁹ The original test matrix consisted of eleven laboratories performing tests on the four fuels with a repeat test on each of two of the fuels for a total of six tests per laboratory. One laboratory did not participate and data from two laboratories were eliminated because of test fuel contamination. Hence, the data from these three laboratories were not included in the ILS database. With the elimination of these 18 tests, the minimum data required for the calculation of precision as stated in ASTM D02-1007 were not met. The repeatability and reproducibility statements may be negatively impacted by the reduced sample size and should, therefore, be used with caution. The TMC will be obtaining data on reference fuels for test stand certification. These data in the future will be available for reassessing the precision calculations.

15.1.1 *Repeatability*—The difference between successive results obtained by the same operator with the same apparatus under constant operating conditions on identical test material would in the normal and correct operation of the test method exceed 287 mg only in one case in twenty.

15.1.2 *Reproducibility*—The difference between two single and independent results obtained by different operators working in different laboratories on identical test material would exceed 317 mg only in one case in twenty.

15.2 *Bias*—No estimate of bias is possible as the behavior of a fuel is determined only under the specific conditions of the test and no absolute standards exist.

16. Keywords

16.1 automotive spark-ignition engine fuel; deposit control additive; deposits (in internal combustion engines); intake valve deposits

¹⁹ CRC Report No. 606, CRC Intake Valve Deposit Study. Available from the Coordinating Research Council, 3650 Mansell Rd., Ste. 140, Alpharetta, GA 30022-8246.

ANNEXES

(Mandatory Information)

A1. DETAILED SPECIFICATIONS AND PHOTOGRAPHS OF APPARATUS

A1.1 See [Figs. A1.1-A1.11](#) for detailed specifications and photographs of apparatus.

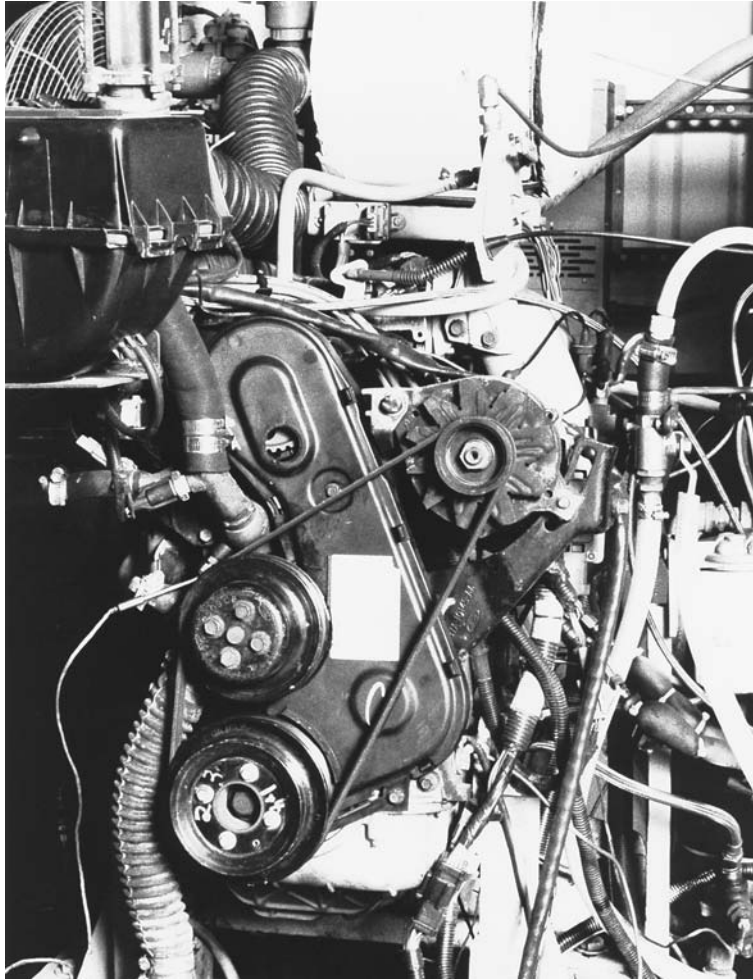


FIG. A1.1 Typical Test Stand, Forward View

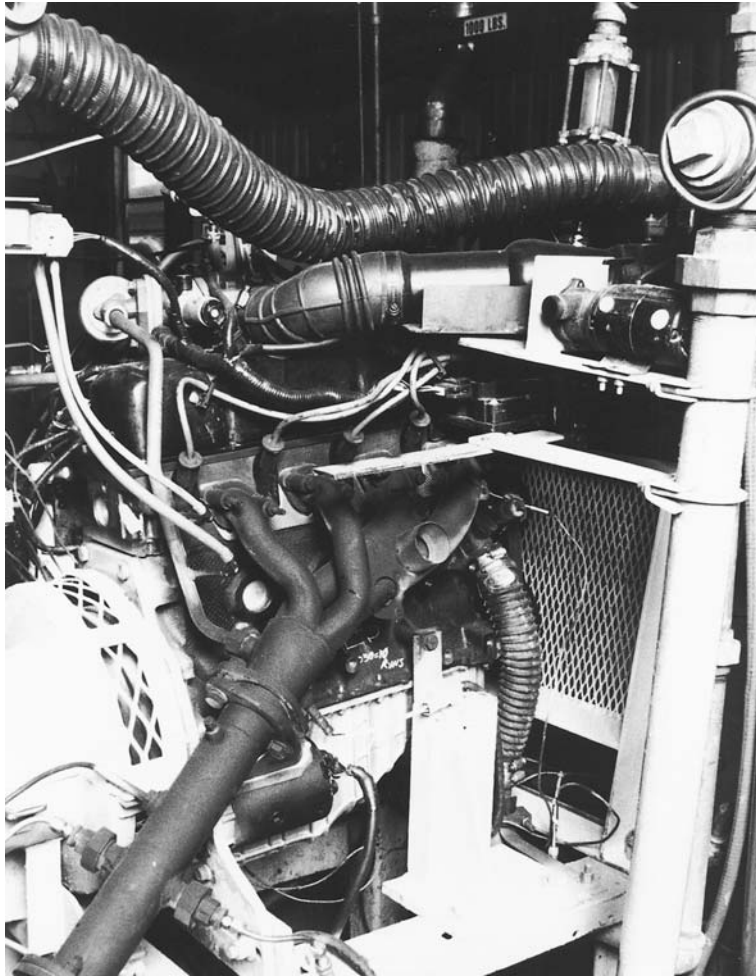


FIG. A1.2 Typical Test Stand, Right Rear View

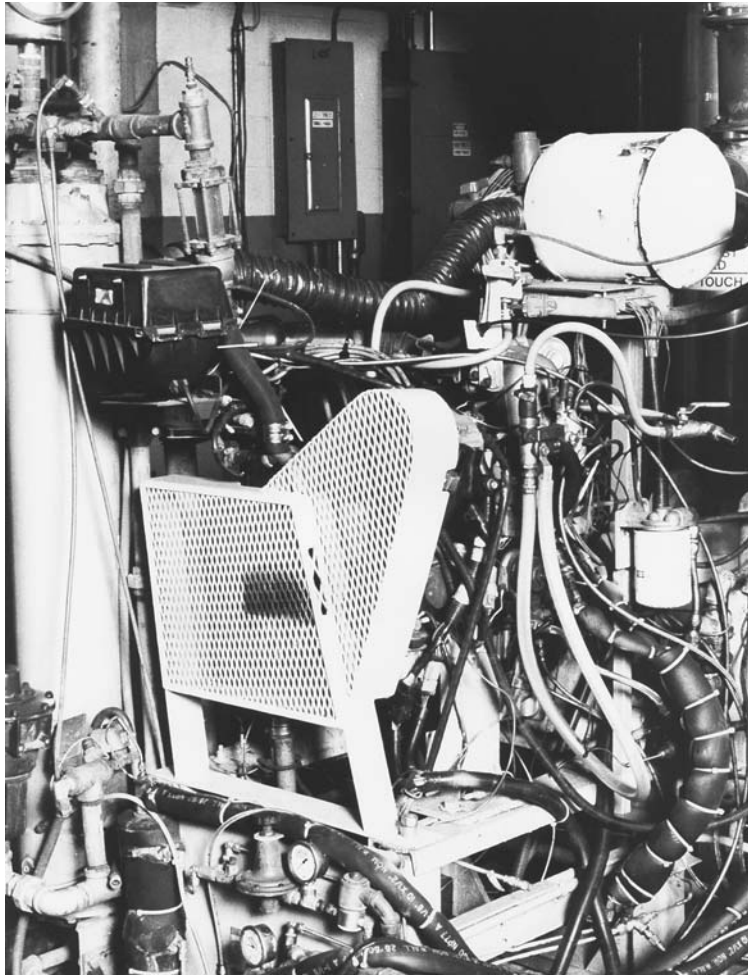


FIG. A1.3 Typical Test Stand, Left Forward View

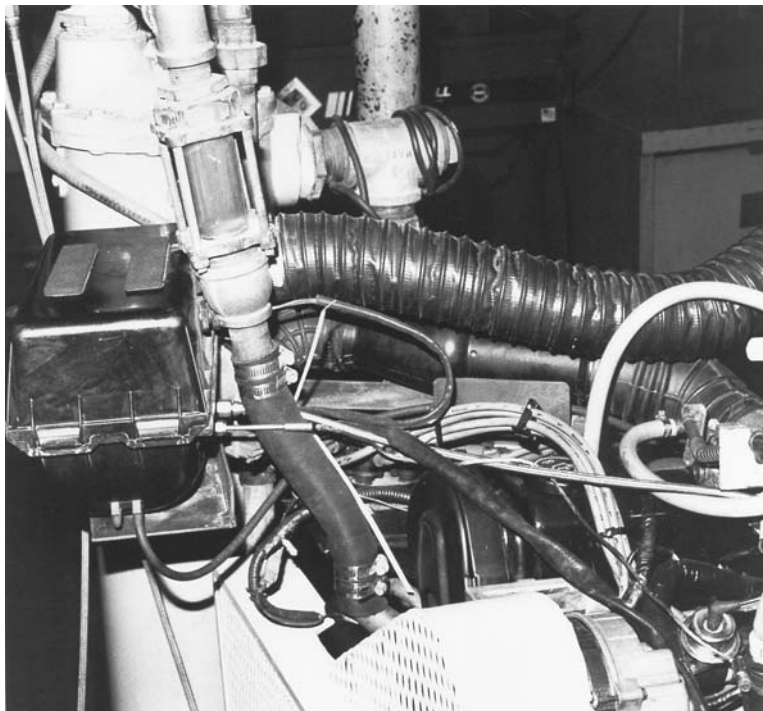


FIG. A1.4 Intake Air Supply System

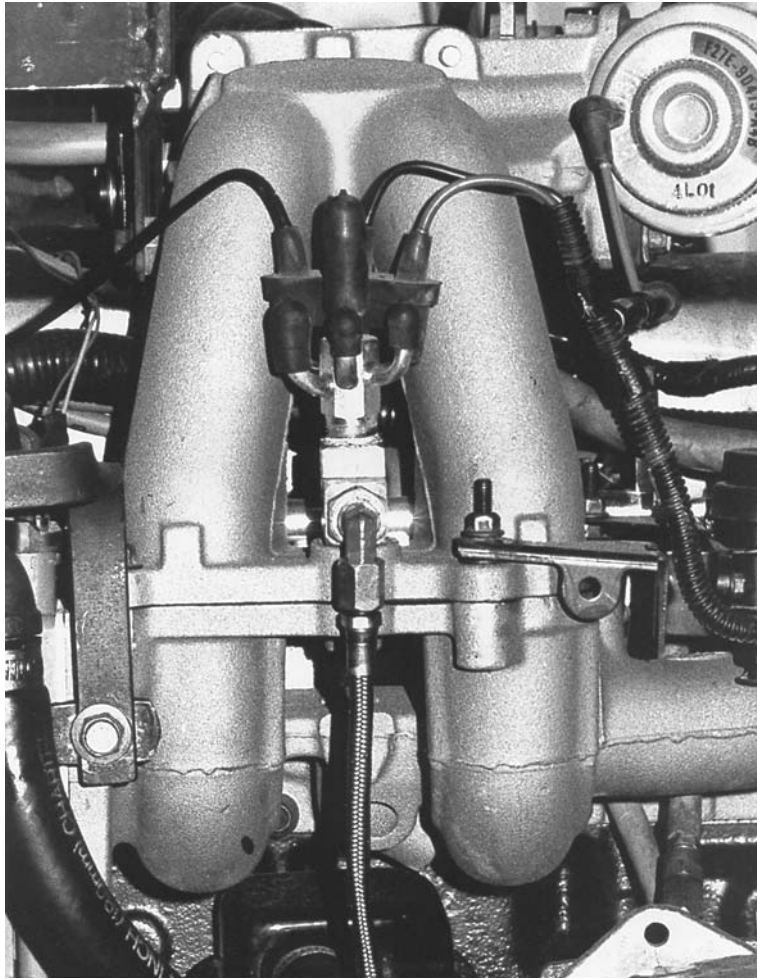


FIG. A1.5 Manifold Absolute Pressure Measurement Location

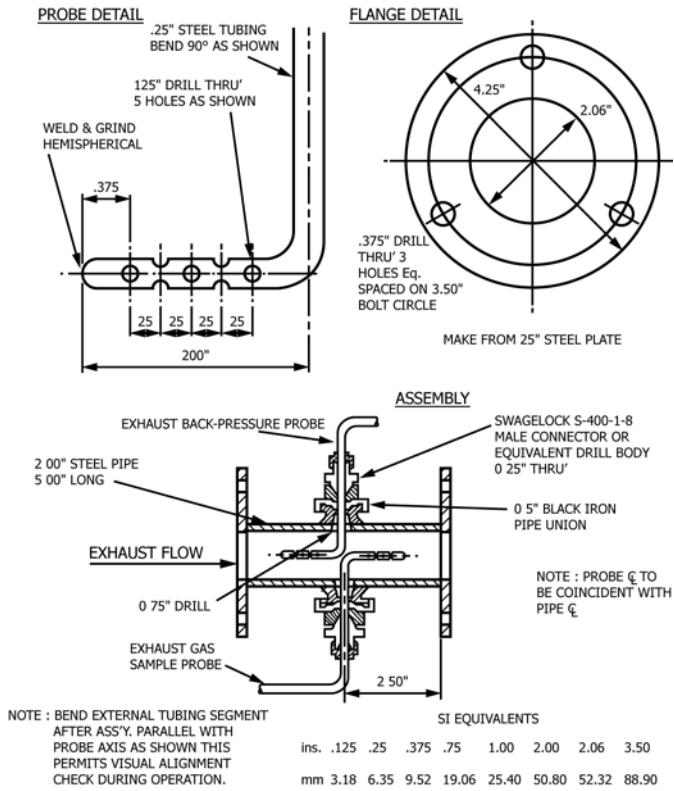


FIG. A1.6 Exhaust Emissions Probe and Exhaust Back Pressure Probe Configuration and Orientation

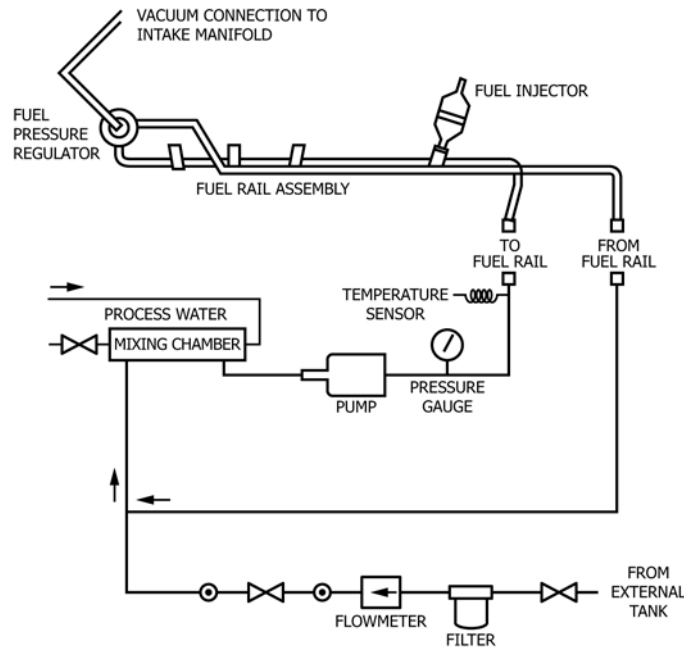


FIG. A1.7 Typical Engine Fuel System

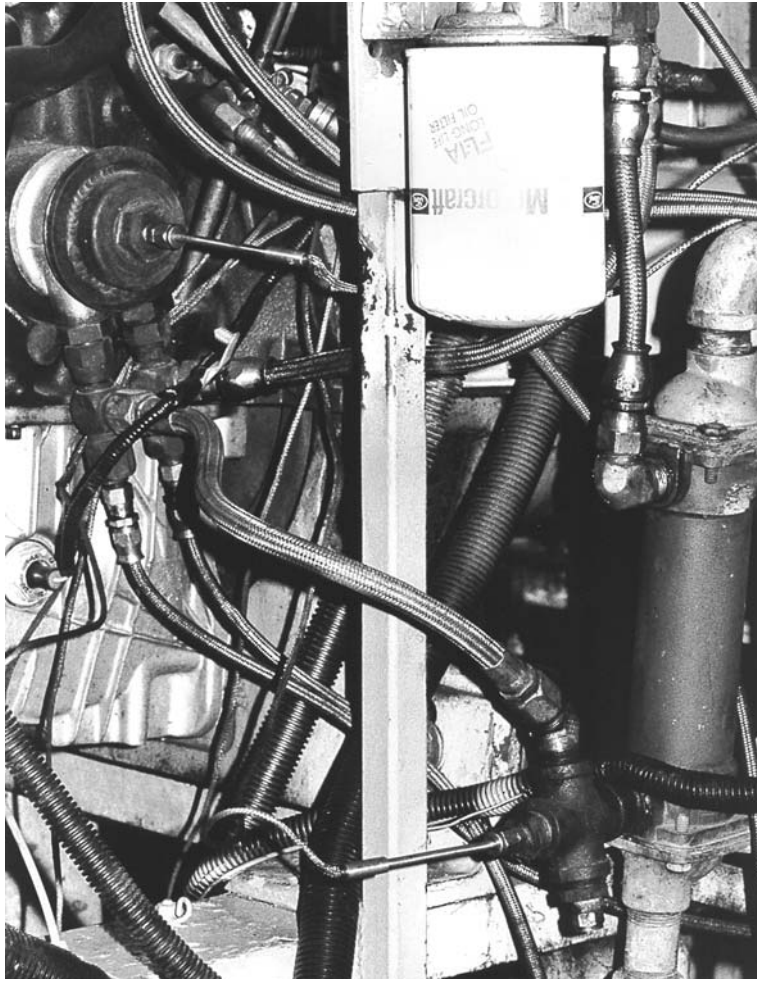


FIG. A1.8 Typical Oil Cooling System

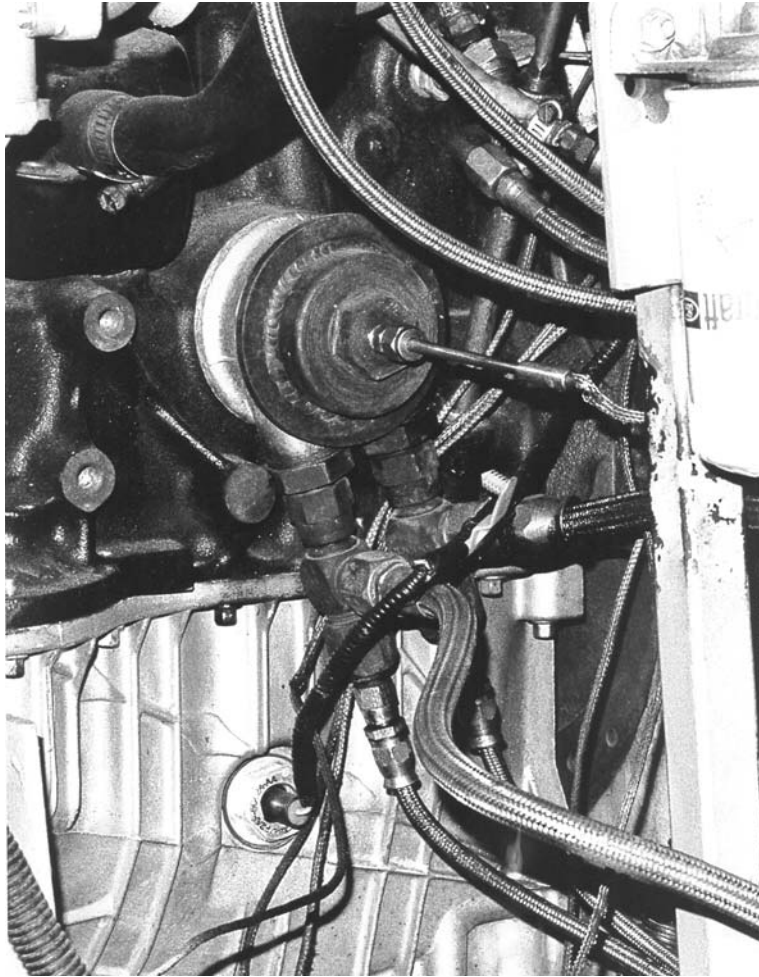


FIG. A1.9 Typical Oil Cooling System Adapter Housing with Typical Fittings for Temperature Sensor, Pressure Taps, and Dipstick Tube

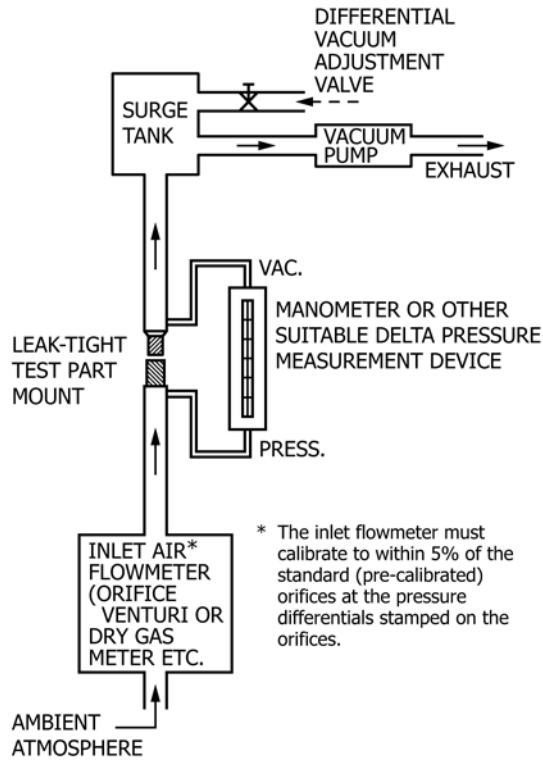
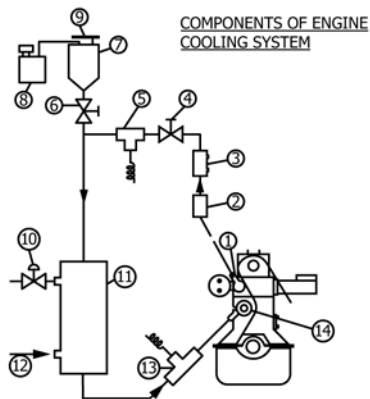


FIG. A1.10 PCV Valve Flow Test Apparatus

- ① THERMOSTAT HOUSING WITH TEMPERATURE SENSOR
- ② SIGHT GLASS.
- ③ VENTURI FLOWMETER MODEL BR12705-16-31 WITH PRESSURE TAPS.
- ④ FLOW CONTROL VALVE.
- ⑤ OPTIONAL TEMPERATURE CONTROL SENSOR.
- ⑥ FLUSHING ISOLATION VALVE.
- ⑦ FABRICATED COOLANT RESERVOIR.
- ⑧ CONSTANT FULL EXPANSION TANK.
- ⑨ PRESSURE RADIATOR CAP. (MOTORCRAFT RS40 P/N D2YY-8100-A)
- ⑩ PROCESS WATER CONTROL VALVE (REGULATED BY TEMPERATURE CONTROLLER)
- ⑪ HEAT EXCHANGER (ITT STANDARD P/N 5-030-06-048-001 TYPICAL)
- ⑫ PROCESS WATER SUPPLY
- ⑬ TEE WITH TEMPERATURE SENSOR FOR COOLANT INLET
- ⑭ ENGINE WATER PUMP.



FRONT VIEW OF ENGINE

NOTE 1 - OBSERVE TEMPERATURE SENSOR LOCATIONS, IN THERMOSTAT HOUSING AND AT WATER PUMP INLET.

FIG. A1.11 Typical Engine Cooling System

A2. ENGINE PART NUMBER LISTING

A2.1 See **Tables A2.1-A2.3** for part numbers and description.

TABLE A2.1 Test Stand Set-up Kit Parts Group Z-060-150

| Part Number | Quantity | Description |
|----------------|----------|--|
| F27E-9F805-AC | 1 | air cleaner tube assembly, out |
| F27E-9A673-AA | 1 | air cleaner tube assembly, in |
| F37E-9600-DD | 1 | air cleaner assembly |
| E9PF-10346-BA | 1 | alternator assembly |
| E97A-10145-AA | 1 | arm, alternator adjusting |
| E27E-8620-AB | 1 | belt, alternator drive (6Kx4475) |
| 390785-S36 | 1 | bolt, adjustment arm to alternator $\frac{9}{16}$ -16 × 1.25 |
| 389483-S36 | 1 | bolt, alternator to bracket $\frac{7}{16}$ -14 × 5.0 |
| N605545-S100 | 2 | bolt, alternator brace to engine M10-1.5 × 25 |
| N605799-S2 | 3 | bolt, adjustment arm to engine M10-1.5 × 20 |
| N606043-S2 | 3 | bolt, alternator bracket to engine M8-1.25 × 50 |
| E87A-10B315-CA | 1 | brace, alternator |
| E97A-10239-AB | 1 | bracket assembly, alternator |
| F5JL-12A200-BA | 1 | engine wire harness |
| E69A-8509-CB | 1 | pulley, water pump |
| F0TE-9J459-A1A | 1 | regulator, EGR vacuum (EVR) |
| F0SF-9F472-AA | 1 | sensor, heated exhaust gas oxygen (HEGO) |
| F37E-9J433-BA | 1 | sensor, pressure feedback EGR assembly (PFE) |
| F47E-9E494-BA | 1 | bracket |
| F1AE-9J460-AA | 1 | sensor |

TABLE A2.2 Critical Parts

| Part Number | Quantity | Description |
|------------------------------|----------|---|
| F47Z-6268-B | 1 | belt, camshaft drive |
| F27E-6049-A11B | 1 | cylinder head, finished casting |
| F47F-12A650-BGB [^] | 1 | EEC-IV processor (for break-in) |
| OHTIVD-001-1 | 1 | modified EEC-IV processor (for test) |
| F5JL-12A200-BA | 1 | engine wire harness |
| E6AE-9601-BC | 1 | filter, air |
| F03E-9F593-A2B | 1 | fuel injector (pintle DRI) |
| F47B-9D930-AA | 1 | fuel injector sub-harness |
| F37U-12029-AA | 1 | coil |
| F2ZE-12A166-DA | 1 | bracket, coil |
| N606502-S36 | 1 | bolt, coil bracket |
| E8TF-12A297-AA | 1 | ignition control assembly |
| F37E-12280-BD | 1 | ignition wire, RH |
| F37E-12281-CA | 1 | ignition wire, LH |
| F37E-6A517-CA | 1 | seal, exhaust valve (III) |
| F37E-6A517-AA | 1 | seal, intake valve (II) |
| F32F-12A697-AA | 1 | sensor, air charge temperature (ACT) |
| F27E-6C351-BA | 1 | sensor, crankshaft timing assembly |
| F2AF-9B989-AA | 1 | sensor, throttle position (TPS) |
| F2AF-12A648-AA | 1 | sensor, engine coolant temperature (ECT) |
| F37F-12B579-FA | 1 | sensor, mass air flow (MAF) |
| F47E-9E494-BA | 1 | bracket, press. feedback EGR assembly (PFE) |
| F1AE-9J460-AA | 1 | sensor, press. feedback EGR assembly (PFE) |
| F0SF-9F472-AA | 1 | sensor, heated exhaust gas oxygen (HEGO) |
| F37E-6507-A2A | 1 | valve, intake |
| F37E-6505-A2A | 1 | valve, exhaust |

[^] EEC-IV processor (Part No. F47F-12A650) can be sent to OH Technologies, Inc.¹¹ to be modified to correspond to the Modified EEC-IV Processor (Part No. OHTIVD-001-1).

TABLE A2.3 Engine Kit, Parts

| Group: Z-060-151 | | |
|-----------------------------|----------|----------------------------------|
| Part Number | Quantity | Description |
| EK-191-AA | 1 | Engine |
| F7JL-6006-AA or F3ZZ-6009-C | 1 | Short Block Assembly |
| Group: Z-060-151-A01 | | |
| F27E-6019-A11B | 1 | cylinder head, finished casting |
| F03E-9F593-A2B | 4 | fuel injector (pintle DRI) |
| F37E-6A517-AA | 16 | seal, intake valve (II) |
| F37E-6507-A2A | 16 | valve, intake std. |
| N600414-S100 ^A | 1 | bolt, cam sprocket M12-1.75×45 |
| F3ZZ-6065-F | 40 | bolt, head to block |
| E77E-6251-AA | 1 | camshaft, finished |
| E2AE-6714-B2A | 4 | filter, oil (Motorcraft) |
| E6AE-9601-BC | 4 | filter, air (Motorcraft) |
| F1TE-9D476-CA | 4 | gasket, EGR valve |
| E89E-9439-AC | 4 | gasket, lower manifold-head |
| E59E-9E936-AA | 4 | gasket, upper manifold-throttle |
| F47E-6051-A5A | 4 | gasket, head |
| F37E-9448-AB | 4 | gasket, exhaust manifold |
| E87E-8255-AA | 4 | gasket, water outlet connection |
| F47E-9H486-AA | 4 | gasket, upper and lower manifold |
| F57E-6584-AA | 4 | gasket, rocker arm cover |
| D42E-6B260-AA | 1 | guide, timing belt |
| F57E-12281-CA | 2 | ignition wire, LH |
| F57E-12280-BC | 2 | ignition wire, RH |
| D0AE-6518-B3 | 16 | key, valve spring retainer |
| F67E-6C501-AA | 8 | lash adjustors |
| E97E-6A666-A2A | 4 | PCV valve |
| F37E-6A222-A3A | 1 | plate, cam |
| E43E-6514-AC | 8 | retainers |
| F07E-6529-AA | 8 | rocker arms |
| N604465-S | 2 | S&W, cam plate, M6-1×16 |
| F37E-6A517-CA | 16 | seal, exhaust valve (III) |
| E6ZE-6700-A1A | 4 | seal, cam |
| F37E-12405-BA | 32 | spark plugs |
| F17E-6256-AA | 1 | sprocket, cam |
| F0EE-8575-AA | 1 | thermostat |
| F57E-8575-AB | 16 | valve, exhaust |
| E59E-6A511-A2A | 8 | valve spring and damper |
| D42E-6278-A | 1 | washer, cam sprocket |

^A Denotes part number change

A3. STATISTICAL EQUATIONS FOR MEAN AND STANDARD DEVIATION

A3.1 See [Eq A3.1](#) and [Eq A3.2](#) for mean and standard deviation.

$$\text{mean} = \frac{1}{n} \sum_{i=1}^n [Y_i(\text{standard}) - Z_i(\text{reading})] \quad (\text{A3.1})$$

$$\text{standard deviation} = \sqrt{\frac{\sum_{i=1}^n [(Y_i - Z_i) - \text{mean}]^2}{df}} \quad (\text{A3.2})$$

where:

n = total number of data pairs, and
 df = degrees of freedom = $n - 1$.

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