Designation: D8279 – 21

Standard Test Method for Determination of Timing-Chain Wear in a Turbocharged, Direct-Injection, Spark-Ignition, Four-Cylinder Engine[1]

This standard is issued under the fixed designation D8279; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

Portions of this test method are written for use by laboratories that make use of ASTM Test Monitoring Center (TMC)[2] services (see Annex A1 to Annex A4).

The TMC provides reference oils, and engineering and statistical services to laboratories that desire to produce test results that are statistically similar to those produced by laboratories previously calibrated by the TMC.

In general, the Test Purchaser decides if a calibrated test stand is to be used. Organizations such as the American Chemistry Council require that a laboratory utilize the TMC services as part of their test registration process. In addition, the American Petroleum Institute and the Gear Lubricant Review Committee of the Lubricant Review Institute (SAE International) require that a laboratory use the TMC services in seeking qualification of oils against their specifications.

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

Laboratories that choose not to use the TMC services may simply disregard these portions.

ASTM International policy is to encourage the development of test procedures based on generic equipment. It is recognized that there are occasions where critical/sole-source equipment has been approved by the technical committee (surveillance panel/task force) and is required by the test procedure. The technical committee that oversees the test procedure is encouraged to clearly identify if the part is considered critical in the test procedure. If a part is deemed to be critical, ASTM encourages alternative suppliers to be given the opportunity for consideration of supplying the critical part/component providing they meet the approval process set forth by the technical committee.

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

1. Scope*

1.1 Undesirable timing-chain wear has been observed with gasoline, turbocharged, direct-injection (GTDI) engines in field service, and data from correlating laboratory engine tests have shown that chain wear can be affected by appropriately formulated engine lubricating. A laboratory engine test has been developed to provide a means for screening lubricating oils for that specific purpose. The laboratory engine test is 216 h in length, conducted under varying conditions, and the increase in timing-chain length determined at the end of test is

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

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[2] Until the next revision of this test method, the ASTM Test Monitoring Center will update changes in the test method by means of information letters. Information letters may be obtained from the ASTM Test Monitoring Center, 6555 Penn Ave., Pittsburgh, PA 15206-4489. Attention: Administrator. This edition incorporates revisions in all Information Letters through No. 20-4.

*A Summary of Changes section appears at the end of this standard the primary result. This test method is commonly known as the Sequence X, Chain Wear (CW) Test.

1.2 The values stated in SI units are to be regarded as standard. The values given in parentheses after SI units are provided for information only and are not considered standard.

1.2.1 *Exception*—Where there is no direct SI equivalent such as screw threads, national pipe threads/diameters, tubing size, or specified single source equipment.

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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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

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

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

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

D4485 Specification for Performance of Active API Service Category Engine Oils

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

D4739 Test Method for Base Number Determination by Potentiometric Hydrochloric Acid Titration

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

D5967 Test Method for Evaluation of Diesel Engine Oils in T-8 Diesel Engine

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

D6593 Test Method for Evaluation of Automotive Engine Oils for Inhibition of Deposit Formation in a Spark-Ignition Internal Combustion Engine Fueled with Gasoline and Operated Under Low-Temperature, Light-Duty Conditions

D8047 Test Method for Evaluation of Engine Oil Aeration Resistance in a Caterpillar C13 Direct-Injected Turbocharged Automotive Diesel Engine

D8291 Test Method for Evaluation of Performance of Automotive Engine Oils in the Mitigation of Low-Speed, Preignition in the Sequence IX Gasoline Turbocharged Direct-Injection, Spark-Ignition Engine

2.2 *American National Standards Institute Standard:*

ANSI MC96.1 Temperature Measurement – Thermocouples[4]

2.3 *Other Document:*

2012 Ford Explorer 2.0 L-4V TiVCT GTDi Build Manual[5]

3. Terminology

3.1 *Definitions:*

3.1.1 *blowby, n—in internal combustion engines*, the combustion products and unburned air-and-fuel mixture that enter the crankcase. **D4175**

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

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

[5] Available from Helminc, https://www.helminc.com/helm/homepage.asp.

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

3.1.2.1 *Discussion*—It may contain additives to enhance certain properties. Inhibition of engine rusting, deposit formation, valve train wear, oil oxidation, and foaming are examples. **D4175**

3.1.3 *enrichment, n—in internal combustion engine operation*, a fuel consumption rate in excess of that which would achieve a stoichiometric air-to-fuel ratio.

3.1.3.1 *Discussion*—Enrichment is usually indicated by elevated CO levels and can also be detected with an extended range air/fuel ratio sensor. **D6593**

3.1.4 *filtering, n—in data acquisition*, a means of attenuating signals in a given frequency range. They can be mechanical (volume tank, spring, mass) or electrical (capacitance, inductance) or digital (mathematical formulas), or a combination thereof. Typically, a low-pass filter attenuates the unwanted high frequency noise. **D4175**

3.1.5 *lambda, n*—the ratio of actual air mass induced, during engine operation, divided by the theoretical air mass requirement at the stoichiometric air-fuel ratio for the given fuel.

3.1.5.1 *Discussion*—A lambda value of 1.0 denotes a stoichiometric air-fuel ratio. **D6593**

3.1.6 *out of specification data, n—in data acquisition*, sampled value of a monitored test parameter that has deviated beyond the procedural limits. **D4175**

3.1.7 *PCM, n*—an engine control unit, most commonly called the powertrain control module (PCM), is an electronic device that instantaneously controls a series of actuators on an internal combustion engine to ensure optimal engine performance.

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

3.1.8.1 *Discussion*—symbols for quantities must be carefully defined; are written in italic font, can be upper or lower case, and can be qualified by adding further information in subscripts, or superscripts, or in parentheses (for example, t_{fuel} = 40 °C, where t is used as the symbol for the quantity Celsius temperature and t_{fuel} is the symbol for the specific quantity fuel temperature). **D8047**

3.1.9 *reading, n—in data acquisition*, the reduction of data points that represent the operating conditions observed in the time period as defined in the test procedure. **D4175**

3.1.10 *time constant, n—in data acquisition*, a value which represents a measure of the time response of a system. For a first order system responding to a step change input, it is the time required for the output to reach 63.2 % of its final value. **D4175**

3.1.11 *wear, n*—the loss of material from a surface, generally occurring between two surfaces in relative motion, and resulting from mechanical or chemical action or a combination of both. **D4175**

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *low-temperature, light-duty conditions, n*—indicative of engine oil and coolant temperatures that average below normal warmed-up temperatures, and engine speeds and power outputs that average below those encountered in typical highway driving.

3.2.2 *ramping, n*—the prescribed rate of change of a variable when one set of operating conditions is changed to another set of operating conditions.

3.2.3 *timing chain, n*—the part of an internal combustion engine that synchronizes the rotation of the crankshaft and the camshaft(s) so that the engine's valves open and close at the proper times during each cylinder's intake and exhaust strokes; in this engine, the timing chain is an inverted tooth configuration.

3.3 *Acronyms and Abbreviations:*

3.3.1 AFR—air fuel ratio

3.3.2 ANSI—American National Standards Institute

3.3.3 CCV—characterized control valve

3.3.4 *CE*—chain elongation (that is, change in timing chain length); see Eq 2

3.3.5 CW—chain wear

3.3.6 EEC—electronic engine control

3.3.7 EOT—end of test

3.3.8 fps—frames per second

3.3.9 GTDI—gasoline turbocharged direct injection

3.3.10 ID—internal diameter

3.3.11 *ip*—intermediate precision

3.3.12 ILSAC—International Lubricants Standardization and Approval Committee

3.3.13 *KV*—kinematic viscosity

3.3.14 L_f—final average chain length

3.3.15 L_i—initial average chain length

3.3.16 L_{nom}—the nominal chain length (1095.375 mm)

3.3.17 MAF—mass air flow

3.3.18 MAPT—manifold absolute pressure and temperature

3.3.19 NIST—National Institute of Standards and Technology

3.3.20 OHT—OH Technologies

3.3.21 OEM—original equipment manufacturer

3.3.22 PCM—powertrain control module

3.3.23 PCV—positive crankcase ventilation

3.3.24 P/N—part number

3.3.25 *R*—reproducibility

3.3.26 *Ra*—average surface roughness

3.3.27 RTV—room-temperature-vulcanizing

3.3.28 SAE—Society of Automotive Engineers

3.3.29 *S*—standard deviation

3.3.30 S_{ip}—standard deviation for intermediate precision

3.3.31 S_R—standard deviation for reproducibility

3.3.32 *TAN*—total acid number

3.3.33 *TBN*—total base number

3.3.34 TDC—top dead center

3.3.35 TGA—thermogravimetric analysis

3.3.36 VCT—variable valve timing

4. Summary of Test Method

4.1 The test engine is completely rebuilt before each test and essentially all aspects of assembly are specified in detail. The piston-ring gaps are increased to increase the level of blowby, and crankcase ventilation is modified to exacerbate chain wear.

4.2 The timing-chain length is measured after engine break in and at the end of test (EOT), 216 h. The test is conducted for 54 cycles, each 4 h cycle consisting of operation at two stages with differing operating conditions for a total test length of 216 h. While the operating conditions are varied within each cycle, overall they can be characterized as a mixture of low- and moderate-temperature, light- and medium-duty operating conditions.

4.3 The increase in timing-chain length, determined at the end of test, is the primary test result.

5. Significance and Use

5.1 This test method evaluates an automotive engine oil's lubricating efficiency in inhibiting timing-chain lengthening under operating conditions selected to accelerate timing-chain wear. Varying quality reference oils of known wear performance were used in developing the operating conditions of the test procedure.

5.2 The test method can be used to screen lubricants for satisfactory lubrication of an engine timing chain and has application in gasoline, automotive, engine-oil specifications. It is expected to be used in specifications and classifications of engine lubricating oils, such as the following:

5.2.1 ILSAC GF-6.

5.2.2 Specification D4485.

5.2.3 SAE Classification J183.

6. Apparatus

6.1 *Test Engine:*

6.1.1 The test engine is a Ford 2.0 L, spark-ignition, four-stroke, four-cylinder, gasoline, turbocharged, direct-injection (GTDI) engine,[6,7] with dual overhead camshafts driven by a timing chain, four valves per cylinder, and electronic fuel injection.

6.1.2 Table A5.1 lists the engine part numbers.

6.1.3 Configure a test stand to accept the test engine. Suggested fixing brackets are shown in Appendix X2.

6.2 *Reusable Engine Parts and Fasteners:*

6.2.1 Tables A5.2 and A5.3 provide the part numbers and descriptions for the reusable engine parts and fasteners, respectively.

6.2.2 All engine parts, other than the 'Required New Engine Parts' (see 6.3), can be used for a maximum of six tests provided they remain serviceable (see Tables A5.2 and A5.3).

6.2.2.1 Crankshaft and bearings, connecting rods and bearings, pistons, camshafts, timing-chain covers, cylinder blocks, cylinder-head assemblies, turbocharger, and fuel injectors can also be used for a maximum of six tests provided they remain serviceable. However, keep these parts together as a set for all six tests.

6.2.3 Test the flowrate of the positive crankcase ventilation (PCV) valve before each test to ensure it meets the required flowrate (see 8.6). The PCV valve stays with the test stand as long as it remains within serviceable test limits.

6.2.4 Correct damaged threads in the block with commercially available thread inserts.

6.3 *Required New Engine Parts for Each Test:*

6.3.1 Part numbers and descriptions for new engine parts (referred to as the "Test Parts") and gaskets are listed in Tables A5.4 and A5.5, respectively.

6.3.2 Use new valve-train drive parts and piston rings for each test.

6.3.3 Do not modify or alter test parts without the approval of the Sequence X Test Surveillance Panel.

6.4 *Additional Related Parts and Tools:*

6.4.1 The part numbers and descriptions of the Test Stand Setup Parts and Special Parts are listed in Tables A5.6 and A5.7, respectively. With a few noted exceptions, they can be reused for numerous tests provided they remain serviceable.

6.4.2 Engine parts other than valve-train and drive parts can be replaced during the test, provided the reason for replacement is not oil related and does not affect the oil.

6.5 *Special Service Tools:*

6.5.1 A list and part numbers of special tools for crankshaft alignment and timing are shown in Table A5.8. The tools are available from a Ford dealership and are designed to aid in performing several service items. The specific service items that require special tools to perform the functions indicated (if not self-explanatory) are listed in relevant sections below.

6.6 *Specially Fabricated Engine Parts:*

6.6.1 The following specially fabricated engine parts are required in this test method:

6.6.1.1 The intake-air system can be fabricated. However, use the stock 2012 Explorer air-cleaner assembly and mass air flow (MAF) sensor listed in Table A5.6 (see also 8.21.13).

6.6.1.2 Use the modified oil pan with dipstick and pick up tube listed in Table A5.7 (see also X1.24 and Fig. A9.6).

[6] The engine is based on the Ford Motor Co. 2012 Explorer engine, and a completely assembled new test engine is available from Ford Component Sales, Ford Motor Co., 290 Town Center Dr., Dearborn, MI 48126.

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

NOTE 1—Sources for some materials and information are provided in Appendix X1.

6.7 *Other Special Equipment:*

6.7.1 Use an appropriate air-conditioning system to control the temperature and pressure of the intake air to meet the requirements listed in Table 1 and Table 2.

6.7.2 Use an appropriate fuel-supply system.

6.7.3 Use the control and data acquisition system described in Annex A10.

6.7.4 Use an appropriate exhaust system to control the pressure and monitor the temperature of the exhaust gases listed in Table 2, Table 3, and Table 4.

6.8 *Driveline:*

6.8.1 Use the flywheel, clutch, pressure plate, bell housing, and clutch spacer listed in Table A5.7 (see also X1.24).

6.8.2 *Driveshaft*—Grease the driveshaft every test. The driveshaft specifications are as follows:

(1) Driveshaft angle degree: 1.5° ± 0.5°;

(2) Installed length from flange to flange: 450 mm to 790 mm;

(3) 1410 series flanges; 1550 joints;

(4) Driveshaft stiffness: 0.1° to 0.3°/136 N·m (100 ft·lbf).

6.8.2.1 P/M MSI-41/55S-22 from Machine Services Inc.[8] (see Table A5.7 and X1.33) has been found to be a suitable driveshaft.

6.9 *Special Engine Measurement and Assembly Equipment:*

6.9.1 *General:*

6.9.1.1 Items routinely used in the laboratory and workshop are not included.

6.9.1.2 Use any special tools or equipment shown in the 2012 Explorer Service Manual for assembly.

6.9.1.3 A list of these tools is provided in Table A5.8.

6.9.1.4 Complete any assembly instructions not detailed in Section 8 according to the instructions in the 2012 Explorer Service Manual.

6.9.2 *Piston-Ring Positioner:*

6.9.2.1 Use the piston-ring positioner to locate the piston rings from the cylinder block deck surface by 38 mm (Fig. A7.1). This allows the compression rings to be positioned in a consistent location in the cylinder bore for the ring-gap measurement.

6.9.3 *Piston-Ring Grinder*—A ring grinder is required for adjusting ring gaps. The Sanford piston-ring grinder has been found suitable.[9,7]

[8] The sole source of supply of this equipment known to the committee at this time is Machine Services, Inc., 1000 Ashwaubenon St., Green Bay, WI 54304.

[9] The sole source of supply of this equipment known to the committee at this time is Sanford Manufacturing Co., 300 Cox St., PO Box 318, Roselle, NJ 07203.

TABLE 1 Sequence X Break-in Controlled Quantities

Quantity	Value
Coolant-Out Temperature, °C	85 ± 0.5
Oil-Gallery Temperature, °C	100 ± 0.5
Inlet-Air Pressure (gauge), kPa	0.05 ± 0.02
Air-Charge Temperature, °C	37 ± 0.5
Inlet-Air Temperature, °C	30 ± 0.5

7. Reagents and Materials

7.1 *Degreasing Solutions:*

7.1.1 *Stoddard Solvent*—Use only mineral spirits meeting the requirements of Specification D235, Type II, Class C for volume fraction of aromatics (0 % to 2 %), flash point (61 °C minimum) and color (not darker than +25 on Saybolt Scale or 25 on Pt-Co Scale). (**Warning—**Combustible. Health hazard.) Obtain a certificate of analysis for each batch of solvent from the supplier.

7.1.2 *Chemtool B-12*[10,7]—(**Warning—**Combustible. Health hazard.)

7.1.3 *Acqueous Detergent Solution*—Prepare from a commercial laundry detergent. Tide has been found suitable for this purpose.[11,7]

7.1.4 *n-Heptane*—(**Warning—**Flammable. Health hazard. Harmful if inhaled.)

7.2 *Test Fuel*—Use only Haltermann HF2021 EPA Tier 3 EEE Lube Certificate test fuel.[12,7] Approximately 1600 L is required for each test. (**Warning—**Flammable. Health Hazard.)

7.3 *Test Oil*—A minimum of 23 L (6 gal) of test oil is required.

7.4 *Engine Coolant*—Use only Dex-Cool[13] concentrate mixed 50/50 with deionized water or pre mixed 50/50.

7.5 *Ultrasonic Cleaner*—Use only Brulin AquaVantage 815 GD and 815 QR-DF or 815 QR-NF.[14,15,7]

7.6 *Sealing Compounds:*

7.6.1 *Silicon-based Sealer*—Use as needed on the contact surfaces between the rear-seal housing and the oil pan and the front cover and cylinder block, cylinder head, and oil pan.

7.6.1.1 Use silicon-based sealer sparingly because it can elevate the indicated silicon content of the used oil.

7.6.2 *Motorcraft Gasket Maker TA-16 or equivalent*—Use between the 6th intake and exhaust camshaft cap and the cylinder head.

7.6.3 *Non-silicon Liquid or Tape Thread Sealers*—Use as needed on bolts and plugs.

7.6.4 *Thread Sealant*—Use Loctite 565.[16,17,7]

[10] The sole source of supply of this product known to the committee at this time is Berryman Products, Inc., 3800 E. Randol Mill Rd, Arlington, TX 76011. Tel: +1 800 433 1704. www.berrymanproducts.com.

[11] The sole source of supply of this detergent known to the committee at this time is Proctor and Gamble Company, 1 P&G Plaza, Cincinnati, OH 45202, USA. Tel. +1-513-983-1100. www.pg.com.

[12] The sole source of supply of this product known to the committee at this time is Haltermann Solutions, P.O. Box 0429, Channelview, TX 777530-0429, USA. Tel: +1 800 969 2542; www.haltermansolutions.com.

[13] Available from retailers and autoparts stores. See also X1.34.

[14] The sole source of supply of this product known to the committee at this time is Brulin Holding Company, 2920 Dr Andrew J Brown Ave., Indianapolis, IN 46205. Tel: +1 317 923 3211; www.bhcinc.com.

[15] Available from Haltermann (P.O. Box 0429, Channelview, TX 777530-0429, USA. Tel: +1 800 969 2542; www.haltermansolutions.com.

[16] Loctite is a registered trade mark of Henkel Corporation.

[17] Available from Henkel corporation, One Henkel Way, Rocky Hill, CT 06067. www.henkelna.com.

TABLE 2 Test Operational Quantities

Quantity, units	Stage 1	Stage 2
Time, min	120	60
Engine speed, r/min	1550 ± 5	2500 ± 5
Torque, N·m	50 ± 2	128 ± 2
Oil-gallery temperature, °C	50 ± 0.5	100 ± 0.5
Coolant-out temperature, °C	45 ± 0.5	85 ± 0.5
Coolant flowrate, L/min	40 ± 2	70 ± 2
Inlet-air pressure (gauge), kPa	0.05 ± 0.02	
Coolant pressure (gauge), kPa	70 ± 2	
Inlet-air temperature, °C	32 ± 0.5	
Exhaust back pressure (absolute), kPa	104 ± 2	107 ± 2
Air-charge temperature, °C	30 ± 0.5	
Air fuel ratio (AFR), lambda	0.78 ± 0.05	1 ± 0.05
Blowby-outlet temperature, °C	23 ± 2	78 ± 2
Humidity, g/kg	11.4 ± 1.0	
Blowby, L/min	Not measured	65 to 75[A]

[A] Only applicable up to 120 h.

TABLE 3 Parameter Logging

Test Point	Units
Controlled	
Engine speed	r/min
Engine torque	N·m
Coolant-out temperature	°C
Oil-gallery temperature	°C
Coolant flowrate	L/m
Air-charge temperature	°C
Inlet-air temperature	°C
Inlet-air pressure (gauge)	kPa
Coolant pressure (gauge)	kPa
Exhaust back pressure (absolute)	kPa
Air fuel ration (AFR), lambda	unitless
Humidity	g/kg
Monitored	
Fuel flowrate	kg/h
Manifold absolute pressure (MAP)	kPa
Boost pressure (absolute)	kPa
Barometric pressure (absolute)	kPa
Oil-gallery pressure (gauge)	kPa
Oil-head pressure (gauge)	kPa
Oil-filter-in temperature	°C
Exhaust temperature	°C
Crankcase pressure (gauge)	kPa
Fuel pressure (gauge)	kPa
Pre-intercooler air pressure (absolute)	kPa
Ambient temperature	°C
Coolant-in temperature	°C
Fuel temperature	°C
PCM CAN BUS Channels	
Ignition timing advance for #1 cylinder	° CA
Absolute throttle position	%
Engine-coolant temperature	°C
Inlet-air temperature	°C
Equivalence ratio (lambda)	unitless
Absolute torque value	%
Intake-manifold absolute pressure	kPa
Fuel-rail pressure (gauge)	kPa
Accelerator pedal position	%
Boost absolute pressure – raw value	kPa
Turbocharger wastegate duty cycle	%
Actual Intake (A) camshaft position	°
Actual exhaust (B) camshaft position	°
Intake (A) camshaft position actuator duty cycle	%
Exhaust (B) camshaft position actuator duty cycle	%
Charge air cooler temperature	°C

TABLE 4 Typical Uncontrolled Ranges for Fuel Flowrate and Exhaust Temperature

Quantity, unit	Stage 1	Stage 2
Fuel flowrate, kg/h	3.2 to 3.5	8.0 to 8.5
Exhaust temperature, °C	400 to 430	640 to 680

7.7 *Engine Build Up Oil—Use EF-411*[18,7]—as engine assembly oil.

8. Preparation of Apparatus

8.1 *Engine Parts Cleaning:*

8.1.1 *Ultrasonic Cleaner Preparation:*

8.1.1.1 The TierraTech model MOT-400 N[19,7] (capacity 400 L) has been found suitable.

8.1.1.2 Add solution once that in the ultrasonic cleaner reaches a minimum of 60 °C (140 °F).

(1) Use Brulin AquaVantage 815 GD and 815 QR-NF solutions with a volume fraction of 12.5 %.

(2) Mix these solutions to give a volume fraction of 50 %. For the TierraTech Model 400N, the quantities involved are 25 L of each solution. Quantities will be different for a different capacity unit.

(3) Change the soap and water solution at least after every 25 h of use.

8.1.2 *Engine Parts for Ultrasonic Cleaning*—The following engine parts are subjected to ultrasonic cleaning:

8.1.2.1 *Cylinder Block*—Remove oil jets and main bearings.

8.1.2.2 *Bare Pistons without Wristpins*—Remove the piston compression and oil rings. A new set of piston rings is used for every test.

8.1.2.3 *Bare Cylinder Head*—Remove valve-train components.

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

[19] The sole manufacturer of this equipment known to the committee at this time is TierraTech, 701 N Bryan Rd., 78572 Mission, TX. Tel: +1 956 519 4545; sales@tierratech.com.

8.1.2.4 *OHT Oil Pan*—This pan is available from OH Technologies[20,7] (see Table A5.7).

8.1.2.5 *Front Cover.*

8.1.3 *Procedure for Ultrasonic Cleaning:*

8.1.3.1 *Bare Pistons without Wristpins:*

NOTE 2—Leaving the pistons in the ultrasonic cleaner longer than 30 min can remove the skirt coating on the piston sides.

(1) Place the bare pistons without wristpins into the ultrasonic cleaner for 30 min maximum. A nylon brush may be used to scrub the pistons and remove heavy deposits. Do not leave the pistons in the ultrasonic cleaner longer than 30 min.

(2) After 30 min, remove the pistons and immediately spray with hot water, then with solvent and leave to air-dry.

(3) Repeat steps (a) and (b) until all the piston deposits have been removed.

8.1.3.2 *Other Parts*—Clean all the other parts listed in 8.1.2 as follows:

(a) First rinse the parts with aqueous detergent solution (see 7.1.3) followed by a hot-water rinse.

(b) Then place the parts in the ultrasonic parts cleaner apparatus for 30 min.

(c) After 30 min, remove the parts and immediately spray with hot water, then with solvent and leave to air-dry.

8.1.4 *Degreasing*—Spray clean the following components with Stoddard solvent, then blow out with pressurized air, and leave to air-dry:

8.1.4.1 Camshafts and all valve-train components;

8.1.4.2 Intake manifold/throttle body (not being separated);

8.1.4.3 Fuel-pump housing with piston;

8.1.4.4 Vacuum pump and oil screen;

8.1.4.5 The oil screen (do not clean the inside of the turbocharger);

8.1.4.6 Oil pump;

8.1.4.7 Valve cover;

8.1.4.8 Turbocharger oil lines;

8.1.4.9 Oil separator (PCV housing on the cylinder block);

8.1.4.10 Oil pick up tube;

8.1.4.11 Oil squirters/jets;

8.1.4.12 Crankshaft;

8.1.4.13 Rods and pins;

8.1.4.14 The test batch camshaft sprockets and crankshaft gear.

8.1.5 *Cleaning of Other Components:*

8.1.5.1 *VCT Solenoids*—Spray with solvent, then blow out with pressurized air, and leave to air-dry.

8.1.5.2 *Turbocharger Intake and Outlet*—Lightly wipe down with solvent.

8.1.5.3 *Injectors*—Wipe off carbon build up.

8.1.5.4 *Test Batch Timing Chain*—Clean as described 8.20.1.

8.2 *Cylinder Deglazing:*

8.2.1 Use a silicon carbide, grit flexible cylinder hone Flex Hone Model GB31232[21,7] and Pneumatic Honing Drill, Westward ½ in. Reversible Air Drill, 500 r/min, 600 kPa (90 psig) max, Model 5ZL26G[21,7] to deglaze the cylinder walls (see 8.13 and Figs. A9.3 and A9.4).

8.3 *PCV Valve Flowrate Device:*

8.3.1 Use this device to verify the flowrate of the PCV valve before the test and to measure the degree of clogging after the test.

8.3.2 Fabricate the device according to the details shown in Fig. A9.1.

8.3.2.1 The device shall have a full-scale accuracy of 5 % and a resolution of 0.05 L/s.

8.3.2.2 The inlet-flowrate meter shall calibrate to within 5 % of the standard (pre-calibrated) orifices at the pressure differentials stamped on the orifices.

8.4 *Preparation of Miscellaneous Engine Components:*

8.4.1 *Area Environment of Engine Build-Up and Measurement:*

8.4.1.1 The ambient atmosphere of the engine build-up and measurement areas shall be reasonably free of contaminants.

8.4.1.2 Maintain a relatively constant temperature (within ±3 °C) to ensure acceptable repeatability in the measurement of parts dimensions.

8.4.1.3 Maintain the relative humidity at a nominal maximum of 50 % to prevent moisture forming on cold engine parts that are brought into the build-up or measurement areas.

8.5 *Throttle Body:*

8.5.1 Clean the butterfly and bore of the throttle body with carburetor cleaner Chemtool B12 (see 7.1.2) and air-dry before each test.

8.5.1.1 Do not disassemble the throttle body as this will cause excessive wear on the components.

8.5.1.2 There is no specific life for the throttle body. The clearance between the bore and the butterfly will, however, eventually increase and render the body unserviceable.

8.5.1.3 Discard the throttle body when the clearance becomes too great to allow control of speed, torque, and air-fuel ratio.

8.6 *PCV Valve Cleaning and Measurement:*

8.6.1 Clean the PCV valve by spraying the inside of the valve with Chemtool B12 until the solvent comes out clear.

8.6.2 Measure and record the flowrates of the PCV valve with the calibrated flow device described in Fig. A9.1.

8.6.2.1 Measure the flowrate at 27 kPa and 60 kPa vacuum.

8.6.2.2 Because of the hysteresis in the PCV valve spring, make the vacuum adjustments in one direction only.

8.6.2.3 Correct the actual flow measurements to 65.5 °C and 100.7 kPa using the formula:

$$F_C = 1.8338 * F_A[(P_{baro})/(T_{AIR} + 273)]^{0.5} \quad (1)$$

where:

F_C	=	the corrected flow rate, L/min,
F_A	=	the actual flow rate, L/min,
P_{baro}	=	the barometric pressure in the measurement area, kPa (absolute), and
T_{AIR}	=	the air temperature in the measurement area, °C.

When using a float type flow meter for the PCV valve measurement, correct the converted flow value from meter's

[20] The sole source of this equipment known to the committee at this time is OH Technologies, 9300 Progress Pkwy., Mentor, OH 44060.

[21] The sole source of supply of this equipment known to the committee at this time is W.W.Grainger, Inc., www.grainger.com.

standard-condition scale to actual flow (using actual temperature and pre-PCV outlet pressure), before applying correction formula Eq 1.

8.6.2.4 Measure the flowrate twice and average the readings.

8.6.2.5 Reject any PCV valve that does not exhibit an average corrected flowrate of 36 L ⁄min to 54 L ⁄min at 27 kPa and 19 L ⁄min to 21 L ⁄min at 60 kPa.

8.7 *Drive System for Water Pump*—The water-pump drive is shown in Fig. A9.2. Use only the pulleys and belt provided in the test stand set-up parts list (Table A5.6) for the crankshaft pulley, water-pump pulley, tensioner, and six-groove belt shown in Fig. A9.2.

8.8 *Oil Separators*—Clean with Stoddard solvent and allow to air-dry.

8.9 *Assembling the Test Engine:*

8.9.1 *General*—Use the long block obtained from the supplier.[22,7]

8.9.1.1 Disassemble the long block in accordance with the 2012 Explorer workshop manual.

8.9.1.2 Required new parts and reusable parts are listed in Tables A5.4 and A5.5.

8.10 *Parts Selection*—Instructions concerning the use of new or used parts are detailed in 6.2 to 6.6.

8.11 *Gaskets and Seals*—Install new gaskets and seals during engine assembly.

8.12 *Block Preparations*—Inspect block, including oil galleries for debris and rust.

8.12.1 Remove any debris or rust that is found.

8.12.2 Remove oil gallery plugs.

8.12.3 Removal of coolant jacket plugs is left to the discretion of the laboratory.

8.13 *Deglazing Procedure:*

8.13.1 *General*—Carry out deglazing after ultrasonic cleaning under the following conditions to achieve an average surface roughness (*Ra*) of 9 µm to 13 µm and 30º ± 5º crosshatch.

8.13.1.1 Mount the engine block on an engine stand or suitable fixture so it is secure and will not move during the deglazing operation.

8.13.1.2 Rinse cylinder bores with Stoddard solvent.

8.13.1.3 Deglaze cylinder bores using the drill[21,7] and hone[21,7] shown in Figs. A9.3 and A9.4 (see also 8.2).

8.13.1.4 Run the drill at 500 r/min horizontal drill speed for 25 vertical strokes to 35 vertical strokes over an elapsed time of 20 s to 25 s. Ensure a steady supply of lubricant is supplied during each stroke.

8.13.1.5 Use a 50/50 ratio of Stoddard solvent and EF411 as the hone lubricant.

8.13.1.6 Clean cylinders after honing deglazing with warm/hot water or hot water and detergent (Tide[23,7] has been found suitable) using a brush, then oil cylinders with EF411.

8.13.1.7 Replace ball hone after deglazing 24 engine blocks.

8.14 *Crosshatch Measurement Procedure:*

8.14.1 *Apparatus*—Use the following:

8.14.1.1 *HatchView Software.*

8.14.1.2 *USB Microscope.*

8.14.1.3 *Computer System*—Minimum requirements: Windows XP, Vista or Windows 7 (32 or 64 bit), an available USB 2.0 port is required for live "video" viewing.

8.14.2 *Preparation:*

8.14.2.1 Clean the cylinder of any oil or residue from honing to maintain consistency of measurements.

8.14.2.2 Adjust the focus of the camera while the face of the camera is placed against the cylinder wall.

8.14.2.3 Set camera resolution to 640 x 480 and 30 frames per second (fps).

8.14.2.4 Use the identification feature available in the program to title the image with cylinder number and test number.

8.14.3 *Measurement:*

8.14.3.1 Take the measurement at the rear-most longitudinal position of each cylinder.

8.14.3.2 Using a ruler, take the measurement 38.1 mm (1.5 in.) down from the top of the cylinder deck.

8.14.3.3 The measurement shall be between 25° to 35° with a target of 30°.

8.15 *Crankshaft Preparation:*

8.15.1 Clean the crankshaft as described in 8.1.4.

8.15.2 Measure the horizontal and vertical diameters of the main and connecting rod journals, the bearing inside diameter and clearance, and verify that they meet the service limits.

8.15.3 Polish the crankshaft with 400 grit aluminum oxide utility cloth while it is still lightly coated in Stoddard solvent. 3M utility cloth 314D[24] has been found to be suitable.

8.15.4 Give a final finish with 600 grit crocus cloth.

8.15.5 Clean with Stoddard solvent as described in 8.1.4 for the final time.

8.16 *Piston and Rod Assembly:*

8.16.1 Clean the pistons as described in 8.1.3.1.

8.16.2 Measure piston, piston pin, and pin-rod-hole diameters to ensure they meet service limits.

8.16.3 Install the pistons on the connecting rods following the procedure in the 2012 Explorer workshop manual.

8.17 *Piston Rings:*

8.17.1 *Ring Gap Adjustment:*

8.17.1.1 Clean the piston rings by spraying them with Chemtool B12 carburetor cleaner to remove the factory coating. Wipe the piston rings with EF411.

8.17.1.2 Typically a gap of 1.651 mm (0.065 in.) for the top ring and 1.778 mm (0.070 in.) for the second ring have been

[22] The sole source of supply of this block known to the committee at this time is Ford Component Sales, Ford Motor Co., 290 Town Center Dr., Dearborn, MI 48126.

[23] The sole source of supply of this product known to the committee at this time is Procter & Gamble Co., 1 P&G Plaza, Cincinnati, OH 45202. Tel: +1 513 983 1100.

[24] The sole source of supply of this product known to the committee at this time is 3M United States, 3M Center, St. Paul, MN.

shown to produce acceptable blowby levels with the surface finish and crosshatch pattern achieved in See 8.14. However, ensure that the delta between the top and second ring gaps is 0.127 mm (0.005 in.).

8.17.1.3 To achieve an average blowby of 65 L/min to 75 L/min, an adjustment may be necessary immediately before or after the 24 h measurement.

8.17.1.4 A 24 h blowby value of at least 70 L/min is recommended. The 24 h to 120 h blowby average shall fall within 65 L/min to 75 L/min.

8.17.1.5 Ring gap adjustments are not allowed once the test has resumed after the 24 h blowby reading.

8.17.1.6 Place the ring 38 mm (1.5 in.) from the deck, using the piston-ring setter (see Fig. A7.1).

8.17.2 *Piston-Ring Cutting Procedure:*

8.17.2.1 Cut the top and second compression-ring gaps to the required gap using a ring grinder. The Sanford Piston Ring Grinder[25,7] has been found suitable with a 3⁄16 in. (4.76 mm) ring cutting burr (P/N 74010020[26,7]) rotated at a rated speed of 3450 r/min.

8.17.2.2 Remove equal amounts from both sides of the gap. Make final cuts on the down stroke only.

8.17.2.3 Cut the ring with a maximum increment of 0.125 mm until the desired ring gap is achieved.

8.17.2.4 After the rings are cut, remove the ring from the cutting tool, debur using a Sunnen soft stone P/N JHU-820,[27,7] and wipe with a dry towel.

8.17.3 *Installation:*

8.17.3.1 Install the oil-control rings and the compression rings on the pistons with the gaps located over the piston pin.

8.17.3.2 Position the gaps at approximately 180° intervals, with the top compression-ring gap toward the rear.

8.17.3.3 Install the rings using a ring spreader tool, keeping the rings' surfaces parallel to the ring groove in the piston.

8.17.3.4 If any rings require replacement, measure and record the new ring gap(s).

8.18 *Cylinder-Bore Measurements:*

8.18.1 Measure the cylinder bores with the bearing caps in place and torqued.

8.18.2 Clean the bores with a dry rag. The bores shall be clean and dry when they are measured.

8.18.3 Use a bore-gauge micrometer, along with the bore ladder (see Fig. A7.2) to determine the diameter of the cylinders at the top, middle, and bottom.

8.19 *Assembling the Test Engine:*

8.19.1 Assemble the engine according to the instructions in the 2012 Explorer service manual unless specified herein.

8.19.2 *Cylinder Block:*

8.19.2.1 Remove the heater-hose tube from the block (see Fig. A9.5) and plug with a 3.2 mm (5⁄8 in.) freeze plug coated in room-temperature-vulcanizing (RTV) silicone.

8.19.3 *Piston Installation:*

8.19.3.1 Install piston and rod assemblies in the appropriate cylinders, taking care to ensure rings are not damaged during installation.

8.19.3.2 Wipe the cylinders with EF-411.

8.19.3.3 Install the pistons and connecting rods with the notches facing the rear.

8.19.3.4 Install the rod-bearing caps and torque according to the procedure in the 2012 Explorer workshop manual.

8.19.4 *Oil System Components:*

8.19.4.1 Use production configuration for all oil-system components in the engine with the exception of the oil pan (see 8.1.2.4) and the oil pickup tube, shown in Fig. A9.6.

8.19.5 *Cylinder Head Installation:*

8.19.5.1 Heads may be used for up to six tests, provided they remain within service limits.

8.19.5.2 Disassemble heads and inspect for any debris or other deleterious materials and remove as necessary.

8.19.5.3 Clean the cylinder head in the ultrasonic cleaner as described in 8.1.2.3.

8.19.5.4 Determine valve-guide clearance at the top and middle of the heads on the transverse side of the guide.

8.19.5.5 Reject any heads that exceed the service limits shown in the 2012 Explorer work shop manual.

8.19.5.6 Measure and record spring free length and spring load at a compressed height of 28.7 mm for the intake and exhaust valve springs.

8.19.5.7 Verify the compressed spring load is 460 N ± 21 N. Reject any springs not meeting this criteria.

8.19.5.8 Assemble the cylinder heads in accordance with the service manual. The valves are lapped before installation and new intake and exhaust valve seals are installed.

8.19.5.9 Set the valve lash according to the procedure in the workshop manual and record the valve lash.

8.19.6 *Chain and Camshaft Installation Procedure:*

8.19.6.1 Measure the test chain according to the Timing-chain Measurement Procedure (see 8.20.5) prior to installing it in the engine.

8.19.6.2 Install camshaft and timing chain according to the procedure in the 2012 Explorer workshop manual.

8.19.6.3 If using the Ford camshaft alignment tool P/N 303-1565[28], ensure it does not bind in the slots at the rear of the camshafts. It should be loose after the timing-chain installation is complete. Ensure the camshaft positioning tool is flat before installing.

8.19.6.4 Use a spanner on the harmonic balancer or a flywheel lock to hold the crankshaft while performing this installation. Alternatively, use the crankshaft positioning TDC timing peg (Ford P/N 303-507[28]) to hold the crankshaft in place

8.19.6.5 Install the timing chain with the lettering on the black link facing forward. This ensures the chain is installed in the same orientation in the event it is removed and reinstalled during the test.

[25] The sole source of supply of this equipment known to the committee at this time is Sanford Mfg. Co., 300 Cox St., PO Box 318, Roselle, NJ 07203.

[26] The sole source of supply of this equipment known to the committee at this time is M.A.Ford Mfg. Co., Inc., 7737 Northwest Blvd., Davenport, IA 52806. www.maford.com.

[27] The sole source of supply of this equipment known to the committee at this time is Sunnen Inc., 7910 Manchester, St Louis, MO 63143.

[28] Available from any Ford or Lincoln dealer.

8.19.6.6 Coat the timing chain with test oil every time it is installed in the engine other than the pre break-in installation. Coat the timing chain with EF-411 when it is first installed before break-in.

8.19.6.7 Install the chain tensioner and guides according to the 2012 Explorer workshop manual.

8.19.6.8 After the tensioner is installed and the pin is pulled from the tensioner to release the tensioner arm, do not move or apply any force to the tensioner arm.

8.19.7 *Balance Shaft Housing:*

8.19.7.1 Do not install the balance shaft housing; it cannot be used with the test oil pan.

8.19.7.2 Remove the balancer and plug the oil passage with a Ford Racing Balance Shaft Delete Kit (Ford Performance P/N M-6026-23BSBP).

8.19.8 *Oil Pan and Baffle:*

8.19.8.1 Install oil-pan baffle to the oil pan as shown in Fig. A9.6.

8.19.8.2 Install the oil pan according to the procedure in the 2012 Explorer service manual.

8.19.9 *Water Pump, Water-Pump Drive:*

8.19.9.1 Install the water pump and pulley, the crankshaft pulley, and the tensioner according to the 2012 Explorer service manual. These are the only components needed to drive the water pump. All other production front-end, accessory-drive components do not need to be installed.

8.19.9.2 Do not use the engine to drive any external engine accessory other than the water pump.

8.19.9.3 Pull back tensioner and install water pump drive belt (see Fig. A9.2).

8.19.10 *Engine Cooling System:*

8.19.10.1 Coolant inlet and outlet housings are available from OH Technologies.[20]

8.19.10.2 Do not install the thermostat.

8.19.10.3 Plumb the external coolant system (see Figs. A9.14 and A9.15).

8.19.10.4 Measure coolant flowrate with a meter having an accuracy of ±1 %.

8.19.10.5 Use a radiator cap to limit the system pressure to 105 kPa.

8.19.10.6 Pressurize the coolant system to 70 kPa ± 10 kPa at the top of the coolant reservoir.

8.19.10.7 Control the flowrate and outlet temperature of the engine coolant in accordance with the specifications listed in Table 4.

8.19.10.8 Cyclic ramping specifications are detailed in Table 5.

8.19.10.9 Prior to running each reference calibration test, inspect the engine-coolant system components, external to the engine, and clean as needed.

8.19.10.10 The coolant side of the system typically does not need cleaning, but the process-water side may need routine cleaning. While a specific flushing technique is not specified, ensure it includes the use of a commercial descaling cleaner.

8.19.11 *Cylinder Block Oil Separator:*

8.19.11.1 Install a dummy PCV valve (that is, a PCV valve with the internal components removed) in the oil separator on the side of the engine block. Measure crankcase pressure at this location.

8.19.11.2 A functional PCV valve is located at the stand in the external ventilation system.

8.19.12 *Oil-Cooling System:*

8.19.12.1 Use the production oil cooler (P/N BB3Z-6A642-A) attached to the oil-filter adapter.

8.19.12.2 Use process water on the coolant side to control the oil temperature.

8.19.12.3 Control oil temperature by a valve on the inlet line of the process water to adjust the flow of process water through a feedback loop from the location of the oil gallery thermocouple (see Fig. A9.7).

8.20 *Timing-chain Preparation, Installation, and Measurement:*

8.20.1 *New Chain Preparation:*

8.20.1.1 Place a new timing chain into an ultrasonic bath with Stoddard solvent for 20 min.

8.20.1.2 Remove the chain from the ultrasonic cleaner and dip into room-temperature Stoddard solvent to cool the chain.

8.20.1.3 Dip the chain in heptane or Stoddard solvent to prevent rust.

8.20.1.4 Oil the chain by dipping in EF-411.

8.20.1.5 Install the chain in the engine for the engine break-in.

8.20.2 *After Engine Break-In:*

8.20.2.1 After engine break-in, remove the chain from the engine.

8.20.2.2 Place the chain into an ultrasonic bath with Stoddard solvent for 20 min.

8.20.2.3 Repeat 8.20.1.2 to 8.20.1.4.

8.20.2.4 Hang the chain to let excess oil run off and let the chain cool off for a minimum of 2 h in the measurement area before starting the measurement procedure for the after break-in. This allows the temperature of the chain to stabilize.

8.20.2.5 Measure timing chain as described in 8.20.5 to 8.20.8.

8.20.3 *Chain Installation After Break In:*

8.20.3.1 Dip the chain in Stoddard solvent to remove EF-411, then dip the chain in new test oil.

8.20.3.2 Reinstall the chain as described in 8.19.6.

8.20.3.3 Do not clean the timing chain if it is removed during the test for an engine repair.

8.20.4 *End of Test:*

8.20.4.1 At the end of test, remove the timing chain from the engine.

8.20.4.2 Repeat 8.20.2.2 to 8.20.2.4.

8.20.4.3 Measure the timing chain as described in 8.20.5 to 8.20.8.

8.20.5 *Chain Measurement—General:*

8.20.5.1 Measure the timing chain twice during the test—after the 8 h engine break-in and at the end of the test.

8.20.5.2 Use the motorized chain measurement apparatus, P/N MCMR 1000, available from Test Engineering Inc.[29,7] and shown in Fig. A9.8.

8.20.5.3 The parts list for the chain measurement rig is given in Table A5.9.

8.20.6 *Chain Measurement—Rig Calibration:*

8.20.6.1 Check the calibration on the measurement apparatus before every test chain measurement using a reference chain (see 8.20.6.3). Ensure the reference chain measurement is within ±25.4 µm (±0.001 in.) of the previous measurement before proceeding to the next step. If the reading is larger, investigate the source of error and rectify.

8.20.6.2 Adjust the rig to achieve a measurement within 25.4 µm (0.001 in.) of the last correct reading.

8.20.6.3 Use a single, new, unused chain as a reference chain. Use this chain only for calibrating the measurement apparatus. Use the same reference chain when calibrating the chain measurement apparatus. Lightly oil the reference chain with EF411 and store in the measurement area.

8.20.7 *Chain Measurement Procedure:*

8.20.7.1 Orient the sprockets of the measurement apparatus so that they are aligned with their alignment orientation marks.

8.20.7.2 Install the chain on the measurement apparatus with the "key" link in the standard (aligned) location.

8.20.7.3 Ensure that the USB digital interface cable between the indicator and the computer is connected and that the first cell of the spreadsheet is selected into which the data will begin being entered.

8.20.7.4 Energize the drive motor on the chain measurement apparatus and run until a minimum of 30 chain lengths worth of readings have been captured (207 sprocket revolutions).

8.20.7.5 When complete, examine the averages for the three measurement ranges and verify that the total range does not exceed ±0.008 mm (±0.0003 in.); if it does, repeat the measurement by overwriting the data.

8.20.8 *Chain Elongation Calculation:*

8.20.8.1 Determine the average chain length for the three measurement ranges.

NOTE 3—828 data points/measurements are collected every time a chain is measured. The 828 total points are divided into three subsets (276 points per subset).

8.20.8.2 Determine the average of those three subset average measurements. This average provides the final average chain length and the initial average chain length which are required when calculating the chain elongation in Eq 2 (see 12.1.1).

8.21 *Test Stand Installation:*

8.21.1 *General*—Functions that are to be performed in a specific manner or at a specific time in the assembly process are noted.

8.21.2 *Test Engine:*

8.21.2.1 Mount the engine on the test stand so that the flywheel friction face is 0.0° ± 0.5° from vertical.

8.21.2.2 Use four motor mounts (Quicksilver P/N 6628A 2) as shown in Figs. A9.19 and A9.20.

8.21.2.3 Suggested designs for the mount brackets are shown in Figs. X2.1 and X2.2.

8.21.2.4 The engine shall be at 0.0° ± 0.5° roll angle.

8.21.3 *Flywheel:*

8.21.3.1 Obtain the flywheel from OH Technologies[20,7] or Test Engineering Inc.[29,7]

8.21.3.2 Lightly coat the flywheel bolts with Loctite 565 to prevent any oil from seeping out of the holes.

8.21.3.3 Torque the flywheel to 108 N.m to 115 N.m. OTC flywheel holding tool (P/N 303-103)[30] has been found suitable to hold the flywheel while torqueing the flywheel bolts.

8.21.4 *Clutch and Pressure Plate:*

8.21.4.1 Obtain the clutch, pressure plate and spacer from OH Technologies[20,7] or Test Engineering Inc.[29,7]

8.21.4.2 Put the flat side on the clutch toward the engine.

8.21.4.3 Put the spacer between the flywheel and pressure plate.

8.21.4.4 Torque the pressure plate bolts to 25 N.m to 33 N.m.

8.21.4.5 Replace each clutch after every 6 runs.

8.21.5 *Driveline:*

8.21.5.1 *General*—Use 1410 series flanges and grease the driveline before every test.

8.21.5.2 *Driveline Specifications*—These are as follows:

(1) driveline angle: 1.5° ± 0.5°;

(2) installed length from flange-to-flange: 595 mm ± 13 mm;

(3) pilot: 69.9 mm (2.75 in.);

(4) bolt circle: 95.25 mm (3.7 in.);

(5) stub and slip: 88.9 mm (3.50 in.) by 2.11 mm (0.083 in.).

8.21.6 *Dynamometer*—Use Midwest dynamometer model 1014A.[31,7]

8.21.7 *Exhaust System and Gas Sampling Fittings:*

8.21.7.1 Fig. A9.21 shows a typical exhaust system and fittings for backpressure probes, O_2 sensors and thermocouple.

8.21.7.2 Construct exhaust components from either solid or bellows pipe/tubing. Other types of flexible pipe are not acceptable.

8.21.7.3 Use the backpressure probes until they become unserviceable.

(1) If the existing probes are not cracked, brittle, or deformed, clean the outer surface and clear all port holes.

(2) Check the probes for possible internal obstruction and reinstall the probes in the exhaust pipe.

(3) Stainless steel probes are generally serviceable for several tests; mild steel probes tend to become brittle after one test.

8.21.7.4 Any leaks in the connections to the sample probe will result in erroneous readings and incorrect air-fuel ratio adjustment. (**Warning—**Exhaust gas is noxious.)

8.21.8 *Fuel Management System:*

8.21.8.1 Use the fuel injectors for a maximum of 6 tests.

[29] The sole source of this equipment known to the committee at this time Test Engineering Inc., 12758 Cimmaron Path, Ste. 102, San Antonio, TX 78249-3417.

[30] The sole source of supply of this tool known to the committee at this time is Bosch Automotive Service Solutions, 28635 Mound Road, Warren, MI 48092.

[31] The sole source of supply of this equipment known to the committee at this time is Dyne Systems, Inc., W209 NI17391 Industrial drive, Jackson, WI 53037. Tel: 0800 657 0278; www.dynesystems.com.

8.21.8.2 Inspect the O-rings to ensure they are in good condition and will not allow fuel leaks. Replace if necessary.

8.21.8.3 Install the fuel injectors into the fuel rail and into the cylinder head.

8.21.8.4 A schematic of the fuel system is shown in Fig. A9.9.

8.21.9 *Powertrain Control Module (PCM):*

8.21.9.1 To run this test, use the engine PCM provided by Ford Motor Company.[32,7]

8.21.9.2 The PCM contains a calibration developed for this test. Use a PCM that contains the calibration U5J0110D1VEPfn13_78_2.

8.21.9.3 The PCM power shall come from a 13.5 V ± 1.5 V battery or a power supply that does not interrupt/interfere with proper PCM operation. Connect the PCM battery/power supply to the engine wire harness with an appropriate gage wire of the shortest practical length so as to maintain a dc voltage of 12 V to 15 V and minimize PCM electrical noise problems.

8.21.9.4 Ground the PCM ground wire to the engine. From the same ground point, run a minimum two gage wire back to the battery negative to prevent interruption/interference of the PCM operation.

8.21.9.5 The power supply can also be used for the lambda measuring devices.

8.21.10 *Spark Plugs:*

8.21.10.1 Install new Motorcraft CYFS-12-Y2 spark plugs.[33] These come pre-gapped.

8.21.10.2 Torque the spark plugs to 9 N·m to 12 N·m.

8.21.10.3 Do not use anti-seize compounds on spark-plug threads.

8.21.11 *Crankcase Ventilation System:*

8.21.11.1 *General*—The crankcase ventilation system is a closed system allowing blowby to be vented from the crankcase and drawn into the intake manifold. Figs. A9.10 and A9.11 show a schematic and a photograph, respectively, of the crankcase ventilation system. Flush the metal parts of the crankcase ventilation system with carburetor cleaner (Chemtool B-12) or any equivalent solvent after every test, then blow out with pressurized air and leave to air-dry before the test starts. Replace all Tygon hoses for every test. Smooth-bore, Teflon-braided, stainless steel hose can, however, be reused after cleaning in an organic degreaser.

8.21.11.2 *System Description:*

(1) Blowby flows through the oil-drain back passages in the cylinder block and head and through the front cover and out through the camshaft cover. The blowby heat exchanger and oil separator prevent loss of oil, fuel, and water into PCV system. A typical heat exchanger cooling system is shown in Fig. A9.18.

(2) The average blowby flowrate shall be 65 L/min to 75 L/min for the first 120 h of the test.

(3) When excessive plugging of the PCV valve occurs or there is excess blowby, the blowby is vented to the fresh air tube after the MAF sensor.

(4) Use a dummy PCV valve (that is, a PCV valve with the internal components removed) placed in the stock PCV valve location in the block-mounted oil separator for crankcase pressure measurement.

8.21.12 *Blowby Heat Exchanger and Oil Separator:*

8.21.12.1 Use ITT heater exchanger P/N S-160-02-008-002[34,7] and Moroso oil separator, P/N MOR 85487.[35,7]

8.21.12.2 Disassemble and soak both in Stoddard solvent for 24 h.

8.21.12.3 Rinse with hot water, then rinse a final time with Stoddard solvent and allow to air-dry.

8.21.13 *Intake Air Components:*

8.21.13.1 Install the fresh air tube, air cleaner assembly, and air filter.

8.21.13.2 Modify the air cleaner assembly to accept fittings for the inlet-air-temperature thermocouple and pressure tap as shown in Fig. A9.23.

8.21.13.3 The excessive blowby tube is shown connected to the fresh-air tube after the MAF sensor.

8.21.13.4 Use the 2012 Explorer fresh-air tubes, or if fresh-air tubes are fabricated they shall be 1040 mm ± 25 mm from the MAF sensor to the turbocharger inlet.

8.21.14 *Water-to-Air Turbocharger Intercooler:*

8.21.14.1 Use a water-to-air intercooler capable of achieving the required air charge temperature (Table 4) and an average system pressure loss less than 3 kPa in both stages.

8.21.14.2 The intercooler accumulates significant amounts of blowby condensate during each test. Spray-clean the air side of the intercooler with Stoddard solvent, then rinse with hot water, and allow to air-dry before each test. Clean the water side of the intercooler with commercial Aqua Safe descaler.[36]

8.21.14.3 *Intercooler Tubing:*

(1) Fabricate the intake-air system from the turbocharger to the intercooler with stainless steel tubing having an internal diameter (ID) of 51 mm and from the intercooler to the throttle body with stainless steel tubing having an ID of 64 mm. The tubing length is not specified but should be the appropriate length to achieve the required air-charge temperature and system-pressure loss.

(2) Locate the manifold absolute pressure and temperature (MAPT) sensor 305 mm ± 25 mm from the intake surface of the throttle body and the thermocouple for the intake-air-charge temperature 25 mm downstream from the MAPT sensor.

(3) Place the post-intercooler turbo boost pressure measurement probe a minimum of 305 mm upstream from the MAPT sensor.

(4) Place the pre-intercooler turbo boost pressure measurement probe a minimum of 130 mm downstream from the turbocharger outlet.

[32] The sole source of supply of this equipment known to the committee at this time is Ford Motor Company, 17225 Federal Drive, Ste. 200 Room P029, Allen Park, MI 48101.

[33] Available from Ford dealership.

[34] The sole source of supply of this equipment known to the committee at this time is ITT Standard Heat Exchangers, Kinetics Engineering Corp., 2055 Silber Road, Suite 101, Houston, TX 77055.

[35] The sole source of supply of this equipment known to the committee at this time is Summit Racing Equipment, PO Box 909, Akron, OH 44309-0909. Tel: +1800 2303030; www.summitracing.com.

[36] Available from various retailers.

(5) A typical installation is shown in Fig. A9.12. The intercooling tubing measurements and instrumentation are shown in Fig. A9.13.

8.21.15 *External Hose Replacement:*

8.21.15.1 Inspect all external hoses used on the test stand and replace any hoses that have become unserviceable.

8.21.15.2 Check for internal wall separations that could cause flow restrictions.

8.21.15.3 Check all connections to ensure security.

8.21.16 *Wiring Harness:*

8.21.16.1 Two wiring harnesses are used on the test stand - a dynamometer harness[20,7] that connects to the stand power and PCM (see Fig. A9.29) and an engine harness[20,7] (see Fig. A9.30). The stand harness receives a constant dc voltage of 12V to pins 4 and 8 and 12V switched to pin 1.

8.21.17 *Electronic Throttle Controller:*

8.21.17.1 *General*—The throttle is controlled using simulated accelerator pedal position signals. The dynamometer wiring harness is supplied with an Accelerator Pedal Position jumper cable with un-terminated pigtail leads.

8.21.17.2 Connect two voltage command signals, Acc Pos Sensor 1 and Acc Pos Sensor 2, to the Accelerator Pedal Position jumper cable. The voltage control ranges for each signal are shown in Table 5. The wiring schematic and pin-out description for this connection are shown in Fig. 1. Run the voltage signals through a voltage isolator otherwise interference will occur between the lab DAC system and the engine ECU and throttle control will be erratic.

8.22 *Engine Fluids (Supply/Discharge Systems):*

8.22.1 *Air Supply System:*

8.22.1.1 Ensure the supply system is capable of delivering 110 L/s of conditioned air, while maintaining the intake/air quantities detailed in Table 2. Condition the intake air to 32 °C ± 0.5 °C, 11.4 g/kg ± 0.8 g/kg humidity, and pressurized to 0.05 kPa ± 0.02 kPa. The test stand intake air duct system is not specified.

8.22.2 *Dew Point:*

8.22.2.1 Measure the dew point either in the main system duct or at the test stand. If measured in the main system duct, verify the dew point periodically at the test stand.

8.22.2.2 Maintain the duct surface temperature above the dew point temperature at all points downstream of the humidity measurement point to prevent condensation and loss of humidity level.

8.22.3 *Fuel System:*

8.22.3.1 A schematic diagram of a typical fuel-supply system is shown in Fig. A9.9.

8.22.3.2 Supply an excess volume of fuel to the fuel rail at all times. The engine has a closed loop fuel system so excess fuel goes into the loop back to the heat exchanger.

TABLE 5 Accelerator Position Sensor Control Ranges

NOTE 1—Acc Pos Sensor 2 should always equal 50 % of Acc Pos Sensor 1.

Command Signal	Operating Range, dc voltage	Min Signal (Idle), dc voltage	Max Signal (WOT), dc voltage
Acc Pos Sensor 1	0 V to 5.0 V	0.75 V (15 %)	4.25 V (85 %)
Acc Pos Sensor 2	0 V to 2.5 V	0.375 V (15 %)	2.125 V (85 %)

8.22.3.3 Deliver the fuel to a high-pressure, engine-driven pump that boosts the pressure and supplies the fuel to the fuel rail.

8.22.3.4 Maintain the fuel temperature to the fuel rail below 50 °C.

8.22.3.5 To ensure good supply to the high-pressure fuel pump, maintain the fuel pressure to the fuel pump above 448 kPa ± 35 kPa. Ensure the fuel pressure is constant at all steady-state conditions to ensure good speed, power, and air-fuel ratio control.

8.22.4 *Fuel Details:*

8.22.4.1 *General*—Approximately 1600 L of Haltermann HF2021 EPA Tier 3 EEE Lube certificate fuel (see 7.2) are required for each test.

8.22.4.2 The laboratory storage tank may be filled with subsequent batches of fuel. A new batch of fuel may be added to existing fuel in the tank. The fuel batch that is reported for a test is the last fuel batch that was added to the tank before the test started.

8.22.4.3 A certificate of analysis accompanies each batch. Maintain a record of a certificate of analysis for each batch.

8.22.5 *Engine Oil:*

8.22.5.1 The test oil sample shall be uncontaminated and representative of the lubricant formulation being evaluated.

8.22.5.2 A minimum of 16.35 L of new oil is required to complete the test. A 20 L sample of new oil is normally provided to allow for inadvertent losses.

8.23 *Temperature Measurement:*

8.23.1 *General:*

8.23.1.1 Temperature-measurement locations for the ten required temperatures are specified (see 8.23.2) allowing reasonable opportunity for adaptation of existing test stand instrumentation.

8.23.1.2 Use thermocouples that are calibrated to ±0.5 °C (see 8.23.3).

8.23.1.3 Use only original equipment manufacturer (OEM) temperature sensors for electronic engine control (EEC) inputs.

8.23.1.4 All thermocouples, except the intake-air thermocouple, shall be premium and sheathed. The intake-air thermocouple may be an open-tip type.

8.23.1.5 The diameter of the thermocouples shall be 3 mm.

8.23.1.6 Thermocouples, wires, and extension wires shall be matched to perform in accordance with the special limits of error as defined in ANSI MC96.1.

8.23.2 *Temperature Sensor Locations:*

8.23.2.1 *Coolant Inlet*—Install the sensor in the coolant inlet on the engine (see OHTVH-008-1 in Fig. A9.15). perpendicular to the run. Install sensor with the tip in the center of the stream of flow (see Fig. A9.14).

8.23.2.2 *Coolant Outlet*—Install the sensor in the coolant outlet on the engine (see OHTVH-009-1 in Fig. A9.15) perpendicular to the run. Install sensor with the tip in the center of the stream of flow (see Fig. A9.14).

8.23.2.3 *Engine-Oil Gallery*—Install the tip of the sensor at the center of the flow stream in the external oil-filter adapter (see Fig. A9.16) through the hole for the oil-pressure switch (not used). Install a tee to accept this temperature sensor and attach the oil-pressure line.

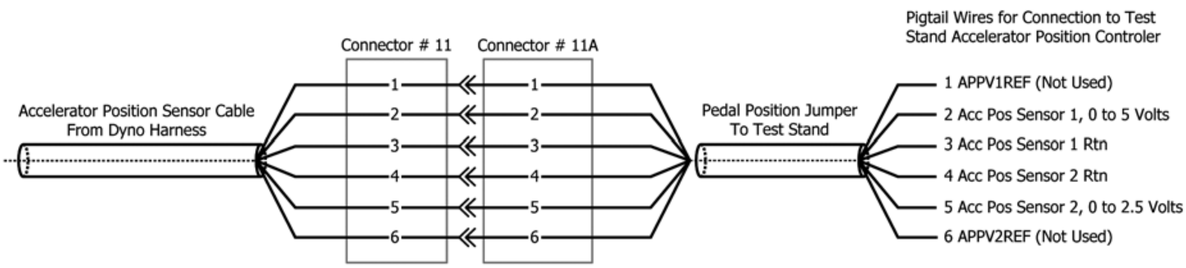

FIG. 1 Accelerator Position Wiring Schematic

8.23.2.4 *Engine-Oil Outlet*—Install the tip of the sensor at the center of the cross fitting attached to the side opposite from the engine-oil inlet-temperature sensor on the oil-filter adaptor. Modify the adapter with a ⅛ in. NPT hole to access the oil passage (see Fig. A9.24).

8.23.2.5 *Intake Air*—Install the tip of the thermocouple midstream in the air cleaner box downstream of the filter (see Fig. A9.23). Insertion depth shall be 37 mm ± 2 mm.

8.23.2.6 *Fuel*—Install the sensor in the fuel line before the high-pressure pump.

8.23.2.7 *Air Charge*—Install the sensor in the intercooler outlet tube 25 mm ± 2 mm downstream from the MAPT sensor (see Fig. A9.13). Locate the tip at the center of the flow.

8.23.2.8 *Pre-intercooler*—Install a sensor in the tube between the turbocharger and the intercooler (see Fig. A9.13).

8.23.2.9 *Exhaust*—Install a sensor 140 mm ± 12 mm downstream on the exhaust flange (see Fig. A9.21).

8.23.2.10 *Blowby Gas*—Install a sensor at the gas outlet of the blowby heat exchanger.

8.23.3 *Thermocouple Calibration:*

8.23.3.1 Calibrate all thermocouples prior to a reference oil test. The temperature measurement system shall indicate within ±0.5 °C of the laboratory calibration standard. The calibration standard shall be traceable to National Institute of Standards and Technology (NIST).[37]

8.24 *Pressure Measurement:*

8.24.1 *General:*

8.24.1.1 Pressure-measurement locations for each of the ten required quantities are specified in 8.24.2, allowing reasonable opportunity for adaptation of existing test stand instrumentation.

8.24.1.2 The accuracy and resolution of the pressure-measurement sensors and the complete pressure measurement system shall meet the requirements of the Data Acquisition and Control Automation (DACA) II Task Force Report.[38]

8.24.1.3 Replace pressure sensors that are part of the EEC system only with Ford-specified equipment.

8.24.1.4 In accordance with good engineering practice, incorporate tubing between the pressure tap locations and the final pressure sensors' condensate traps. This is particularly important in applications where low air pressures are transmitted by means of lines that pass through low-lying trenches between the test stand and the instrument console.

8.24.2 *Pressure Sensor Locations:*

8.24.2.1 *Manifold Absolute Pressure (MAP)*—Measure the manifold absolute pressure at the port downstream of the throttle-body on the front side of the intake manifold (see Fig. A9.13).

8.24.2.2 *Engine Oil*—Measure oil-pump pressure in the external oil-filter adapter (see Fig. A9.16) through the hole for the oil pressure switch (not used). Install a tee to accept the temperature sensor and attach the oil pressure line.

8.24.2.3 *Coolant*—Measure engine-coolant pressure at the top of the coolant reservoir as shown in Fig. A9.15.

8.24.2.4 *Fuel*—Measure fuel pressure in the lower pressure fuel line at the exit of the stand fuel pump.

8.24.2.5 *Crankcase*—Measure crankcase pressure at the dummy PCV valve in the cylinder block oil separator.

8.24.2.6 *Exhaust Gas*—Measure the exhaust back pressure with the exhaust gas sampling probe located 76 mm ± 12 mm downstream of the exhaust flange (see Fig. A9.21). A sensor capable of absolute or gauge measurement corrected with barometric pressure reading is recommended. Install a condensate trap between the probe and sensor to accumulate water present in the exhaust gas.

8.24.2.7 *Inlet Air*—Measure inlet-air pressure in the air cleaner downstream of the air filter (see Fig. A9.23).

8.24.2.8 *Pre-intercooler*—Measure the pre-intercooler pressure with the exhaust gas sampling probe located a minimum of 130 mm downstream of the turbocharger flange (see Fig. A9.13).

8.24.2.9 *Boost (Post-Intercooler)*—Measure the post-intercooler pressure with the exhaust gas sampling probe located downstream of the intercooler and at least 305 mm upstream of the MAPT sensor (see Fig. A9.13).

8.24.2.10 *Cylinder Head Oil*—Measure cylinder-head pressure at the oil gallery plug on the left side of the cylinder head next to the belt tensioner.

8.24.3 *Calibration of Pressure Sensors:*

[37] National Institute of Standards and Technology, 100 Bureau Drive, Stop 2300, Gaithersburg, MD 20899-2300. www.nist.gov.

[38] Available from the ASTM Test Monitoring Center, 6555 Penn Avenue, Pittsburg, PA 15206-4489. Attention Administrator.

8.24.3.1 Calibrate all pressure measurement sensors prior to a reference oil test.

8.24.3.2 The MAP pressure measurement system shall indicate within 0.1 kPa of the laboratory calibration standard.

8.24.3.3 All other pressure measurement systems shall conform to the guidelines in ASTM Research Report.[39]

8.24.3.4 The calibration standard shall be traceable to NIST.[37]

8.25 *Flowrate Measurement:*

8.25.1 *General:*

8.25.1.1 Flowrate measurement for each of the three required quantities is detailed 8.25.2.

8.25.1.2 With the exception of the engine coolant and blowby flowrates, measurement equipment is not specified for a given quantity. This allows reasonable opportunity for adaptation of existing test stand instrumentation.

8.25.2 *Flowrate Measurement Locations:*

8.25.2.1 *Engine Coolant*—Determine the engine coolant flowrate using a flow meter with a mass flow accuracy of ±1 % (see Fig. A9.15). A suitable coolant flow meter is available from Micro Motion.[40,7]

(1) Take precautions to prevent air pockets from forming in the lines to the pressure sensor. Transparent lines or bleed lines, or both, are beneficial in this application.

(2) Ensure that the manufacturer's requirements for orientation and straight sections of pipe are installed immediately up- and down-stream of the flow meter.

8.25.2.2 *Fuel*—Measure fuel flowrate in kg/h on the low-pressure fuel system before the high-pressure engine fuel pump. A suitable fuel flow meter is available from Micro Motion.[41,7]

8.25.3 *Calibration of Flowrate Devices:*

8.25.3.1 Calibrate the flow meters used in the measurement of fuel flowrate, the engine-coolant flowrate and blowby heat exchanger coolant flowrate prior to a reference oil test. Calibrate as installed in the system at the test stand with the test fluid. Calibrate with a turbine flow meter or by a volume/time method at Stage 1 and 2 operating conditions.

8.26 *Blowby Flowrate:*

8.26.1 Measure the blowby flowrate using either the blowby cart apparatus shown in Fig. 2 or the J-TEC flowmeter setup shown in Fig. 3 (the blowby procedures are given in 10.5.2).

8.26.1.1 Details of the crankcase ventilation system are shown in Fig. 4. The critical dimensions are detailed below:

NOTE 4—Subsections *(a)*, *(b)*, and *(c)* ensure all labs have an equivalent position of the heat exchanger relative to the valve cover ventilation port with an equivalent drain-back capability.

NOTE 5—Subsections *(d)*, *(e)*, and *(f)* ensure all labs have an equivalent position of the PCV valve in relation to the oil separator with an equivalent drain-back capability.

[39] Supporting data have been filed at the ASTM International Headquarters and may be obtained by requesting the Research Report RR:D02-1218.22.

[40] Emerson Automation Solutions, Micro Motion, 7070 Winchester Circle, Boulder, Co 80301 +1 800522 6277; www3.emersonprocess.com.

[41] Emerson Automation Solutions, Micro Motion, 7070 Winchester Circle, Boulder, Co 80301 +1 800522 6277; www3.emersonprocess.com.

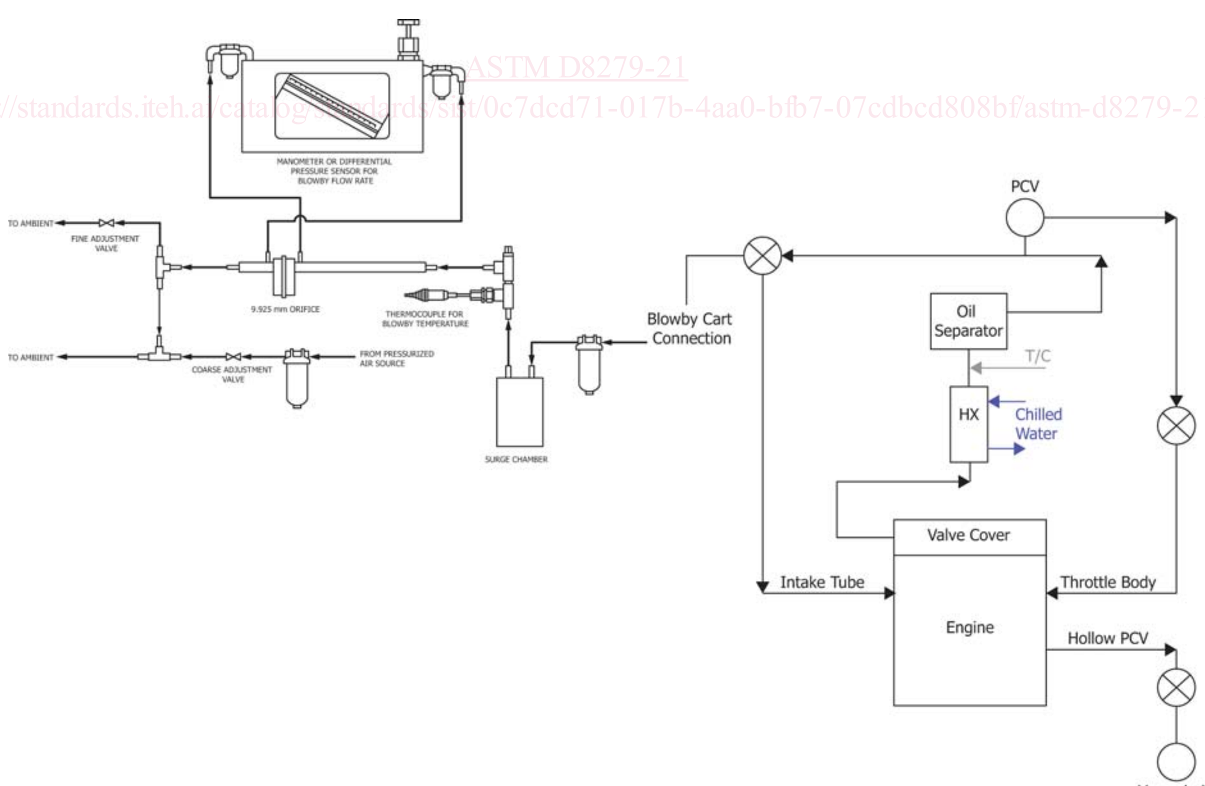

FIG. 2 Blowby Cart Setup for Measuring Blowby Flowrate