Date: March 3, 2019
To: Subcommittee D02.B0 members
Technical Contact: Terry Bates, batesterryw@aol.com
Work Item: WK49675
Ballot Action: New engine oil test method
Rationale: This test method is expected be in a new engine oil specification

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 X XXXX; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in 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 Annexes A1 to 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.

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[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.B0.01 on Passenger Car Engine Oils.
[2] ASTM Test Monitoring Center (TMC), 6555 Penn Ave., Pittsburgh, PA 15206–4489.

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 alternate suppliers to be given the opportunity for consideration of supplying the critical part/component providing they meet the approval process set forth by the technical committee.

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

1. Scope

1.1 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 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 the standard. (Values in parentheses are provided for information.)

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.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* See Annex A6 for general safety precautions.

1.4 *Table of Contents:*

2. Referenced Documents

2.1 *ASTM Standards*[3]*:*

D445Test 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

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

2.2 *American National Standards Institute Standards*[4]:

ANSI MC96.1 Temperature Measurement – Thermocouples

2.3 *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**

3.1.2 *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

[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 ANSI, 1899 L Street, NW, 11th Floor, Washington DC,.Tel: +1 202 293 89020; www.ansi.org.
[5] Available from Helminc, https://www.helminc.com/helm/homepage.asp.

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:*

AFR—air fuel ratio

ANSI—American National Standards Institute

CCV—characterized control valve

CE—chain elongation (that is, change in timing chain length) - see Eq (1)

CW—chain wear

EEC—electronic engine control

EOT—end of test

fps—frames per second

GTDI— gasoline turbocharged direct injection

ID—Internal diameter

ip—intermediate precision

ILSAC—International Lubricants Standardization and Approval Committee

KV—kinematic viscosity

L_f—final average chain length

L_i—initial average chain length

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

MAF—mass air flow

MAPT— manifold absolute pressure and temperature

NIST— National Institute of Standards and Technology

OHT—OH Technologies

OEM—original equipment manufacturer

PCM—powertrain control module

PCV— positive crankcase ventilation

P/N—part number

R—reproducibility

*R*a—average surface roughness

RTV—room-temperature-vulcanizing

SAE—Society of Automotive Engineers

S—standard deviation

S_{ip}—standard deviation for intermediate precision

S_R—standard deviation for reproducibility

TAN—total acid number

TBN—total base number

TDC—top dead center

TGA—thermogravimetric analysis

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], 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 and stand 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.

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[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.

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 X1.28 and Fig. A9.6).

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 Tables 3 and 4.

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 Tables 4, 6 and 8.

6.8 *Driveline:*

6.8.1 Use the flywheel, clutch, pressure plate, bell housing, and clutch spacer listed in Table A5.7 (see also X1.28).

6.8.2 Use the driveshaft listed in Table A5.7.

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[7] has been found suitable.

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*[8,9] —(**Warning**—Combustible. Health hazard.)

7.1.3 *Acqueous Detergent Solution*—Prepare from a commercial laundry detergent. Tide has been found suitable for this purpose[10,9].

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[11,9]. 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[12] 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[13,9,14].

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.

7.6.1.2 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[15,16,9].

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[7] 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.

[8] 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.

[9] 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 which you may attend.

[10] 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.

[11] 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.

[12] Available from retailers and autoparts stores. See also X1.33.

[13] 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.

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

7.7 *Engine Build Up Oil*—Use EF-411[17,9] 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[18,9] (capacity 400 L) has been found suitable.

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

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

b) 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.

c) 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.

8.1.2.4 *OHT Oil Pan*—This pan is available from OH Technologies[19,9] (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:*

(a) 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.

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

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

(c) 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.

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[15] Loctite is a registered trade mark of Henkel Corp[ration.
[16] Available from Henkel corporation, One Henkel Way, Rocky Hill, CT 06067. www.henkelna.com.
[17] 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.
[18] 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.
[19] The sole source of this equipment known to the committee at this time is OH Technologies, 9300 Progress Pkwy., Mentor, OH 44060.

(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[20,9] and Pneumatic Honing Drill, Westward ½ in. Reversible Air Drill, 500 r/min, 600 kPa (90 psig) max, Model 5ZL26G[20,9] 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:*

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

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 Measure the flowrate twice and average the readings.

8.6.2.4 Reject any PCV valve that does not exhibit an average 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[21,9].

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.

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[21] 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.

8.13 *Deglazing Procedure*:

8.13.1 *General*—Carry out deglazing after ultrasonic cleaning under the following conditions to achieve an average surface roughness (*R*a) 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[20,9] and hone[20,9] 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[22,9] 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[23] has been found to be suitable.

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[22] 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.

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

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 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 0.127mm (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[24,9] has been found suitable with a 3/16 in. (4.76 mm) ring cutting burr P/N 74010020[25,9]) 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[26,9], 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.

55144-1000. Tel: 1-888 364 3677; www.3m.com.

[24] 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.

[25] 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.

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

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[27], 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[27]) 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.

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[19].

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

[27] Available from any Ford or Lincoln dealer.

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.[28,9] 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. 1 (see 11.1.1).

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 6628-A) 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.

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[28] The sole source of this equipment known to the committee at this time Test Engineering Inc., 12758 Cimmaron Path, Ste. 102, San Antonio, TX78249-3417.

8.21.3 *Flywheel:*

8.21.3.3 Obtain the flywheel from OH Technologies[19,9] or Test Engineering Inc.[28,9].

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

8.21.3.2 Torque the flywheel to 108 N·m to 115 N·m. OTC flywheel holding tool (P/N 303-103)[29] 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[19] or Test Engineering Inc.[28,9].

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:

a) driveline angle: 1.5° ± 0.5°;

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

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

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

e) 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[30,9].

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.

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

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

c) 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.

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[29] 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.

[30] 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[31,9].

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[32]. 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:*

(a) 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.

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

(c) 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.

(d) 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:*

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[31] 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.
[32] Available from Ford dealership.

8.21.12.1 Use ITT heater exchanger P/N S-160-02-008-002[33,9] and Moroso oil separator, P/N MOR 85487[34,9].

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[35].

8.21.14.3 *Intercooler Tubing:*

(a) 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.

(b) 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.

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

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

(f) 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.

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[33] 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.

[34] 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.

[35] Available from various retailers.

8.21.16 *Wiring Harness:*

8.21.16.1 Two wiring harnesses are used on the test stand - a dynamometer harness[19,9] that connects to the stand power and PCM (see Fig A9.29) and an engine harness[19,] (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 1.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.

Table 1: Accelerator Position Sensor Control Ranges

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 %)
Note: Acc Pos Sensor 2 should always equal 50 % of Acc Pos Sensor 1			

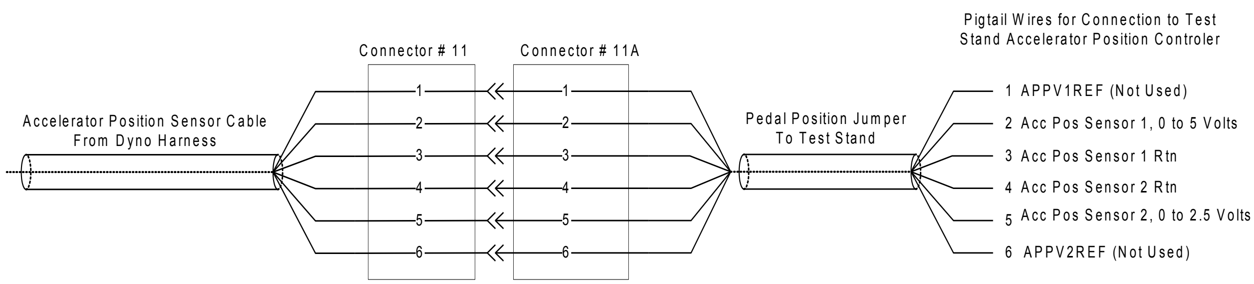

FIG. 1 Accelerator Position Wiring Schematic

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 4. 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.

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 7.3.1) 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 Inlet*—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.

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 1/8" 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 ~~F~~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[36] (NIST).

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[37].

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

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

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

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 155 mm ± 25 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:*

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[38].

8.24.3.4 The calibration standard shall be traceable to NIST[36].

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[39,9].

a) Take precautions to prevent air pockets from forming in the lines to the pressure sensor. Transparent lines or bleed

[38] Supporting data have been filed at the ASTM International Headquarters and may be obtained by requesting the Research Report RR:D02-1218.22.
[39] Emerson Automation Solutions, Micro Motion, 7070 Winchester Circle, Boulder, Co 80301 +1 800522 6277; www3.emersonprocess.com.

lines, or both, are beneficial in this application.

b) 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 *Blowby Heat Exchanger Coolant*—Measure the total volumetric coolant flowrate through the blowby heat exchanger system as shown in Fig. A9.11. A suitable heat exchanger is available from Standard Xchange[40,9].

8.25.2.3 *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[41,9].

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 ~~the~~ 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:

a) Vertical distance from valve cover ventilation port to the bottom of the heat exchanger shall be 20.5 cm ± 2.5 cm (8 in. ± 1 in.).

b) The hose used to connect the valve cover vent port to the heat exchanger shall have ID of ¾ in. with a length of 5.8 cm ± 7.6 cm (20 in. ± 3 in.). No part of this hose shall be lower than the valve cover vent, and there shall be no sags or dips in the hose that can retain fluid.

c) Use a 45° elbow at the inlet (bottom) of the heat exchanger where the hose from the valve cover is connected.

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

d) Vertical distance from oil separator outlet port to center for PCV valve shall be 35.6 cm ± 7.6 cm (14 in. ± 3 in.).

e) The total linear length of all hoses, tubes, pipes, fitting, etc. between the oil separator outlet port and the PCV valve shall not exceed 53 cm (21 in.). No part of this line shall be lower than the outlet port of the oil separator, and there shall be no low points that can retain fluid.

f) Place the center of the tee where blowby gas tees off to return to the fresh air inlet tube no lower than 7.6 cm (3 in.) below the center of the PCV valve.

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

g) Blowby gas tees off to return to the fresh air inlet tube drains back to the oil separator.

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[40] Standard Xchange, 175 Standard Pkwy, Buffolo, NY 14227-1233.

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

h) Use stainless steel for all wetted materials of pipes, tubing, and fittings.

i) Use Tygon PTFE hose or equivalent hose rated for use with fuel for all wetted materials of hoses.

j) Mount the PCV valve vertically.

8.26.2 The measurement system routes the blowby into the atmosphere through an external, sharp-edged orifice in the case of the cart apparatus or through a J-TEC flowmeter VF563AA[42,9].

8.26.2.1 Maintain crankcase pressure during operation of the system at 0.0 Pa ± 25 Pa to minimize the potential for crankcase leakage.

8.26.2.2 Mount the orifice plate or the J-TEC flowmeter in a vertical position .

8.26.2.3 In the case of the cart system:

a) Determine the blowby flowrate by measuring the differential pressure drop across the sharp-edged orifice using an inclined manometer or differential pressure sensor. The differential pressure drop sensor shall have a range from 0 kPa to 1 kPa.

b) Fabricate the sharp-edged orifice assembly that is specifically designed for blowby flowrate measurement in strict compliance with the specifications that are available from the TMC.

c) The complete orifice assembly (P/N RX-116-169-A1) can also be purchased from OH Technolgies[19,9] who will provide additional information..

d) The assembly contains five orifices. The 9.525 mm orifice is generally satisfactory for the range of blowby flowrates encountered.

[42] The sole source of supply of this equipment known to the committee at this time is J-TEC Automotive. Tel: +1 319 393 5200. www.jtecautomotive.com.

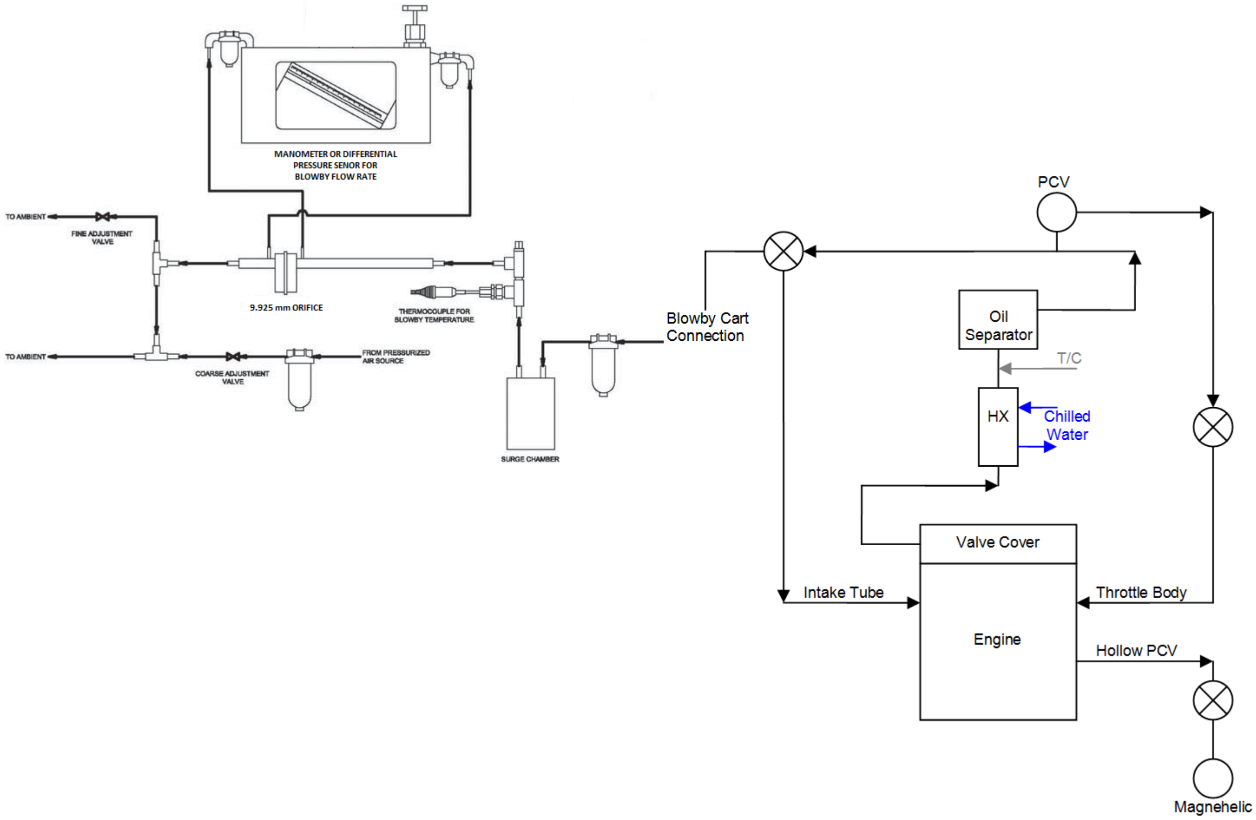


FIG. 2 Blowby Cart Setup for Measuring Blowby Flowrate

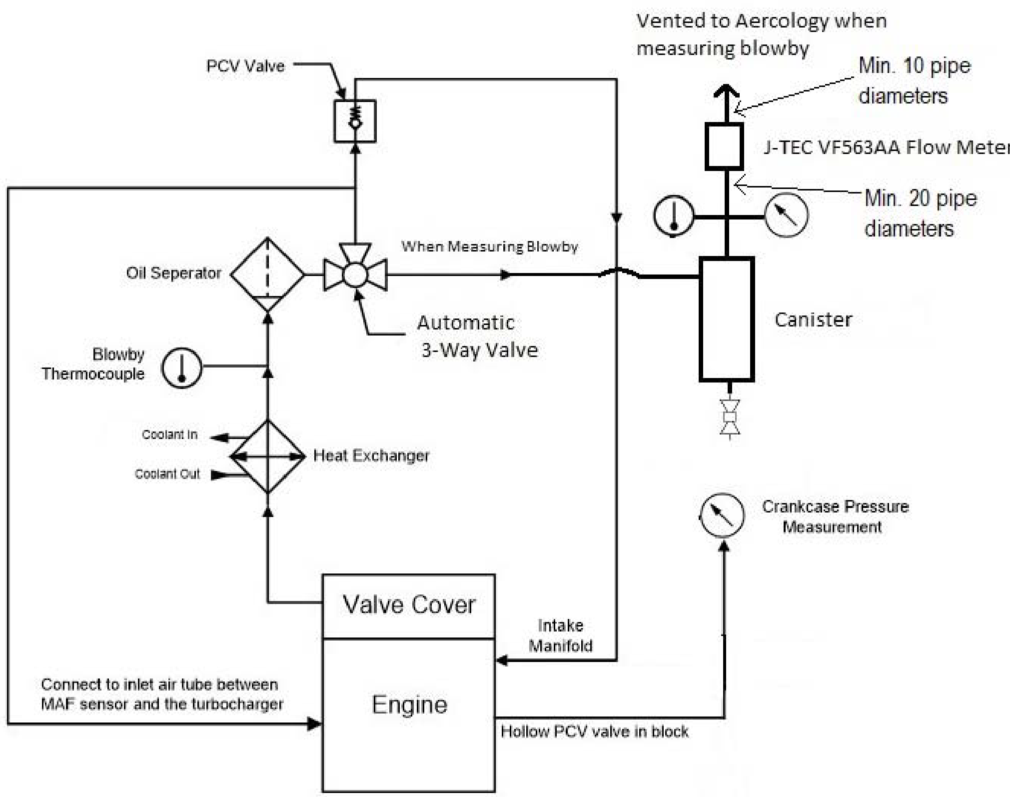


FIG. 3 J-TEC Flowmeter Setup for Measuring Blowby Flowrate

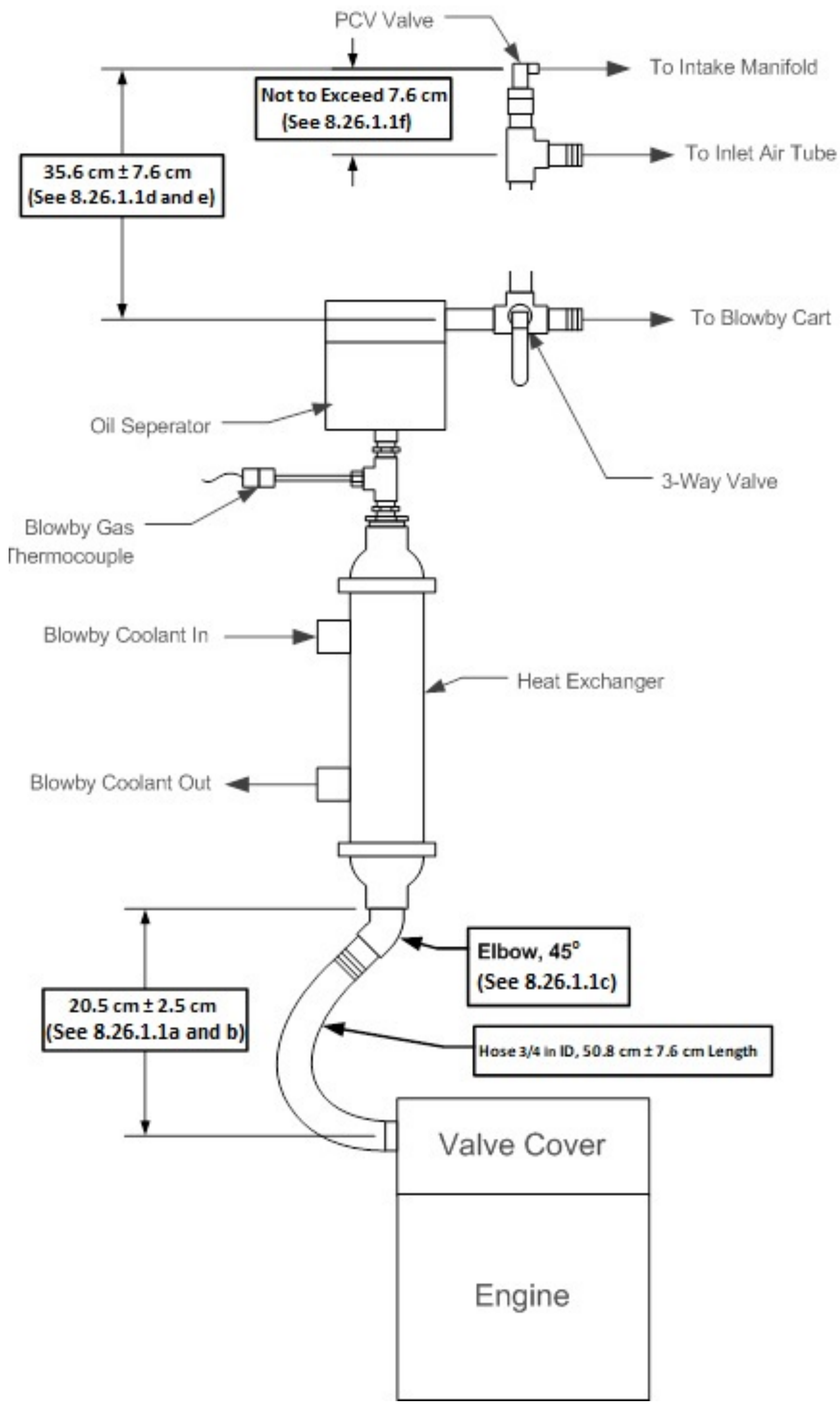


FIG. 4 Crankcase Ventilation System and Blowby Conditioning Critical Dimensions

9. Stand Calibration

9.1 *General:*

9.1.1 Annex A2 describes calibration procedures using the TMC reference oils, including their storage and conditions of use, the conducting of tests, and the reporting of results.

9.1.2 Annex A3 describes maintenance activities involving TMC reference oils, including special reference-oil tests, special use of the reference-oil calibration system, donated reference-oil test programs, introducing new reference oils, and TMC information letters and memoranda.

9.1.3 Annex A4 provides information regarding new laboratories, the role of the TMC regarding precision data, and the calibration of test stands used for non-standard tests.

9.1.4 Calibrate the test stand by conducting a test with a blind reference oil (see A2.2). Submit the results to the TMC as described in A2.6. Determine the acceptability of a reference-oil test according to the LTMS.

9.2 *New Test Stand*—A new test stand is one that has never been calibrated or has not completed an acceptable reference-oil test within 24 months of the EOT date of the last acceptable reference-oil test. Perform a calibration as described in 9.1.4 to introduce a new test stand.

9.3 *Stand-Calibration Period*—The calibration period is normally 180 days or after completing 15 non-reference oil tests, whichever comes first. However, calibration time periods may be adjusted by the TMC. Additionally, any test terminated with 26 test hours or less will not be counted towards the 15 allowed runs. Any non-reference oil test started within 180 days of the previous calibration test is considered within the calibration period, provided the 15 allowed non-reference oil tests that have been completed since the previous calibration test in the stand are not exceeded.

9.4 *Stand Modification and Calibration Status*—Stand-calibration status will be invalidated by conducting any non-standard test or modification of the test and control systems, or both. A non-standard test is any test conducted under a modified procedure, or using non-procedural hardware, or using controller-set-point modifications, or any combination thereof. Any such changes terminate the current calibration period. A reference test is required before restarting the current calibration period (see A2.2.2). If changes are contemplated, contact the TMC beforehand to ascertain the affect on the calibration status.

9.5 *Test-Numbering System:*

9.5.1 *Acceptable Tests*—The test number shall follow the format *AAA-BB-CCC* where:

AAA represents the test stand number,

BB represents the number of tests since last reference, and

CCC represents the total number of tests on the stand.

As an example, 95-5-100 represents the 100th test on stand 95 and the fifth test run since the last reference.

9.5.1.1 Consecutively number all tests on a given stand.

9.5.1.2 For a reference test, *BB* would be 0.

9.5.2 *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. Begin the suffix with the letter A and continue alphabetically until a calibration test is completed within the acceptance limits. For example, if three consecutive unacceptable calibration test are completed on the same test stand, and the test stand number of the first test is 95-0-100 the next two test numbers would be 95-0-100A and 95-0-100B. If the results of the next calibration test are acceptable, the test number 95-0-100C would permanently identify the test and appear on future correspondence.

9.5.2.1 The completion of any amount of operational time on tests other than calibration tests will cause the test number to increase by one.

9.5.2.2 Add no letter suffix to the test number of tests other than calibration tests.

10. Test Procedure

10.1. *Pre-Test Procedure and Engine Break-In:*

10.1.1 *General*—The pre-test procedure comprises an engine break-in schedule as described in Table 2. This is run before each test involving the test oil. The break-in procedure has 12 steps and is 8.25 h long. There are 30 s ramps between steps that are counted as part of the 8.25 h. There are three oil flushes, the oil being drained for 15 min after each flush.

10.1.2 Coat a pre-measured timing chain with EF-411 oil and install in the engine as described in 8.19.6.

10.1.3 Prime and install a new oil filter and charge the engine with 3600 g of test oil.

10.1.4 Start the engine as described in 10.2.1 and initiate Step 1 of the break-in as listed in Table 2.

TABLE 2 Sequence X Break-in Schedule

Step	Engine Speed, r/min	Torque, N·m	Time per stage, h:min	Total Time, h:min
Charge engine with 3600 g of new test oil and new primed oil filter				
1	Idle	0	0:30	0:30
Oil Flush 1: Shut engine down and drain used test oil and remove oil filter. Add 3600 g of new test oil and install new primed oil filter				
Start engine and idle for 5 min				
2	1500	38	0:30	1:00
3	2000	72	0:30	1:30
4	2500	111	0:30	2:00
5	3000	135	0:30	2:30
6	3000	150	3:15	5:45
7	2000	72	0:15	6:00
8	3250	155	0:15	6:15
9	3500	155	0:15	6:30
10	3750	155	0:15	6:45
11	4000	155	1:15	8:00
Bring engine to idle for 5 min and shutdown.				
Oil Flush 2: Shut engine down and drain used test oil and remove oil filter. Add 3600 g of new test oil and install a new primed oil filter.				
12	Idle	0	0:15	8:15

10.1.5 The controlled quantities and their values during break-in are listed in Table 3. All other controls are left wide open/free flowing. The engine does not produce enough heat in the early steps to reach all target temperatures. All controlled quantities shall be on target at the beginning of Step 4.

TABLE 3 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

10.1.6 The laboratory ambient atmosphere shall be reasonably free of contaminants. The temperature and humidity levels of the operating area are not specified. A fan is allowed to divert air toward the turbocharger during break-in only.

10.1.7 During the break-in, check the PCM system operation, check for leaks in the various systems, and purge air from the cooling systems.

10.1.8 Perform Oil Flush 1 at the end of Step 1.

10.1.8.1 Shutdown the engine as described in 10.4.1, drain the used oil, remove the used oil filter and allow the oil drain for 15 min.

10.1.8.2 Measure out 3600 g of new test oil, use a portion to prime a new oil filter and install it on the engine.

10.1.8.3 Charge the engine with the remaining new test oil.

10.1.8.4 Start the engine as described in 10.2.1.

10.1.8.5 Carry out Steps 2 to 11 of the break-in (see Table 2).

10.1.9 At the end of Step 11, idle the engine for 5 min and perform Oil Flush 2 by repeating 10.1.8.1 to 10.1.8.4.

10.1.10 Initiate Step 12 of the Break-in (see Table 2).

10.1.11 At the end of Step 12, perform Oil Flush 3.

10.1.11.1 Repeat 10.1.8.1.

10.1.12 Remove the timing chain for cleaning and 0 h measurement as described in 8.20.2 and 8.20.7, respectively.

10.1.13 After measuring the chain, coat the chain in new test oil and install it back in the engine as described in 8.19.6.

10.1.14 After the timing chain has been installed, repeat 10.1.8.2 and 10.1.8.3.

10.1.15 Start the engine as described in 10.2.1, run at idle for 5 min, and then shutdown the engine as described in 10.4.1.

10.1.16. After the engine has been shutdown for 20 min ± 2 min, record the dipstick level in millimeters.

10.1.16.1 Rotate the calibrated dipstick 360° while still in the oil pan to capture the oil level at the highest point.

10.1.16.2 Remove the dipstick to view the reading.

10.1.17 Break-in and the initial oil level measurement are now completed and the test procedure described in 10.3 can be initiated.

10.1.17.1 No makeup oil is added.

10.2 *Engine Start-up Procedures:*

10.2.1 *Normal Engine Start-up:*

10.2.1.1 *General*—Use this procedure each time the engine is started.

10.2.1.2 Turn on the ignition, safety circuits, fuel-management system, fuel pump, and the blowby-coolant pump. Ensure the intake-air supply duct is connected.

10.2.1.3 Crank the engine. The engine should start within 4 s.

a) Because the engine has a crankshaft-driven oil pump, cranking oil pressure might be low.

b) If used, disable a low oil-pressure ignition shutoff during engine starting to allow the engine to start even though the oil pressure is low. The use of such a shutoff switch could lead to excessive cranking time to start the engine.

10.2.1.4 If starting difficulties are encountered, do not crank the engine excessively. Perform diagnostics to determine the reason the engine will not start (for example, ignition problems, or insufficient or excess fuel). **Warning—**Excessive cranking times can promote additional fuel dilution of the test oil and can adversely affect the test result. In addition to other precautions, do not attempt to pour gasoline into the intake-air horn.

10.2.2 *Start-Up After Oil Leveling Period:*

10.2.2.1 *General*—Follow this procedure each time an engine start-up is performed after an oil leveling period.

10.2.2.2 Start the engine as described in 10.2.1, idle for 5 min, then ramp to Stage 1 conditions for 30 min as shown in Table 5. The 5 min of idle does not count toward the total test time.

10.2.2.3 The test timer starts at the beginning of the ramp to Stage 1 conditions.

10.2.3 *Start-Up After Unscheduled Shutdown*—Follow the procedure detailed below each time an engine start-up is performed after an unscheduled shutdown:

10.2.3.1 *To Return to Stage 1*—Start the engine as described in 10.2.1, idle for 5 min, then ramp to Stage 1 conditions for 30 min using the ramp as described in Table 5. Once Stage 1 conditions are reached resume the total test timer and the stage timer from where they left off before shutdown

10.2.3.2 *To Return to Stage 2*— Start the engine as described in 10.2.1, idle for 5 min, then ramp to Stage 2 conditions for 30 min using the ramp as described in Table 5. Once Stage 2 conditions are reached resume the total test timer and the stage timer from where they left off before shutdown..

10.3 *Test Sequence:*

10.3.1 After completion of the engine break-in (see 10.1), carry out the two-stage test procedure shown in Table 4. The test stage and ramp order are shown in Table 5.

TABLE 4 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.

10.3.2 Start the engine as described in 10.2.1, allow to idle for 5 min, and then shut the engine down as described in 10.4.1. This idle time does not count towards the test time.

10.3.2.1. Take a dipstick level (as described in 10.7.3) 20 min ± 2 min after the engine shutdown.

10.3.2.2 Record the 0 h dip reading.

10.3.2.3 Start the engine and allow to idle for 5 min. This 5 min does not count toward total test time.

10.3.3 Initiate the 30 min ramp to Stage 1 conditions.

10.3.3.1 Start the test timer at the beginning of this ramp to Stage 1.

10.3.3.2 Use the ramping conditions shown in Table 5.

10.3.4 *Cyclic Schedule:*

10.3.4.1 *General Description*—The test is composed of two stages as shown in Tables 4 and 5. Together, the two stages and two ramps comprise one cycle. Each cycle lasts 4 h and is repeated 54 times for a total of 216 h. Six consecutive cycles are completed each 24 h period.

10.3.4.2 Perform oil level measurement and sampling every 24 h or 6 cycles and at EOT. The oil level measurement and sampling procedure, which is described in 10.7, does not count toward test time.

10.3.4.3 *Test Cycle:* Each 4 h cycle contains a Stage 2 to 1 ramp for 30 min (or startup/idle to Stage 1 at test start or after an oil dip), a Stage 1 for 120 min, a Stage 1 to 2 ramp for 30 min, and a Stage 2 for 60 min. This 4 h sequence is the only time that is counted as test time.

10.3.5 *Ramps*:

10.3.5.1 The ramps between stages are 30 s (engine speed and coolant flow), 30 min (oil and coolant temperature), and 60 min (blowby temperature), to stabilize at stage conditions.

10.3.5.2 The torque ramps are different lengths.

10.3.5.3 Ramp details are shown in Table 5.

10.3.5.4 The ramps are considered complete after 30 min when the oil and coolant temperatures have reach stage conditions; at this time the stage timer starts.

10.3.5.5 Note that half of the blowby-temperature ramp occurs during stage operation.

10.3.5.6 The coolant and oil temperature ramps between the steady-state stage conditions, within ± 2 min, for the first 25 min to reach the next stage conditions.

10.3.5.7 After the next stage, oil and coolant temperatures are achieved between 23 min and 27 min, with the last remaining minutes of the 30 min ramp used to stabilize at the stage conditions shown in Table 4.

10.3.5.8 Figs. A9.25 to A9.28 show the desired shapes of the temperature and torque ramps.

10.3.5.9 The rate of speed, temperature, fuel and torque changes, as well as the amount of enrichment between stages, can influence test severity and engine component wear. Therefore, ramping rates are very important.

10.3.6 *End of Test Procedures:*

10.3.6.1 *Final Drain*—Drain the engine coolant after the completion of the last test cycle. Engine oil can be drained with the engine in or out of the engine stand.

10.3.6.2 *Engine Disassembly*—During disassembly, ensure the original location of the parts can be identified with respect to either the cylinder number, valve location, bearings, etc.

10.3.7.3 *Parts Layout for Measurement:* Lightly wipe down the timing chain of any excess oil and ensure the chain is kept free of any contaminants or debris. Prepare the timing chain for end of test measurement as described in the 8.20.4.

TABLE 5 Stages Order and Ramp Description

Stage	**Description**	**Time, min**
Stage 1	Stage 1 conditions	120
Ramp 1 to 2 (or start up/idle to stage 2)	30 s speed and flow ramps. 3 min to 3.5 min torque ramp. 30 min oil and coolant temperature ramp. 60 min blowby temperature ramp, to Stage 2. (Ramp 1 to 2 details below.)	30
Stage 2	Stage 2 conditions	60
Ramp 2 to 1 (or start up/idle to stage 1)	30 s speed and flow ramps. 3.5 min to 4.5 min torque ramp. 30 min oil and coolant temperature ramp. 60 min blowby temperature ramp to Stage 1 (Ramp details below)	30
Stage 1 to 2 torque ramp	30 s 95 N·m to 100 N·m 90 s 115 N·m to120 N·m 180 s to 240 s 126 N·m to 130 N·m	
Stage 2 to 1 torque ramp	30 s 75 N·m to 85 N·m 90 s 55 N·m to 60 N·m 150 s to 180 s 48 N·m to 52 N·m	
Stage 1 to 2 oil temperature ramp	Reach 75 °C by 12.5 min ± 2 min. Reach 100 °C ± 0.5 °C by 25 min ± 2 min. Remaining time used to stabilize at 100°C ± 0.5 °C.	30

Stage 2 to 1 oil temperature ramp	Reach 75 °C by 12.5 min ± 2 min. Reach 50 °C ± 0.5 °C by 25 min ± 2 min. Remaining time used to stabilize at 50 °C ± 0.5 °C	30
Stage 1 to 2 coolant temperature ramp	Reach 65 °C by 12.5 min ± 2 min. Reach 85 °C ± 0.5 °C by 25 min ± 2 min. Remaining time used to stabilize at 85 °C ± 0.5 °C	30
Stage 2 to 1 coolant temperature ramp	Reach 65 °C by 12.5 min ± 2 min. Reach 45 °C ± 0.5 °C by 25 min ± 2 min. Remaining time used to stabilize at 45 °C ± 0.5 °C	30
Stage 1 to 2 blowby temperature ramp	Ramp from 23 °C to 73 °C: Reach 49 °C by 15 min ± 2 min, reach 73 °C by 30 min ± 2 min. Ramp from 73 °C to 78 °C: reach 78 °C ± 2 °C by 60 min. (30 min of this ramp is run during Stage 2.)	30
Stage 2 to 1 blowby temperature ramp	Reach 55 °C by 15 min ± 2 min. Reach 32 °C by 30 min ± 2 min. Reach 23 °C ± 2 °C by 60 min. (30 min of this ramp is run during Stage 1.)	60

10.4 *Engine Shutdown Procedures:*

10.4.1 *Scheduled Shutdown Procedure:*

10.4.1.1 *General*—Scheduled shutdowns include those that occur during engine break-in and oil leveling. Follow the procedure described here each time a scheduled shutdown is performed.

10.4.1.2 Bring the engine speed to idle. Allow flow valves and all temperature valves, other than the blowby gas temperature valve, to open to maximum to cool the engine down.

10.4.1.3 Switch the ignition off.

10.4.1.4 Turn off power to the ignition power source.

10.4.1.5 Turn off fuel and coolant pumps.

10.4.1.6 Reduce the intake-air pressure to atmospheric.

10.4.2 *Unscheduled Engine Shutdown*—Follow this procedure each time an unscheduled engine shutdown is performed:

10.4.2.1 Stop test timer when ramp down starts.

10.4.2.2 Ramp down to idle in 30 s and allow flow valves and all temperature valves, other than the blowby gas temperature valve, to open to maximum to cool engine down.

10.4.2.3 Allow the engine to idle for a total of 2 min, the 30 s ramp down counting as part of the 2 min. Shut the engine down after 2 min.

10.4.2.4 Switch the ignition off.

10.4.2.5 Turn off fuel and coolant pumps.

10.4.2.6 Reduce the intake-air pressure to atmospheric.

10.4.3 *Unscheduled Downtime*—The oil leveling periods of 25 min ± 2 min are the only scheduled shutdowns allowed during the test. The test can, however, be interrupted to perform necessary maintenance. Note all unscheduled downtime on the Supplemental Operational Data Form of the final test report.

10.4.4 *Resumption of Test Time After Unscheduled Shutdown*—After an unscheduled shutdown, test time does not begin until the engine has reached operating conditions for the stage at which the shutdown occurred. On start-up, idle for 5 min, then use the ramp as shown in Table 5 for reaching the appropriate stage.

10.5 *Blowby Flowrate Measurement:*

10.5.1 *General*—Every sixth cycle, measure and record the blowby flowrate at 30 min to 45 min into Stage 2.

10.5.1.1 The engine shall be stable and operating at normal Stage 2 operating conditions.

10.5.1.2 The installation of the blowby flowrate measurement apparatus is described in Figs. 2 and 3.

10.5.1.3 The procedure for measuring blowby flowrate is described in 10.5.2.

10.5.1.4 Complete only one set (Stage 2) of blowby flowrate measurements during each six cycles.

10.5.1.5 Under special circumstances additional blowby flowrate measurements can be performed to determine or verify a problem with the flowrate measurement apparatus or the engine.

10.5.1.6 Record additional blowby flowrate measurements and an explanation of the reason for the additional measurements. Include these data in the supplemental operational data in the final test report.

10.5.2 *Blowby Cart Procedure:*

10.5.2.1 Connect the blowby measurement device to the pressurized air source.

10.5.2.2 Open the flow valve (bleeder valve) completely.

10.5.2.3 Connect the blowby apparatus flow line to the 3-way valve located between the oil separator and intake tube.

10.5.2.4 Position the 2-way valve to divert air to the manometer from the hollow PCV valve.

10.5.2.5 Position the 2-way valve in between the PCV and throttle body to keep air from entering the throttle body.

10.5.2.6 Position the 3-way valve to divert intake manifold vacuum from the engine PCV to the exhaust plumbing of the blowby apparatus meter.

10.5.2.7 Adjust the flow valve (bleeder valve) to maintain crankcase pressure at 0 kPa to 0.025 kPa.

10.5.2.8 Record the differential pressure across the blowby meter orifice, the blowby gas temperature, and the barometric pressure.

10.5.2.9 After completing the measurements, return the engine to normal operating configuration.

a) First, reposition the 3-way valve and both 2-way valves to ensure porting of the intake vacuum to the engine PCV.

b) Then disconnect the blowby apparatus hose from the closed port of the 3-way valve.

10.5.2.10 Calculate the blowby flowrate and correct the value to standard conditions (38 °C, 100.3 kPa) using the calibration data for that orifice.

10.5.3 *J-TEC Flowmeter Procedure:*

10.5.3.1 *General*—This procedure assumes that the JTEC flowmeter is hard plumbed into the blowby system (see Fig. 3).

10.5.3.2 Position the 3-way valve to divert the blowby gas from the engine PCV valve to the J-TEC flowmeter. This can be done manually or automatically.

10.5.3.3 Allow 1 min for the flow to stabilize before recording blowby flowrate.

10.5.3.4 Measure and record blowby flowrate for a period to allow for an accurate average flowrate to be obtained. This can be up to the full 15-minute measurement period.

10.5.3.5 After completing the measurements, position the 3-way valve to divert the blowby gas back to the engine PCV valve.

10.5.3.6 Calculate the average blowby flowrate and correct the value to standard conditions (38 °C, 100.3 kPa).

10.6 *Parameter Logging*

10.6.1 Refer to Tables 6 and 7 for parameter logging information.

10.6.2 Fuel flowrate and exhaust temperature are monitored parameters. Both are good indicators of proper engine operation. Their typical uncontrolled ranges are given in Table 8.

TABLE 6 Parameter Logging

	TEST POINT	UNITS
Controlled	Engine speed	r/min
	Engine torque	N•m
	Coolant-out temperature	°C
	Oil-gallery temperature	°C
	Air-charge temperature	°C
	Inlet-air temperature	°C
	Inlet-air pressure (gauge)	kPa
	Exhaust back pressure (absolute)	kPa
	Fuel temperature	°C
	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
	Power	kW
	Pre-intercooler air pressure (absolute)	kPa
	Ambient temperature	°C

	Coolant-In temperature	ºC
	Coolant pressure (gauge)	kPa
	Coolant flowrate	L/m
	Blowby heat exchanger coolant flowrate	L/m
	Lambda (λ)	unitless
PCM CAN BUS Channels	Ignition timing advance for #1 cylinder	° CA
	Absolute throttle position	%
	Engine-coolant temperature	ºC
	Inlet-air temperature	ºC
	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 7 PCM Quantity Logging Information

Mode	PID Number (Hex)	Parameter Description	Type	Bytes	Scale	Offset	Minimum	Maximum	Units
1	47	Absolute Throttle Position B	Unsingned Numeric	1	0.392156863	0	0	100	%
1	0E	Ignition Timing Advance for #1 Cylinder	Unsingned Numeric	1	0.5	-64	-64	63.5	°
1	11	Absolute Throttle Position	Unsingned Numeric	1	0.392156863	0	0	100	%
1	5	Engine Coolant Temperature	Unsingned Numeric	1	1	-40	-40	215	˚C
1	0F	Intake Air Temperature	Unsingned Numeric	1	1	-40	-40	215	˚C
1	34	Equivalence Ratio (Lambda)	Unsingned Numeric	2	3.0518E-05	0	0	2	undefined/not used
1	43	Absolute Load Value	Unsingned Numeric	2	0.392156863	0	0	25700	%
1	0B	Intake Manifold Absolute Pressure	Unsingned Numeric	1	1	0	0	255	kPa
22	318	Actual Intake (A) Camshaft Position Bank 1	Signed Numeric	2	0.0625	0	-2048	2047.9375	°
22	319	Actual Intake (B) Camshaft Position Bank 1	Signed Numeric	2	0.0625	0	-2048	2047.9375	°
22	461	Charge Air Cooler Temperature Bank 1 Sensor 1- Raw	Signed Numeric	2	0.015625	0	-512	511.984375	˚C

Table 8 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

10.7 *Oil Consumption Calculation:*

10.7.1 *General*—Carry out oil level measurements and sampling at intervals of 24 h or 6 cycles as detailed in Table 9 and calculate the oil consumption as described below.

10.7.2 *Sampling:*

10.7.2.1 Stop the total test timer after completion of every 6th cycle and Stage 2.

10.7.2.2 Perform a 30 s (speed and torque) ramp to idle and allow the engine to idle for 4.5 min. While the engine is at idle, remove a 120 mL to 150 mL purge sample from the valve attached to the "T" connected to the oil-filter housing. The location of this "T" is shown in Fig A9.7.

10.7.2.3 During the 4.5 min idle period, take a 60 ml oil sample from the valve as described in 10.7.2.2.

10.7.3 *Oil Level Measurement:*

10.7.3.1 Shut-down the engine 5 min after the start of oil sampling and oil-level measurement stage.

10.7.3.2 Immediately return the purge sample to the engine.

10.7.3.3 Record the dipstick level in millimeters 20 min ± 2 min after the engine is shutdown.

10.7.3.4 The engine begins to lose oil pressure below the 100 mm mark on the calibrated dipstick. Therefore, it is not recommended to run the engine with the oil level below the 100 mm mark on the calibrated oil dipstick to prevent engine damage.

10.7.3.5 To measure the highest mark, rotate the calibrated dipstick 360° while still in the oil pan.

10.7.3.6 Remove the dipstick to view the mark.

10.7.4 *Oil Consumed Calculation*

10.7.4.1 Using Table A11.1, convert the oil level measurement to oil charge.

10.7.4.2 Calculate the oil consumed as the difference between the calculated oil charge and Test Full oil charge.

10.7.4.3 Record the results on Form 7 of the standardized report set (see Annex A12).

10.7.5 Restart the engine as described in 10.2.2.

TABLE 9 Oil Level Measurements and Sampling

Test Hours	24	48	72	96	120	144	168	192	216 (EOT)
Test Cycles	6	12	18	24	30	36	42	48	54

10.8 *General Maintenance:*

10.8.1 The scheduled shutdown periods of 30 min during oil leveling provide (limited) opportunity for engine and stand maintenance.

10.8.2 In addition, the test can be shutdown at any convenient time to perform unscheduled maintenance. However, minimize the duration of such a shutdown. Report any unscheduled shutdown on the Supplemental Operational Data Sheet.

10.9 *Special Maintenance Procedures*

10.9.1 *General*—Functions that require special maintenance procedures are listed in this section. These maintenance procedures are specifically detailed because of their effect on test validity or because they require special care while being completed.

10.9.2 Check the oil level before performing any maintenance requiring removal of the front cover or rear seal housing. If the level is above 130 mm, or the oil level is above the oil pan rail, remove a portion of the oil from the oil-drain plug before performing the maintenance to ensure oil does not leak over the pan rail.

10.9.2.1 Use a clean container to catch the oil removed from the pan.

10.9.2.2 Before restarting the test, return the oil to the engine after the maintenance is completed.

10.10 *Blowby Flowrate Adjustment:*

10.10.1 A blowby adjustment can only be carried out within the first 24 h of the test. However, only one blowby adjustment is allowed within the first 24 h.

10.10.2 The blowby measurement taken during the first test Stage 2 after break in (3.5 h to 3.75 h) provides a good indication how the blowby will perform for the rest of the test. If that blowby value is less than 70 L/min, a blowby adjustment may be made to achieve at least 70 L/min flow.

10.10.2.1 Adjust the blowby by changing the ring gaps or replacing piston rings, if necessary.

10.10.2.2 Ring gaps shown in Table 11 typically produce the blowby flowrate values less than 70 L/min. However, these gaps can be adjusted as necessary to achieve the correct blowby level.

10.10.2.3 Use the ring cutting procedure outlined in 8.17.2.1 to adjust the ring gap.

10.10.3 Stage 2 average blowby flowrate for the test during the first 120 h of the test shall fall within the range 65 L/min to 75 L/min as listed in Table 10. The Stage 2 times are also listed in Table 10.

TABLE 10 2nd Stage Recommended Blowby Readings

Test Hours	Recommended average blowby reading, L/min
3.5 to 3.75	70
23.5 to 23.75	65 to 75
47.5 to 47.75	65 to 75
71.5 to 71.75	65 to 75
95.5 to 95.75	65 to 75
119.5 to 119.75	65 to 75
143.5 to 143.75	65 to 75
167.5 to 167.75	65 to 75
191.5 to 191.75	65 to 75
215.5 to 215.75	65 to 75

TABLE 11, Suggested Piston Ring Gaps

Top piston ring gap	1.651 mm (0.065 in.)
2nd piston ring gap	1.778 mm (0.070 in.)

10.10.4 *High Blowby Flowrate Adjustment*—Reduce high blowby flowrate by replacing the compression rings with new rings that have smaller ring gaps. Ensure that the ring-gap stagger remains at 0.127 mm (0.005 in.)

10.10.5 *Low Blowby Flowrate Adjustment*—Increase low blowby flowrate by increasing the ring gaps of the compression rings. Measure ring gaps to determine existing ring gaps and ring gap stagger. Maintain the same ring-gap stagger.

10.11 *Engine Disassembly and Reassembly for Maintenance (Before End of Test):*

10.11.1 *Engine Assembly and Disassembly*—Adhere to the procedures in 8.9

10.11.1.1 When the engine is disassembled for maintenance, drain as much test oil as possible from the oil pan into a clean container, and retain that oil for installation in the engine after reassembly.

10.11.1.2 Take precautions to ensure the oil is not contaminated and that deposits are not disturbed on any parts.

10.11.1.3 Place all parts in or over clean drain pans to collect oil that drains off while maintenance is being performed.

10.11.1.4 Place the timing chain in a separate container to prevent it from getting contaminated.

10.11.2 *Engine Reassembly:*

10.11.2.1 During reassembly, lubricate the engine parts with used drained test oil.

10.11.2.2 Do not use EF-411 oil or new test oil to lubricate parts during engine reassembly.

10.11.2.3 After the engine has been reassembled, reinstall the used test oil removed from the oil pan and collected from the engine parts during disassembly and maintenance.

10.11.2.4 Do not add any new test oil to the pan.

11. Diagnostic Data Review

11.1 *General*—The PCM quantities listed in this section can directly influence the test results or can be used to indicate normalcy of other quantities. This section outlines significant characteristics of specific engine operating quantities.

11.2 *Engine Torque:*

11.2.1 Engine torque, which is controlled in Stage 1 and 2, should remain relatively constant throughout a test and from test-to-test. Large differences in engine torque could be indicative of control or engine problems.

11.3 *Fuel-Consumption Rate:*

11.3.1 Although fuel-consumption rate is not a specifically controlled parameter it is used as a diagnostics tool and should remain relatively constant throughout the test.

11.4 *Exhaust Gas Component Levels:*

11.4.1 *General*—The lambda (λ) value in the exhaust gas determines the characteristics of combustion that occur during the test and can be used to determine the normalcy of combustion and any significant changes in combustion that occur throughout a particular test.

11.4.2 Lambda in all two stages is controlled by the program in the PCM. No adjustments can be made to change the exhaust-gas lambda.

11.4.3 If the lambda value differs from that given in Table 4, check the PCM and test-cell control system. Correcting a fault in the PCM and test-cell control system is the only way to achieve the correct lambda value.

11.5 *Crankcase Pressure:*

11.5.1 *General*—Crankcase pressure is a function of blowby flowrate and PCV-valve flowrate.

11.5.2 High crankcase pressure is usually caused by high-blowby flowrate or a significant loss of PCV-valve flowrate. Incorrect three-way valve plumbing or port plugging also promotes high-crankcase pressure.

11.5.3 Low- or negative-crankcase pressure might be caused by low-blowby flowrate or a restriction of vent air to the PCV valve.

11.6 *Oil Pressure:*

11.6.1 *General*—The oil pressure is a function of oil viscosity and operating temperature.

11.6.2 The oil pressure should remain consistent throughout the test, unless the oil exhibits a significant change in viscosity.

11.7 *Oil-Temperature Differential:*

11.7.1 *General*—The oil-temperature differential is primarily a function of oil flowrate and oil viscosity and is normally stable throughout the test. It can change if the oil viscosity changes significantly during the test.

11.8 *Coolant-Temperature Differential:*

11.8.1 *General*—The coolant temperature differential is primarily a function of the coolant flowrate and is normally stable throughout the test.

11.8.2 Large variations in the differential can be caused by coolant flowrate or temperature measurement errors.

12. Test Results

12.1 *Timing-Chain Elongation:*

12.1.1 Use the following equation to calculate the chain elongation (that is, the change in timing-chain length) from hour 0 to EOT:

$$CE = 2(L_f - L_i)/L_{nom} \quad (1)$$

where:

CE = the chain elongation from hour 0 to EOT, mm,

L_f = final average chain length (see 8.20.8), mm,

L_i= initial average chain length (see 8.20.8), mm,

L_{nom} = the nominal chain length = 1095.375 mm (43.125 in.).

12.1.2 The procedure for measuring of chain length is described in 8.20.7.

12.2 *Oil Analyses*—Analyse the fresh oil, each of the 24 h oil samples, and the EOT sample as follows and report the results on Form 6 of the standardized report form set[43] (see Annex A12).

12.2.1. *Metals Concentrations*—Using Test Method D5185, determine the mass fraction of the following 15 elements: aluminum, boron, calcium, chromium, copper, iron, lead, manganese, molybdenum, potassium, phosphorus, silicon, sodium, tin and zinc. Report the results in mg/kg.

12.2.2. *Water Concentration*—Measure by Test Method D6304. Report in %.

12.2.3. *Total Base Number (TBN)*—Measure by Test Method D4739. Report in gKOH/g.

12.2.4. *Total Acid Number (TAN)*— Measure by Test Method D664. Report in gKOH/g.

12.2.5. *Kinematic Viscosity (KV)*—Measure at 40 °C and 100 °C by Test Method D445. Report in mm^2/s

12.2.6. *Soot Concentration*—Measure by thermogravimetric analysis (TGA) by Test Method D5967, Annex A4. Report in %.

13. Report

13.1 For reference oil results, use the standardized report form (see Annex A12) set available from the ASTM TMC[43] and data dictionary for reporting test results and for summarizing operational data.

NOTE 6—Report the non-reference oil test results on these same forms if the results are intended to be submitted as candidate oil results against a specification.

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

13.1.2 Transmit results to the TMC within 5 working days of test completion.

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

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

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

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

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

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

14. Precision and Bias

14.1 *Precision:*

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

14.1.2 *Intermediate Precision Conditions*—Conditions where test results are obtained with the same test method using the

[43] Available on the ASTM TMC website: www.astmtmc.cmu.edu.

same test oil, with changing conditions such as operators, measuring equipment, test stands, test engines, and time.

NOTE 7—Intermediate precision is the appropriate term for this test method, rather than repeatability, which defines more rigorous within-laboratory conditions.

14.1.2.1 *Intermediate Precision Limit (ip)*—The difference between two results obtained under intermediate precision conditions that in the long run, in the normal and correct conduct of the test method, exceed the value shown in Table 11 in only one case in twenty. When only a single test result is available, the intermediate precision limit can be used to calculate a range (test result ± intermediate precision limit) outside of which a second test result would be expected to fall about one time in twenty.

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

14.1.3.1 *Reproducibility Limit (R)*—The difference between two results obtained under reproducibility conditions that would, in the long run, in the normal and correct conduct of the test method, exceed the values in Table 11 in only one case in twenty. When only a single test result is available, the reproducibility limit can be used to calculate a range (test result ± reproducibility limit) outside of which a second test result would be expected to fall about one time in twenty.

14.2 *Bias*—No estimate of bias for this test method is possible because the performance results for an oil are determined only under specific conditions of the test and no absolute standards exist.

Table 11 Test Precision for the Sequence X[A]

Quantity, units	Intermediate Precision[B]		Reproducibility[C]	
	S_{ip}[D]	*ip*	S_R[D]	*R*
Chain elongation[E], mm	0.14148	0.39215[F]	0.17856	0.49493[F]

[A] These statistics are based on results obtained on TMC Reference Oils 270, 271 and 1011 over the period from January 1, 2016 through October 7, 2017.

[B] See 14.1.2.

[C] See 14.1.3.

[D] *S* is the estimated standard deviation.

[E] Change in timing-chain length (see Eq (1).

[F] This value is obtained by multiplying the standard deviation by 2.77178.

15. Keywords

15.1 timing chain; chain wear; chain elongation; engine oil; turbocharger, ramp, blowby

ANNEXES
(Mandatory Information)

A1. ASTM TEST MONITORING CENTER ORGANIZATION

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

ASTM Test Monitoring Center
6555 Penn Avenue
Pittsburgh, PA 15206-4489
www.astmtmc.cmu.edu

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

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

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

A2. ASTM TEST MONITORING CENTER: CALIBRATION PROCEDURES

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

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

A2.2 *Calibration Testing:*

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

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

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

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

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

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

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

A3. ASTM TEST MONITORING CENTER: MAINTENANCE ACTIVITIES

A3.1 *Special Reference Oil Tests*—To ensure continuous severity and precision monitoring, calibration tests are conducted periodically throughout the year. Occasionally, the majority or even all of the industry's test stands will conduct calibration tests at roughly the same time. This could result in an unacceptably large time frame when very few calibration tests are conducted. The TMC can shorten or extend calibration periods as needed to provide a consistent flow of reference oil test data. Adjustments to calibration periods are made such that laboratories incur no net loss or gain in calibration status.

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

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

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

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

A3.6 *TMC Information Letters*—Occasionally it is necessary to revise the test method, and notify the test laboratories of the change, prior to consideration of the revision by Subcommittee D02.B0. In such a case, the TMC issues an Information Letter. Information Letters are balloted semi-annually by Subcommittee D02.B0, and subsequently by D02. By this means, the Society due process procedures are applied to these Information Letters.

A3.6.1 *Issuing Authority*—The authority to issue an Information Letter differs according to its nature. In the case of an Information Letter concerning a part number change which does not affect test results, the TMC is authorized to issue such a letter. Long-term studies by the surveillance panel to improve the test procedure through improved operation and hardware control may result in the issuance of an Information Letter. If obvious procedural items affecting test results need immediate attention, the test sponsor and the TMC issue an Information Letter and present the background and data supporting that action to the surveillance panel for approval prior to the semiannual Subcommittee D02.B0 meeting.

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

A4. ASTM TEST MONITORING CENTER: RELATED INFORMATION

A4.1 *New Laboratories*—Laboratories wishing to become part of the ASTM Test Monitoring System will be requested to conduct reference oil tests to ensure that the laboratory is using the proper testing techniques. Information concerning fees, laboratory inspection, reagents, testing practices, appropriate committee membership, and rater training can be obtained by contacting the TMC Director.

A4.2 *Information Letters: COTCO Approval*—Authority for the issuance of Information Letters was given by the committee on Technical Committee Operations in 1984, as follows: "COTCO recognizes that D02 has a unique and complex situation. The use of Information Letters is approved providing each letter contains a disclaimer to the affect that such has not obtained ASTM consensus. These Information Letters should be moved to such consensus as rapidly as possible."

A4.3 *Precision Data*—The TMC determines the precision of test methods by analyzing results of calibration tests conducted on reference oils. Precision data are updated regularly. Current precision data can be obtained from the TMC.

A5. ENGINE AND STAND PARTS

A5.1 Tables A5.1 to A5.6 list the engine and stand part numbers

Table A5.1 Assembled Test Engine[A]

ENGINE ASSEMBLY		
Ford Service Part Number	**Ford Engineering Part Number**	**Description**
BB5Z-6006-A	**BB5E-6006-AD** **DA8E-6006-BB**	**2.0L ENGINE ASY LB**
[A] Factory superseded numbers are also acceptable parts.		

Table A5.2 Reusable Engine Parts

~~Current~~ Ford Service Part Number	Ford Engineering Part Number	Description
1S7Z6507B	1S7G6507D7G	**VALVE - INLET**
1S7Z6514AA	1S7G6514AE	**RETAINER - VALVE SPRING**
1S7Z6518AA	1S7G6518AD	**KEY, VALVE SPRG**
1S7Z8501A	1S7G8501BD	**PUMP ASY - WATER**
8W9Z6C287A	AG9E6C287AA	**TAPPET ASY, FU PMP**
AG9Z6010B	AG9E6010A34B	**CYLINDER BLOCK**
AG9Z6135B	AG9E6135AA	**PIN - PISTON**
AG9Z6140A	AG9G6140BA	**RETAINER - PISTON PIN**
AG9Z6200D	AG9E6200CD	**ROD - CONNECTING**
AG9Z6250A	AG9E6A268AB	**CAMSHAFT, LH (EXHAUST)**
AG9Z6303A	BB5E6300A33A	**CRANKSHAFT ASY**
AG9Z6505A	AG9E6505AA	**VALVE - EXHAUST**
AG9Z6600B	AG9E6600AB	**PUMP ASY - OIL**
AG9Z6A785A	AG9G6A785CA	**SEPARATOR ASY - OIL**
AG9Z9350B	AG9E9D376AB	**PUMP ASY - FUEL**
AG9Z9P847A	AG9G9P847AA	**BRACKET, FU INJ CLIP**
BB5Z2A451C	BB5E2A451BD	**PUMP ASY - VACUUM**
BB5Z6019C	BB5E6019AF	**COVER - CYLINDER FRONT**
BB5Z6250A	BB5E6A267AB	**CAMSHAFT, RH (INTAKE)**

BB5Z6881A	BB5E6881AD	**ADPT OIL FILTER**
BB5Z6K269A	DB5E6K269AA	**COUPLING - PUMP DRIVE**
BB5Z9F593B	BB5E9F593BA	**INJECTOR ASY**
CJ5Z6049C	CJ5E6C032AC	**CYLINDER HEAD ASY**
CJ5Z6513A	CJ5E6513AA	**SPRING - VALVE**
CJ5Z6582A	CJ5E6K271BG	**COVER - CYLINDER HEAD**
CJ5Z6K254A	CJ5E6C271AA	**TENSIONER, OIL PUMP DRIVE**
CJ5Z6M280A	CJ5E6B297AA	**SOLENOID - ENGINE VARIABLE TIMING**
CJ5Z9D280A	CJ5E9D280BF	**MANIFOLD ASY - FUEL SUPPLY**
CJ5Z9D440A	CJ5E9B374BC	**COVER - FUEL PUMP**
CM5Z6652A	CM5E6652AA	**GEAR, OIL PUMP DRIVE**
CM5Z6A895A	CM5E6A895AA	**CHAIN ASY - OIL PUMP DRIVE**
CYFS12Y2	CB5E12405AA	**SPARK PLUG**
AG9Z-6108-H	AG9E-6110-AC2	**PISTON- STD**

Table A5.3 Fasteners

Current Ford Service Part Number	Ford Engineering Part Number	Description
F5TZ6A785A	F57E6A785AC	**SEPARATOR ASY - OIL, EXT**
W500033S437	W500033S437	**BOLT - FLANGED HEX.**
W500114S442	W500114S442	**BOLT**
W500212S437	W500212S437	**SCREW**
W500214S437	W500214S437	**BOLT - HEX.HEAD**
W500221S437	W500221S437	**BOLT - HEX.HEAD**
W500224S437	W500224S437	**BOLT**
W500300S437	W500300S437	**BOLT**
W500301S437	W500301S437	**BOLT**
W500310S437	W500310S437	**BOLT - HEX.HEAD**
W500313S437	W500313S437	**BOLT**
W500328S437	W500328S437	**BOLT**
W500414S442	W500414S442	**BOLT**
W503275S437	W503275S437	**BOLT - HEX. HEAD - FLANGED**
W505531S442	W505531S442	**SCREW**
W506976S442	W506976S442	**SCREW**
W520214S440	W520214S440	**NUT**
W700115S437	W700115S437	**SCREW AND WASHER ASY**
W701183S300	W701183S300	**DOWEL - BUSH**
W701219S437	W701219S437	**BOLT**
W702426S303	W702426S303	**BOLT - HEX.HEAD**
W702492S437	W702492S437	**STUD**

W702700S437	W702700S437	**STUD**
W703383S437	W703383S437	**BOLT**
W703643S430	W703643S430	**BOLT**
W703649S300	W703649S300	**PIN**
W704474S437	W704474S437	**STUD**
W706282S430	W706282S430	**BOLT**
W706284S437	W706284S437	**BOLT**
W706487S437	W706487S437	**BOLT-OIL COOLER FILTER**
W711261S437	W711261S437	**BOLT**
W711574S439	W711574S439	**STUD**
W712022S430A	W712022S430	**BOLT - HEX.HEAD**
W713095S403	W713095S403	**NUT**
W715323S300	W715323S300	**WASHER - COPPER, T/C OIL LINE**
W715638S443	W715638S443	**STUD**
W715848S437	W715848S437	**BOLT**
W716137S437	W716137S437	**BOLT**
W716735S437	W716735S437	**BOLT**
W716841S900	W716841S900	**PIN, BELL HOUSING**
1L5Z6379AA	W706161S300	**BOLT**
1S7Z6A340AA	1S7G6K340BC	**BOLT, CRK SHFT PULLEY**
1S7Z6K282AA	1S7G6K282AB	**BOLT, CHAIN TEN**
AG9Z6065A	AG9G6065BA	**BOLT - HEX.HEAD, CYL HEAD**
AG9Z6345A	AG9G6345AC	**BOLT - BEARING CAP - HEX. HEAD**
BB5Z6214A	BB5E6214CA	**BOLT - CONNECTING ROD**
CV6Z6279A	CV6E6279AA	**BOLT, CAMSHAFT**

Table A5.4 Test Parts List

Current Ford Service Part Number	Ford Engineering Part Number	Description
1S7Z6378AA	1S7G6378AB	**WASHER,CRK DIAMOND CRUSH**
AG9Z-6148-A	AG9E-6148-AA	**KIT-PISTON RING**
6M8Z6278A	6M8G6278AA	**WASHER, CAM, DIAMOND CRUSH**
7T4Z9601A	7T439601AA	**ELEMENT ASY - AIR CLEANER**
CJ5Z6256B	CJ5E6C524AD	**SPROCKET - CAMSHAFT, LH**
CJ5Z6268A	CJ5E6268AA	**BELT/CHAIN - TIMING**
CJ5Z6306A	CJ5E6306AB	**GEAR - CRANKSHAFT**
CJ5Z6C525A	CJ5E6C525AD	**SPROCKET - CAMSHAFT, RH**
CJ5Z6K254B	CJ5E6K254AA	**TENSIONER - TIMING**

		CHAIN
CJ5Z6K255A	CJ5E6K255AB	**ARM - TIMING-CHAIN TENSIONER**
CJ5Z6K297A	CJ5E6K297AB	**GUIDE, TIMING CHAIN**

Table A5.5 Gaskets List

Current Ford Service Part Number	Ford Engineering Part Number	Description
CJ5Z6079D	CJ5E6079AC	**KIT - GASKET**
1S7Z6571EA	1S7G6A517BG	**SEAL - VALVE STEM EX**
1S7Z6840AA	1S7G6A636AD	**GASKET, OIL FILTER ADPT**
1S7Z6B752AA	1S7G6B752AC	**GASKET, OIL SEP**
1S7Z6K301BA	1S7G6A321AA	**SEAL - CRANKSHAFT REAR OIL**
1S7Z8507AE	1S7G8507AF	**GASKET - WATER PUMP**
3M4Z6625AA	3M4G6625AA	**GASKET, OIL PMP P/U TUBE**
3M4Z8255A	3M4G8K530AB	**GASKET, T/STAT HSG**
3S4Z6571AA	3S4G6A517AA	**SEAL - VALVE STEM INT**
9L8Z9E936A	9L8E9E936AA	**GASKET, T/B**
AA5Z9E583A	AA5E9E583AA	**SEAL, FU PUMP**
AG9Z9P431A	AG9G9P431AA	**GASKET, T/C COOL LINE**
BB5Z2A572B	BB5E2D224BB	**GASKET - VACUUM PUMP**
BB5Z6584A	BB5E6K260AB	**GASKET, CAM COVER**
BB5Z6L612A	BB536L612AA	**GASKET, EXHAUST**
BG9Z9229A	BG9E9U509AB	**KIT - "O" RING, FU INJ**
BR3Z6C535B	BR3E6P251BA	**SEAL - VALVE VCT**
CB5Z9276A	CJ5E9A420BA	**GASKET, FU PUMP CVR**
CJ5Z6051A	CJ5E6051EC	**GASKET - CYLINDER HEAD**
CJ5Z6N652A	CJ5E6N652AA	**GASKET, T/C OIL DRAIN LINE**
CJ5Z8255A	CJ5E8255AA	**SEAL - THERMOSTAT**
CJ5Z9439A	CJ5E9439AA	**GASKET - INTAKE MANIFOLD**
CJ5Z9448A	CJ5E9448BA	**GASKET, EX MANIFOLD**
CM5Z6700A	CM5E6700AB	**SEAL ASY - CRKSHAFT OIL - FRT**

Table A5.6 Test Stand Set Up Parts List

Current Ford Service Part Number	Ford Engineering Part Number	Description
AG9Z9D930B	AG9T9H589BE	**WIRE ASY, FE INJ**
1S7Z12A699BB	1S7A12A699BB	**SENSOR - ENGINE KNOCK**
6M8Z6C315AA	6M8G6C315AB	**SENSOR - CRANKSHAFT POSITION - CPS**
8F9Z9F472A	8F9A9Y460AB	**SENSOR ASY, MAF**

8V2Z12B579A	8V2112B579AA	**SENSOR ASY**
9L8Z6G004E	9L8A6G004BC	**SENSOR ASY, CYL HD TMP**
AA5Z9A600B	AA539A600AD	**CLEANER ASY - AIR**
AE5Z6A228A	AE5Q6A228AA	**PULLEY ASY - TENSION BELT**
AE5Z8620A	AE5Q6C301AA	**V-BELT**
AG9Z6K679A	AG9G6K679BC	**PIPE - OIL FEED, T/C**
AG9Z6K868A	CJ5E6K868AA	**VALVE ASY, ENG PST OIL COOL**
AG9Z6L092A	AG9G6K677BC	**HOSE - T/C OIL DRAIN**
AG9Z8555A	AG9G8A506BB	**HOSE - WATER INLET, T/C**
AG9Z9F479A	AG919F479AB	**SENSOR ASY, MAP**
AS7Z6B288A	AS7112K073AA	**SENSOR - CAMSHAFT POSITION**
BB3Z6A642A	BB3E6A810AA	**KIT ENGINE OIL COOLER**
BB5Z11002C	BB5T11000AA	**STARTER MOTOR ASY**
BB5Z5A231A	BB535A281AA	**CLAMP - HOSE, T/C TO EXH**
BB5Z6C640A	BB536K863CE	**CONNECTION - AIR INLET T/B END**
BB5Z6C640B	BB536K863DF	**CONNECTION - AIR INLET, I/C END**
BB5Z6C646C	BB536C646CD	**DUCT - AIR, TURBO END**
BB5Z6C646D	BB536C646DF	**DUCT - AIR, INTERCOOLER END**
BB5Z6C683A	BB5E6L663AA	**FILTER ASY (T/C SCREEN)**
BB5Z9647A	BB539647AB	**BRACKET, AIRBOX**
BB5Z9661A	BB539643AA	**COVER, AIRBOX**
BB5Z9B659B	BB539F805DE	**HOSE - AIR, TURBO END**
BB5Z9B659E	BB539F805CG	**HOSE - AIR, AIR BOX END**
BM5Z9F972A	BM5G9F972BA	**SENSOR - FUEL INJECTOR PRESSURE**
BR2Z9E499A	BR2E9E499AA	**CONNECTOR, VAC CONTRL, T/C**
CB5Z6K682F	CB5E6K682BF	**TURBO CHARGER**
CB5Z8592A	CB5E8592AB	**CONNECTION - WATER OUT, T/C**
CB5Z8K153B	CB5E8B535AC	**TUBE - WATER OUTLET**
CB5Z9424D	CB5E9424AF	**MANIFOLD ASY - INTAKE**
CB5Z9S468C	CB5E9S468AF	**HOSE, EMS (VAC HARNESS)**
CJ5Z9J323B	CJ5E9J323BC	**TUBE ASY FE PMP TO FE MAN**
CM5Z12029A	CM5E12A366CA	**COIL ASY - IGNITION**
CP9Z9E926A	CM5E9F991AD	**THROTTLE BODY AND MOTOR ASY**
D4ZZ7600A	D4ZA7120AB	**SLEEVE, PILOT BEARING**
DU5Z12A581U	DU5T12C508UE	**WIRE ASY, ENGINE MAIN**
YS4Z6766A	YS4G6766DA	**CAP ASY - OIL FILLER**
5M6Z8509AE	5M6Q8509AE	**PULLEY - WATER PUMP**
AG9Z6312B	AG9E6D334AA	**PULLEY - CRANKSHAFT**

Table A5.7 Special Parts List

Part number[A]	Description	
OHTVH-002-1	PAN, OIL MODIFIED, ASSY. (INCLUDING DIPSTICK AND PICK UP TUBE)	
VH002-2	TUBE, PICK UP	
OHTVH-005-1	HOUSING, FLYWHEEL	
OHTVH-006-1	FLYWHEEL, MODIFIED, 2.0L	
VH006-8	CLUTCH, ASSY. W/ PRESSURE PLATE	
VH006-8-1	CLUTCH	
VH006-8-2	PLATE, PRESSURE	
OHTVH-007-1	HARNESS, DYNO, 2.0L	
OHTVH-008-1	INLET, COOLANT	
VH008-1	CLIP, RETAINER, SENSOR, COOLANT INLET	
VH008-2	SEAL, COOLANT INLET	
OHTVH-009-1	OUTLET, COOLANT	
VH009-6	SEAL, COOLANT OUTLET	
OHTVH-011-1	SHIM, CLUTCH PRESSURE PLATE	
M-6026-23BSBP	Ford Racing Balance Shaft Delete Kit	
MSI-41/55S-22	MSI Driveshaft	

[A] OHT denotes OH Technology[19], MSI denotes Machine Service Inc.[44]

TABLE A5.8 Special Service Tools

Description	Ford P/N
Camshaft alignment tool	303-1565
Crankshaft TDC timing peg	303-507
Crankshaft sensor alignment tool	303-1521

Table A5.9 Chain Measurement Rig Parts

Description	Quantity	Manufacturer	Mfg P/N	Suggested Supplier[A]	Supplier P/N
PUSH PIN FOR END CAP	6	80/20	3274		
PC DATA INPUT DEVICE	1	Mitutoyo	264-012-10	Cleveland Specialty Inspection Services, Inc.	264-012-10
SPC CABLE	1	Mitutoyo	905338	Cleveland Specialty Inspection Services, Inc.	905338
MITUTOYO ELECTRONIC DIAL INDICATOR	1	Mitutoyo	543-792	MSC	60777216
CLAMP	1	Destaco	609-B	MSC	90968736

[44] Machine Services Inc., 1000 Ashwaubenon St6.,m Greerm Bay, WI 54304.

BEARING, FOR GEARS	2	Nice	3016DCTNTG18	Fastenal	4194269
PILLOW BLOCK BEARING, SPB12	4	Thompson	SPB12	Grainger	2HXW8
SHAFTS 24 IN	2	Thompson	QS 3/4 L 24	Grainger	5JW62
T-NUT, SLIDE-IN, OFFSET, 80/20 3278	69	80/20	3278		
BRACKET, 4-HOLE, CORNER, 80/20, 4301	14	80/20	4301		
BRACKET, 2-HOLE, CORNER, 80/20, 4302	4	80/20	4302		
END CAP, 1515 LITE, 80/20, 2030	6	80/20`	2030		
CRANKSHAFT GEAR, MODIFIED	2	FORD	CJ5Z-6306-A	Marshall Ford	CJ5Z-6306-A
NEODYMIUM DISC MAGNET, 1/4" DIAMETER, 1/4" THICK, 2.5 LBS. MAXIMUM PULL	4			Mcmaster	58605K35
NEODYMIUM DISC MAGNET, 3/8" DIAMETER, 1/8" THICK, 3 LBS. MAXIMUM PULL	1			Mcmaster	5862K95
MAGNETIC SWITCH	2			Mcmaster	65985K14
ROUND BUMPER, RUBBER, 1-1/2" DIAMETER, 5/16" DIAMETER HOLE, WITH WASHER	4			Mcmaster	9540K756
PARKER MPE SERIES 60 MM FRAME 2 STACK SERVO MOTOR WITH 2500 LINE ENCODER	1	PARKER	MPE0602A4E-KC1N	Parker	MPE0602 A4E-KC1N
PARKER ARIES 750 WATT SERVO DRIVE WITH CONTROLLER (REQUIRES PROGRAMMING)	1	PARKER	AR-08CE	Parker	AR-08CE
PARKER MPE TO ARIES 25 FOOT POWER CABLE	1	PARKER	71-030630-25	Parker	71-030630-25
PARKER MPE TO ARIES 25 FOOT FEEDBACK CABLE	1	PARKER	71-030631-25	Parker	71-030631-25
3.5MM AUDIO CABLE	1				

[A] Supplier contact information is provided in X1.37.

A6. SAFETY PRECAUTIONS

A6.1 The operating of engine tests can expose personnel and facilities to safety hazards. Personnel trained and experienced with engine testing should perform the design, installation, and operation of test stands.

A6.2 Install guards (shields) around all external moving, hot, or cold components. Design the guard to contain the energy level of a rotating component should the component break free. Fuel, oil, coolant, and electrical wiring should be properly routed, guarded, grounded and kept in good order.

A6.3 Keep the test stand free of oil and fuel spills and tripping hazards. Do not permit containers of oil or fuel, or both, to accumulate in the testing area. Firefighting equipment should be immediately accessible. Observe normal precautions whenever using flammable solvents for cleaning purposes.

A6.4 Safety masks, glasses, or hearing protection, or a combination thereof, should be worn by personnel working on the test stand. No loose or flowing clothing, including long hair or other accessory to dress, should be worn near rotating equipment. Caution personnel against working alongside the engine and driveline while the engine is running.

A6.5 Interlocks should automatically shutdown the engine when an anomaly in any of the following occur: engine or dynamometer coolant temperature, engine oil pressure, dynamometer field current, engine speed, exhaust temperature, excessive vibration, or when the fire protection system is activated. The interlock should include a method to cut off the fuel supply to the engine at the injector pump (including the return line). A remote fuel cut off station (external to the test stand) is recommended.

A6.6 Employ other safety precautions as required.

A7. ENGINE REBUILD TEMPLATES

A7.1 Figs. A7.1 and A7.2 show the piston ring setter and cylinder bore ladder, respectively.

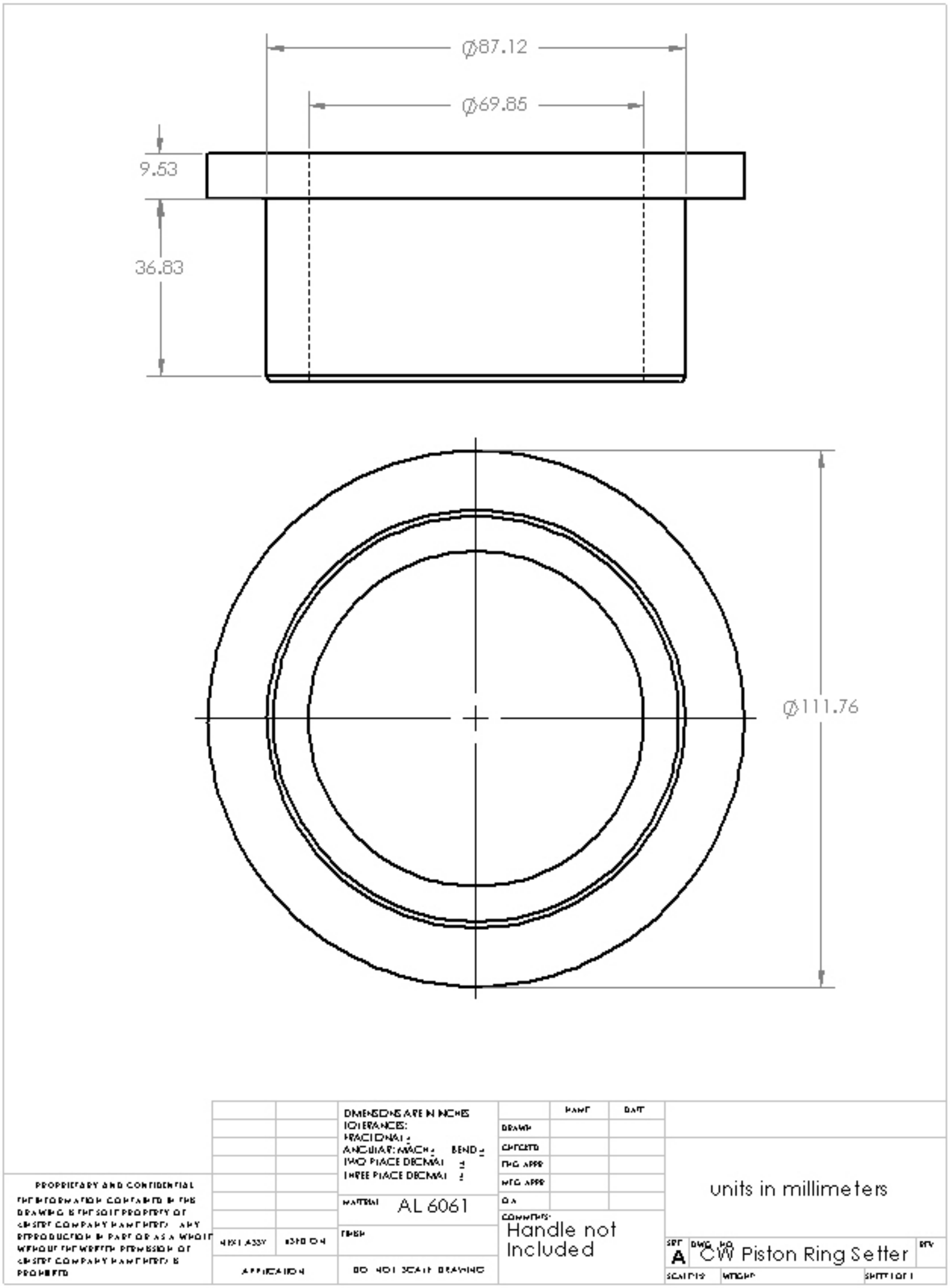


Fig. A7.1 Piston Ring Setter

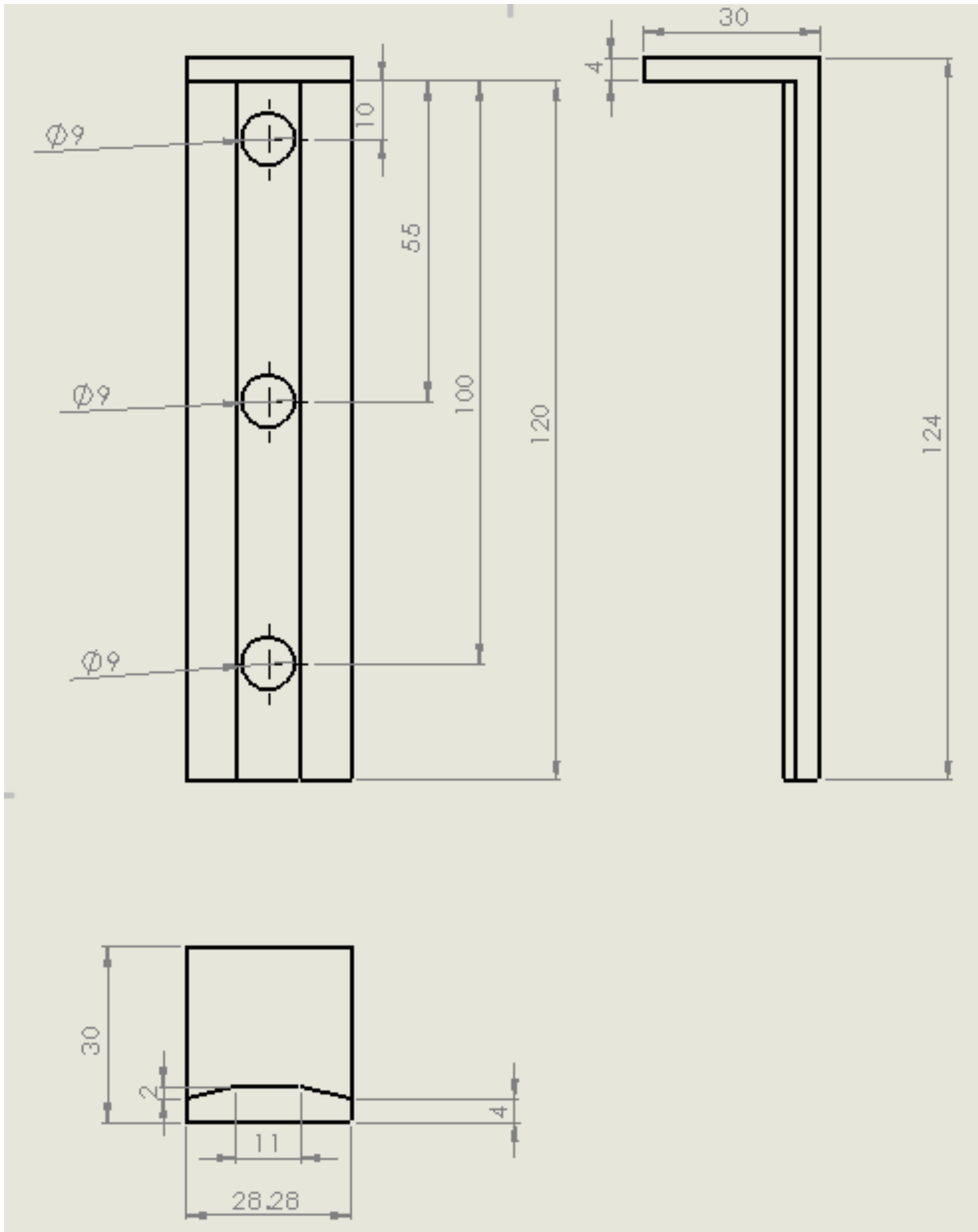


Fig. A7.2 Cylinder Bore Ladder (dimensions are in mm)

A8. ENGINE BUILD RECORDS

A8.1 Record the cylinder head measurements on the datasheet shown in Table A8.1.

CW Head Build Data Sheet

Head #: ____________ **Engine #:** ____________

Head Run #: ____________ **Tests#:** ____________

Date: ____________

	Valve Guide Diameter (mm)	Valve Stem Diameter (mm)	Clearance (mm)
1A Intake			
1B Intake			
2A Intake			
2B Intake			
3A Intake			
3B Intake			
4A Intake			
4B Intake			

	Valve Guide Diameter (mm)	Valve Stem Diameter (mm)	Clearance (mm)
1A Exhaust			
1B Exhaust			
2A Exhaust			
2B Exhaust			
3A Exhaust			
3B Exhaust			
4A Exhaust			
4B Exhaust			

	Spring Free Length (mm)	Spring Tension @28.7mm
1A Intake		
1B Intake		
2A Intake		
2B Intake		
3A Intake		
3B Intake		
4A Intake		
4B Intake		

	Spring Free Length (mm)	Spring Tension @28.7mm
1A Exhaust		
1B Exhaust		
2A Exhaust		
2B Exhaust		
3A Exhaust		
3B Exhaust		
4A Exhaust		
4B Exhaust		

Intake Valve Lash Measurement (mm)	
1F	
1R	
2F	
2R	
3F	
3R	
4F	
4R	

Exhaust Valve Lash Measurement (mm)	
1F	
1R	
2F	
2R	
3F	
3R	
4F	
4R	

Head Flatness: ____________ **Mechanic Initials:** ____________

Table A8.1: Cylinder Head Build Record

A8.2 Record the cylinder bore measurement on the datasheet shown in Table A8.2.

CW Cylinder Bore Measurement Record

Block #: ____________ **Test #** ____________

Block Run #: ____________ **Date:** ____________

Cylinder Bore Measurements

Finish Target (RA):
Bore Gauge Set: XXX mm

Out of Round (limit): 0.0XXmm
Taper (limit): 0.0XX mm

Cylinder Number	Location	Longitudinal Diameter (mm)	Transverse Diameter (mm)	Surface Finish (µmm)
	Top			
1	Middle			
	Bottom			
	Top			
2	Middle			
	Bottom			
	Top			
3	Middle			
	Bottom			
	Top			
4	Middle			
	Bottom			

Cylinder Number	Top Ring Gap (mm)	Second Ring Gap (mm)
1		
2		
3		
4		

REGAP/EOT

Cylinder Number (mm)	Top Ring Gap (mm)	Second Ring Gap (mm)
1		
2		
3		
4		

Approved ____________

Block Flatness: ____________ Mechanic Initials: ____________

Table A8.2 Cylinder Bore Measurement Record

A8.3 Record the bearing journal measurements on the datasheet shown in Table A8.3.

CW Engine Measurment Record

Engine Number: ______________________ **Date:** ______________________

Test Number: ______________________ **Technician:** ______________________

Main Bearing Journals (mm)

Journal Number	Horizontal Diameter	Vertical Diameter	Bearing Inside Diameter	Clearance
1				
2				
3				
4				
5				

Rod Bearing Journals (mm)

Journal Number	Horizontal Diameter	Vertical Diameter	Bearing Inside Diameter	Clearance
1				
2				
3				
4				

Crankshaft End Play (mm) ______________________

Table A8.3: Bearing Journals Measurement Record

A9. ENGINE PART PHOTOGRAPHS, SCHEMATICS, AND FIGURES

A9.1 See Figs. A9.1 to A9.30.

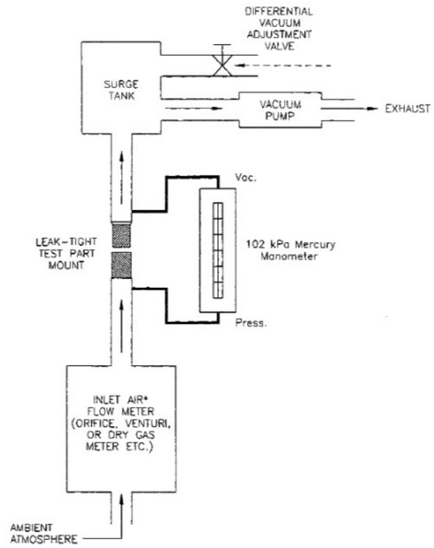


FIG. A9.1 PCV Valve Flow Test Apparatus

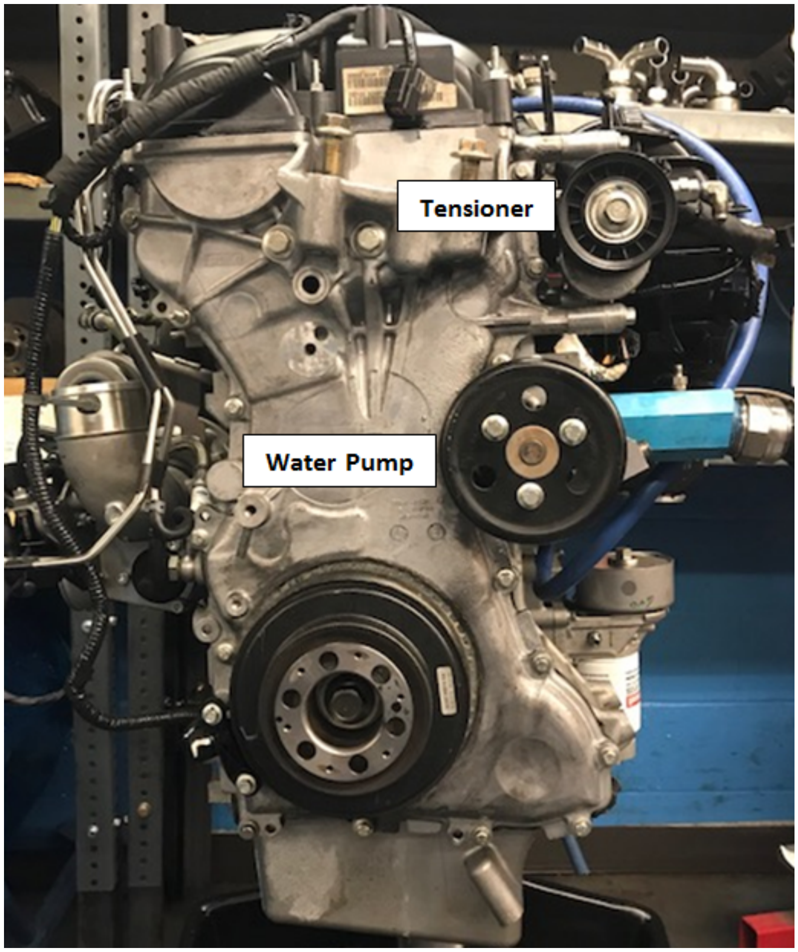
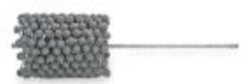


FIG. A9.2 Water-Pump Drive Arrangement

<u>Pneumatic Honing Drill (8.2.1)</u>
Brand: Westward
1/2 Reversible Air Drill
Model: 5ZL26G
Speed: 500 r/min

620 kPa (90 psig), max.

FIG. A9.3 Pneumatic Honing Drill



Flexible cylinder hone (see 8.2.1).

Flex, Model: GB31232

Bore Diam.: 88.0 mm (3.50 in.)

Abrasive material: Silicon Carbide Grit

FIG. A9.4 Cylinder Hone

FIG. A9.5 Cylinder Block Heater Hose Tube

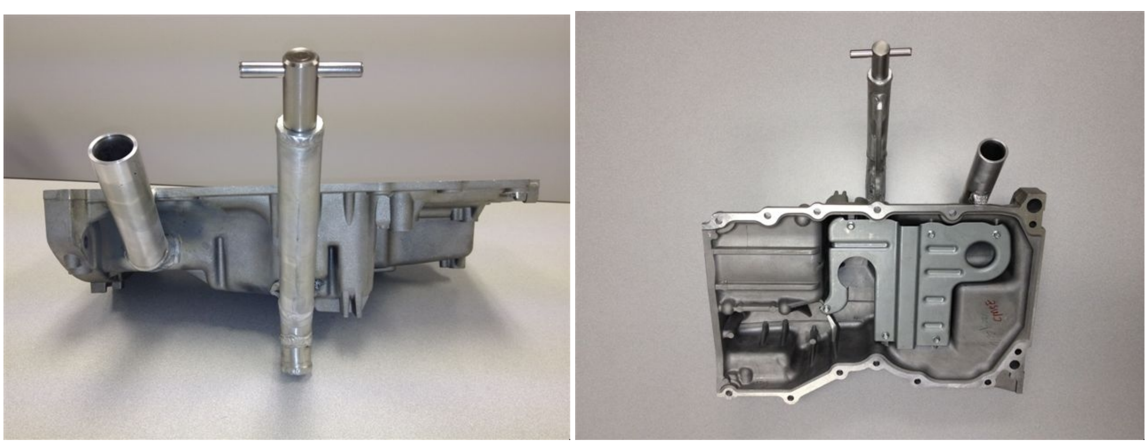


FIG. A9.6 Oil Pan

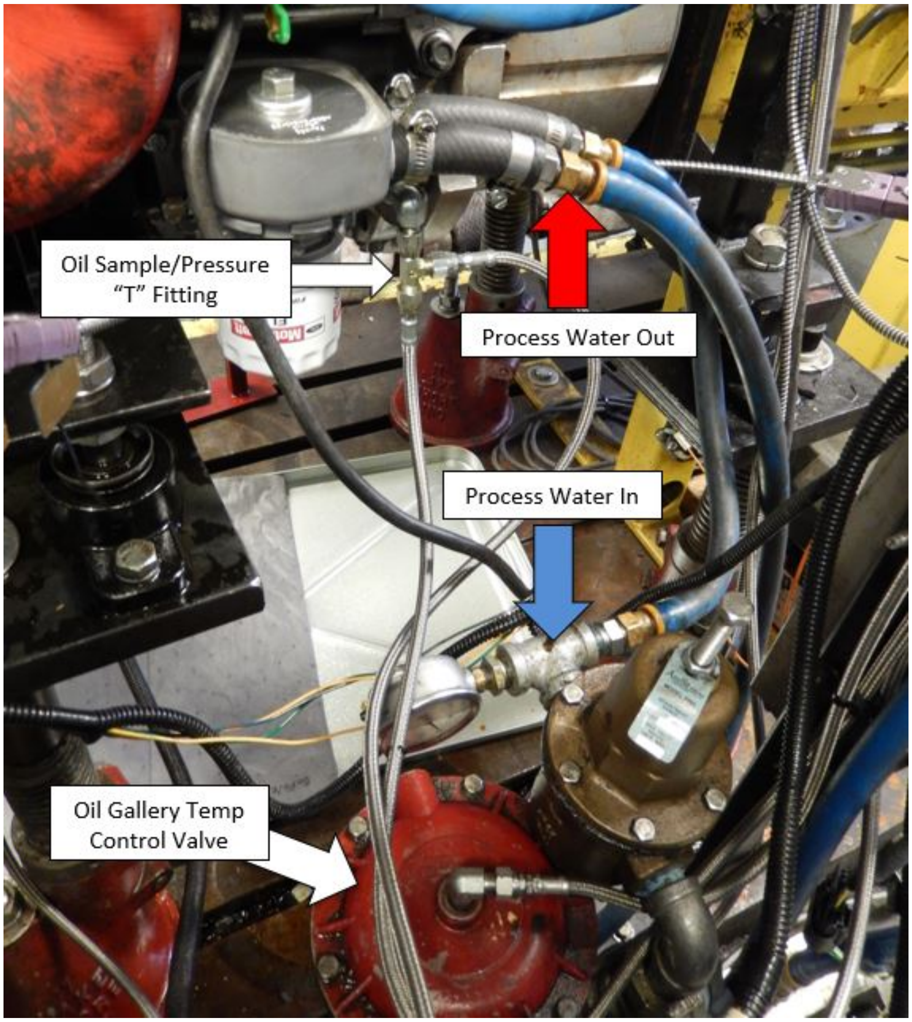


FIG. A9.7 Control System for Oil-Gallery Temperature

FIG. A9.8 Motorized Chain Measurement Apparatus

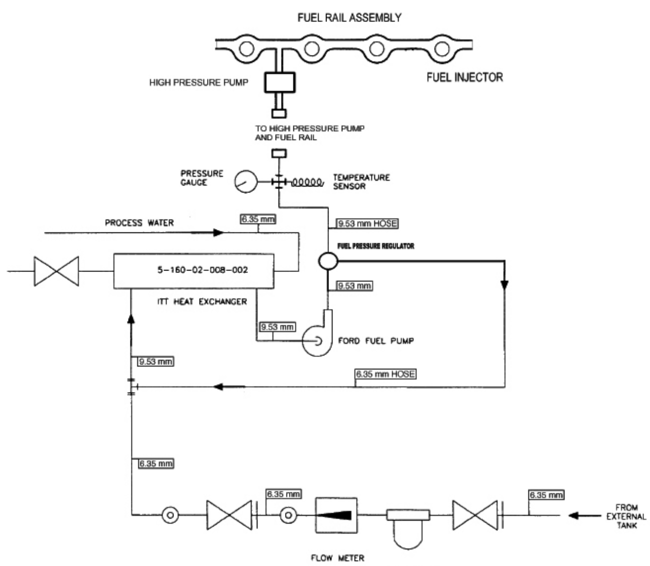


FIG. A9.9 Fuel System Schematic

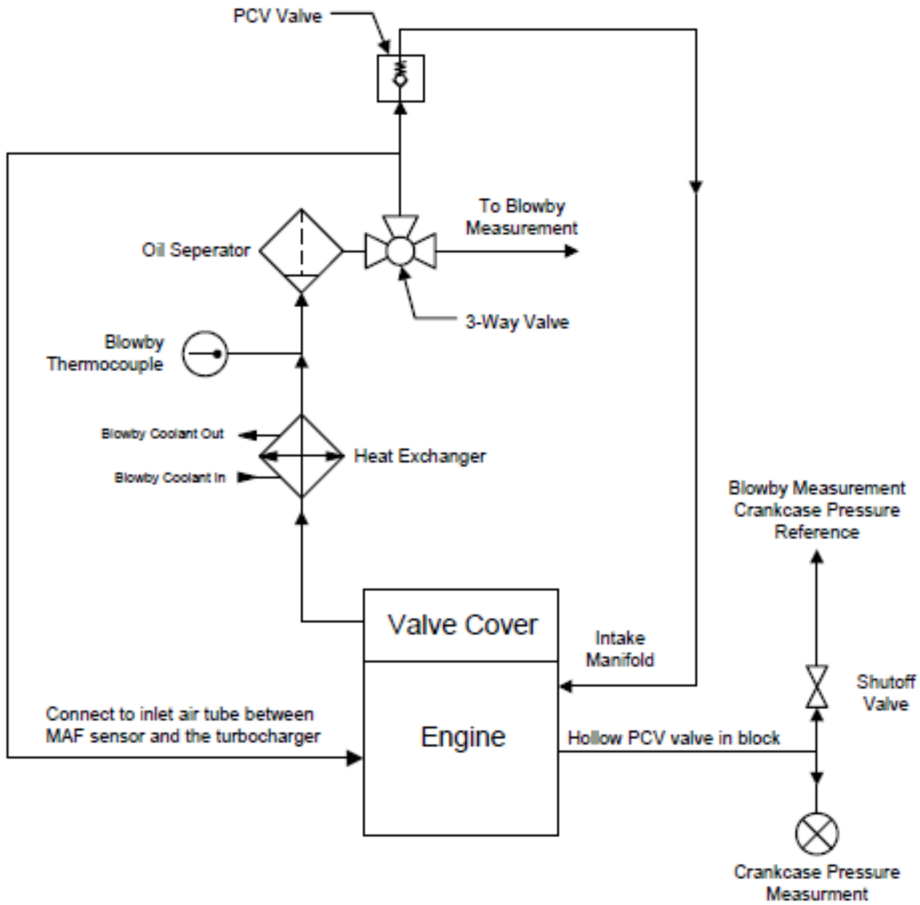


FIG. A9.10 Crankcase Ventilation System Schematic

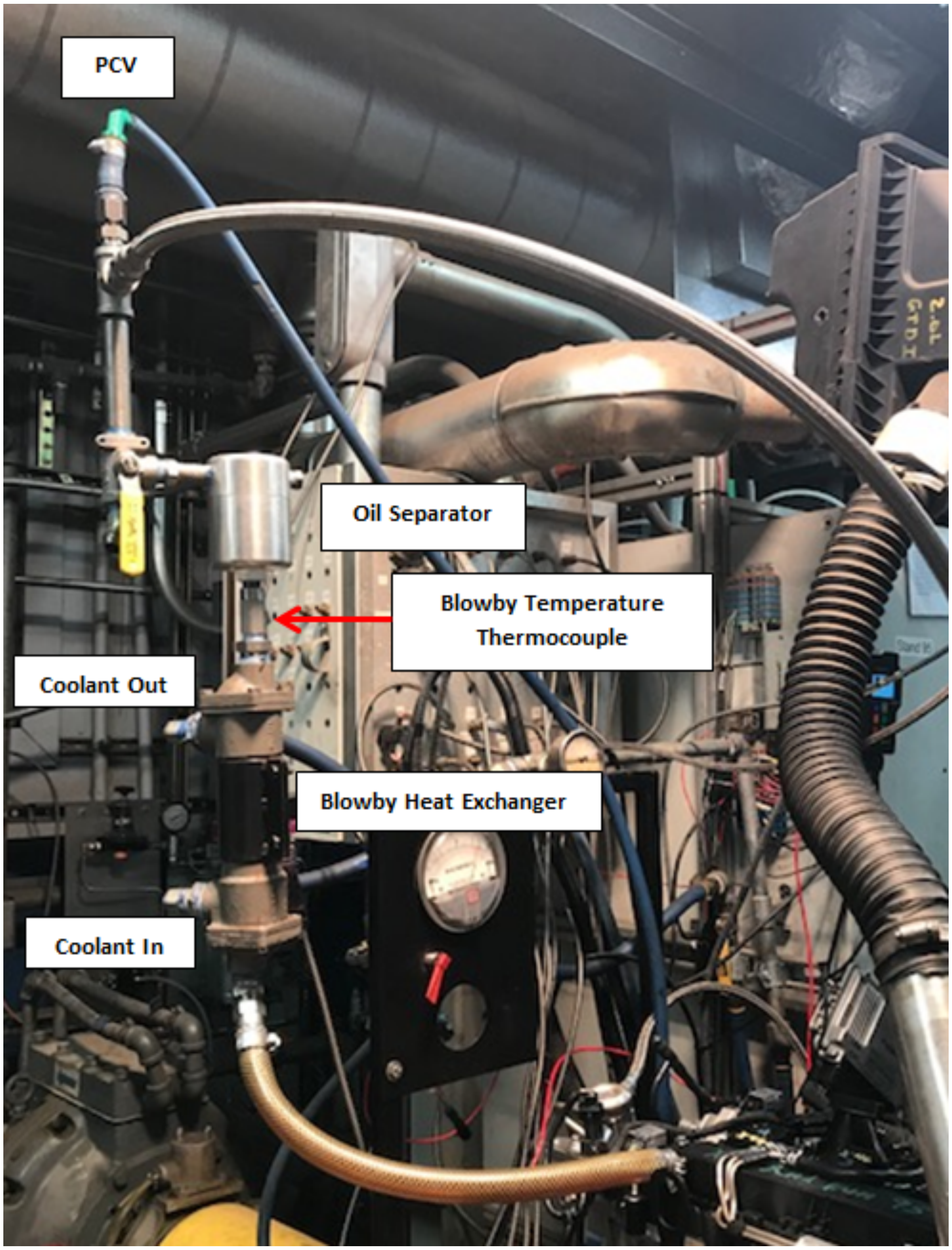


FIG. A9.11 Crankcase Ventilation System

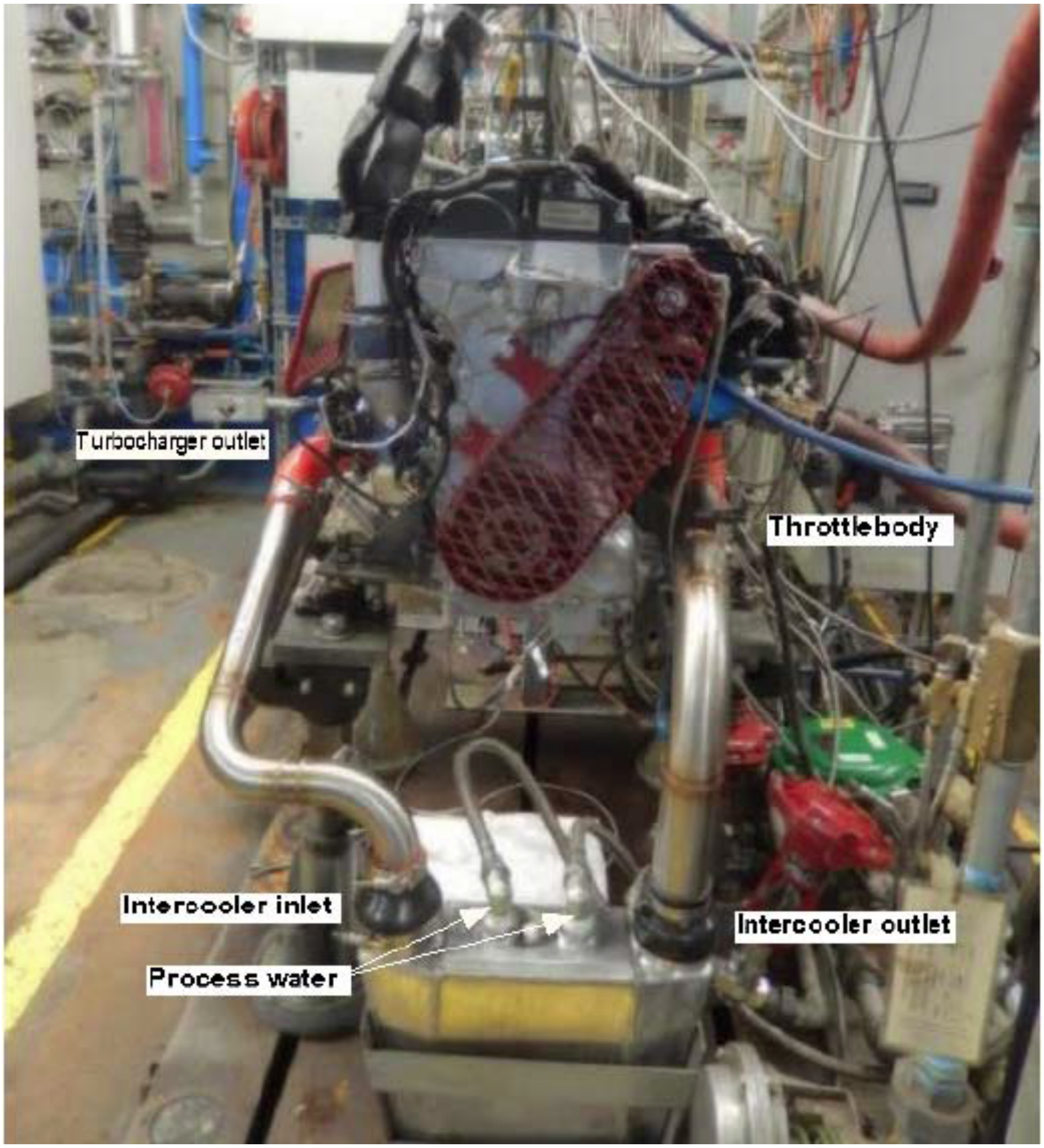


FIG. A9.12 Typical Intercooler Installation

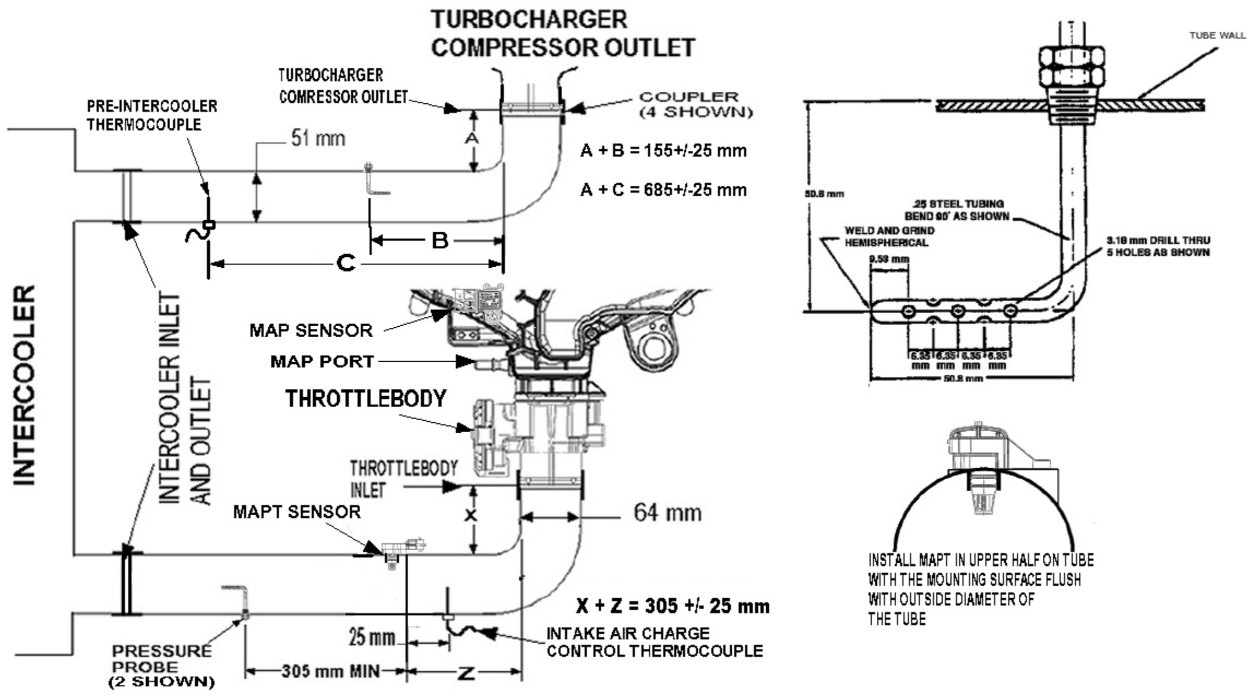
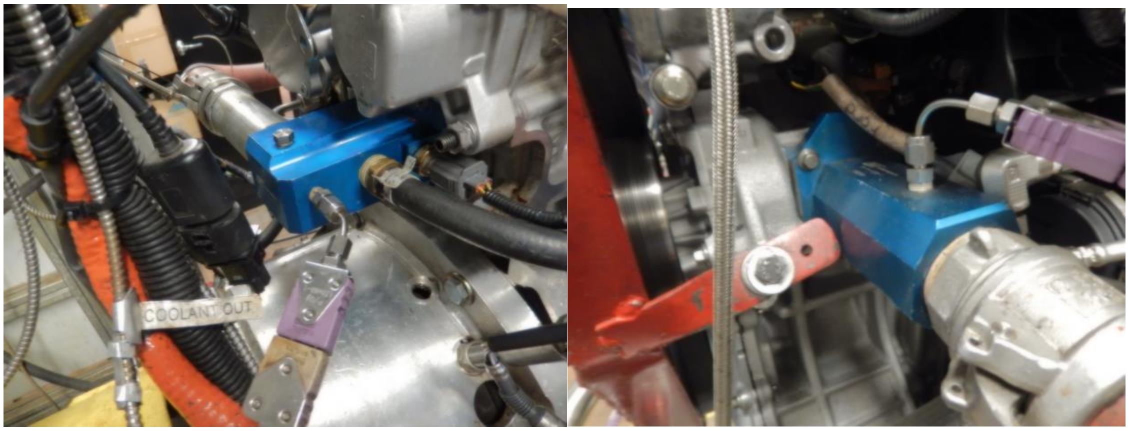
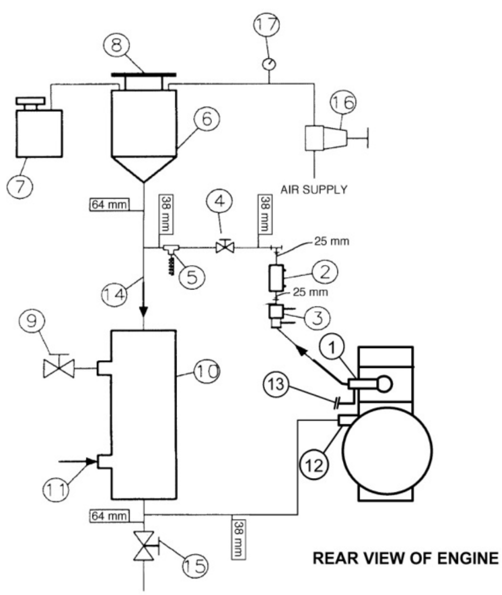


FIG. A9.13: Intercooler Tubing Measurements and Instrumentation



Coolant out Coolant in

FIG. A9.14 Coolant-in and -out connections and thermocouple locations



The following numbers identify components of the engine cooling system (observe temperature sensor locations in thermostat housing and at water pump inlet):

(1) Thermostat housing, coolant out with temperature sensor (OHTVH-009-1)
(2) Sight glass
(3) Flowmeter
(4) Flow control valve
(5) Optional temperature sensor
(6) Fabricated coolant reservoir
(7) Constant full expansion tank
(8) Pressure radiator cap (MOTORCRAFT RS40 P/N D2YY-8100-A)
(9) Process water control valve (regulated by temperature controller with three remote set points)
(10) Heat exchanger (ITT Standard P/N 5-030-06-048-001 TYP)
(11) Process water supply (shell side)
(12) Water pump inlet with temperature sensor (OHTVH-008-1)
(13) Turbocharger coolant return
(14) Engine coolant (tube side)
(15) Coolant system drain valve
(16) Coolant pressure regulator
(17) Coolant pressure gauge

FIG. A9.15 Typical Engine Cooling System Schematic

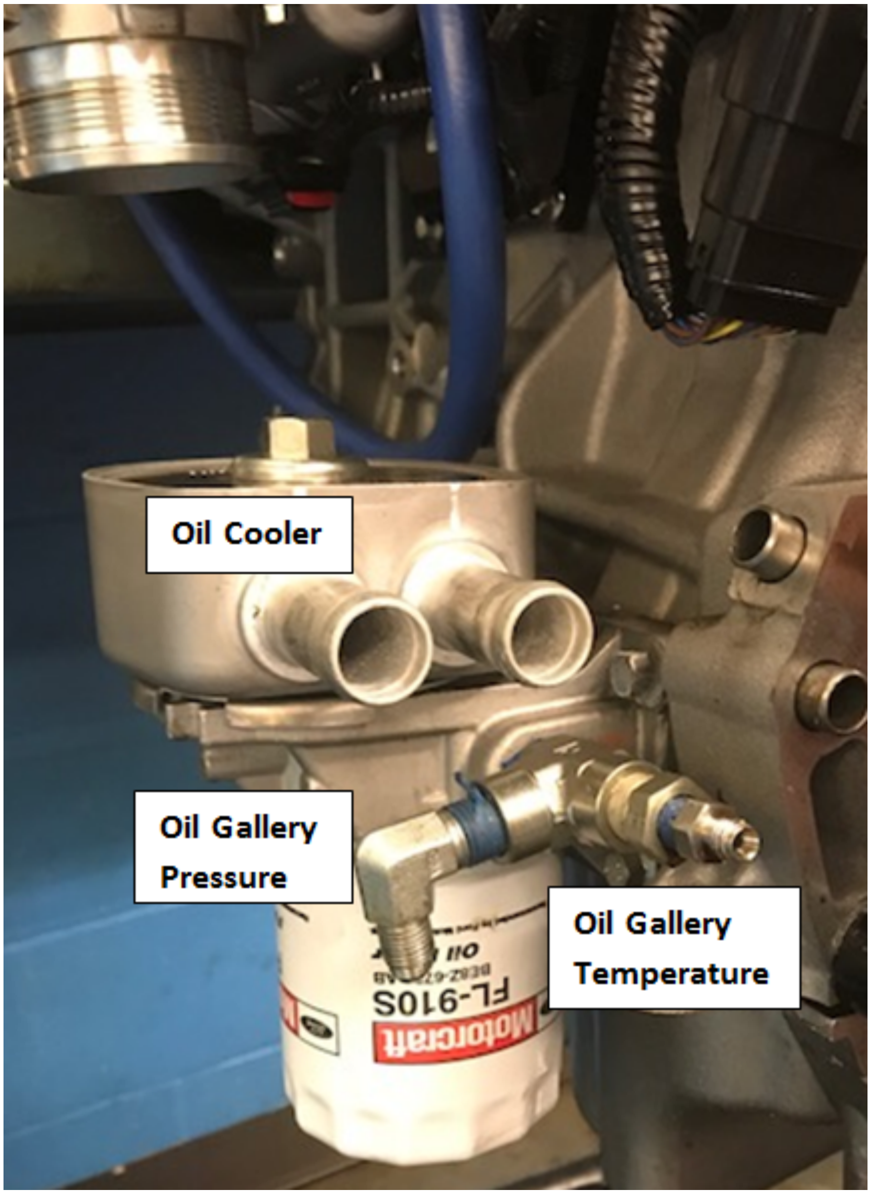


FIG. A9.16 Oil Cooler Showing Temperature And Pressure Measurement Locations

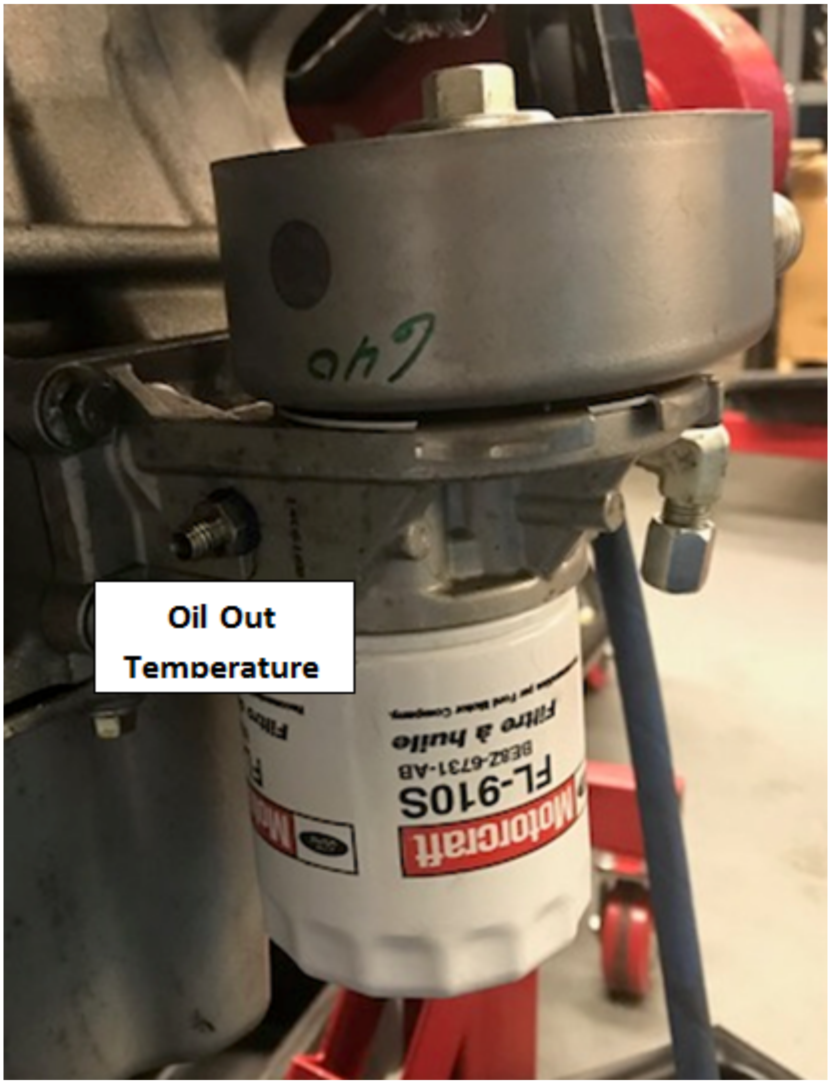
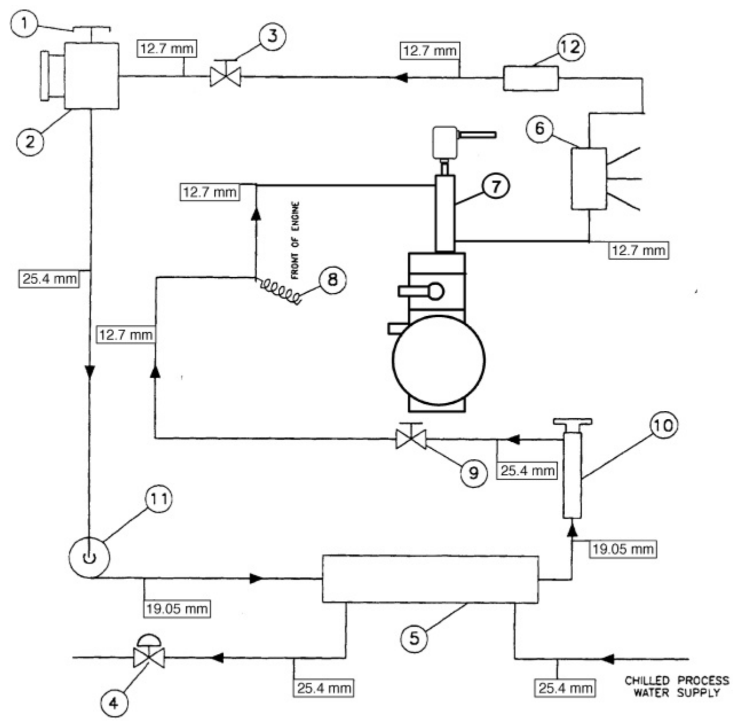


FIG. A9.17 Oil Cooler Showing the Measurement Location for the Oil-Out Temperature



Legend

(1)	Vented reservoir cap
(2)	Coolant reservoir (fabricated)
(3)	Pressure control valve (optional)
(4)	Chilled process water control valve
(5)	System heat exchanger
(6)	F and P Co. flowrator tube, FF-1-35-G-10/448D053U06
(7)	CCV Heat Exchanger
(8)	Inlet temperature sensor
(9)	Flow control valve
(10)	External heat source
(11)	Electric coolant pump DAYTON 6K581A
(12)	ABB Kent-Taylor flow element, 1330LZ08000-8375A

FIG. A9.18 Typical Characterized Control Valve (CCV) Heat Exchanger Heating and Cooling System

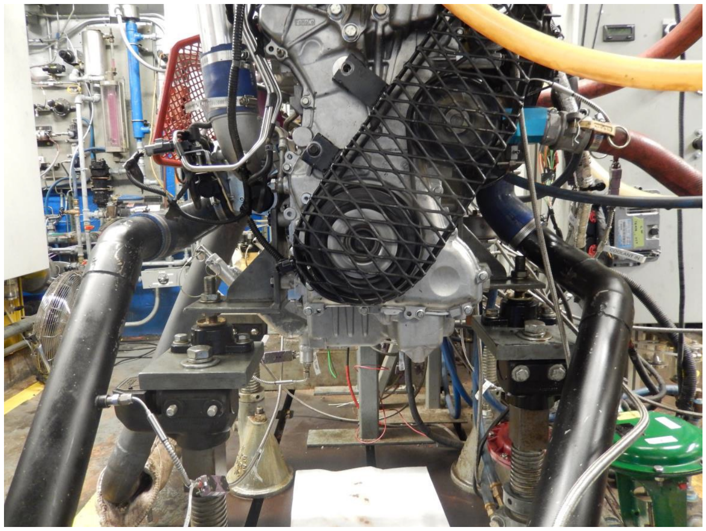


FIG. A9.19 Motor Mounts, Front

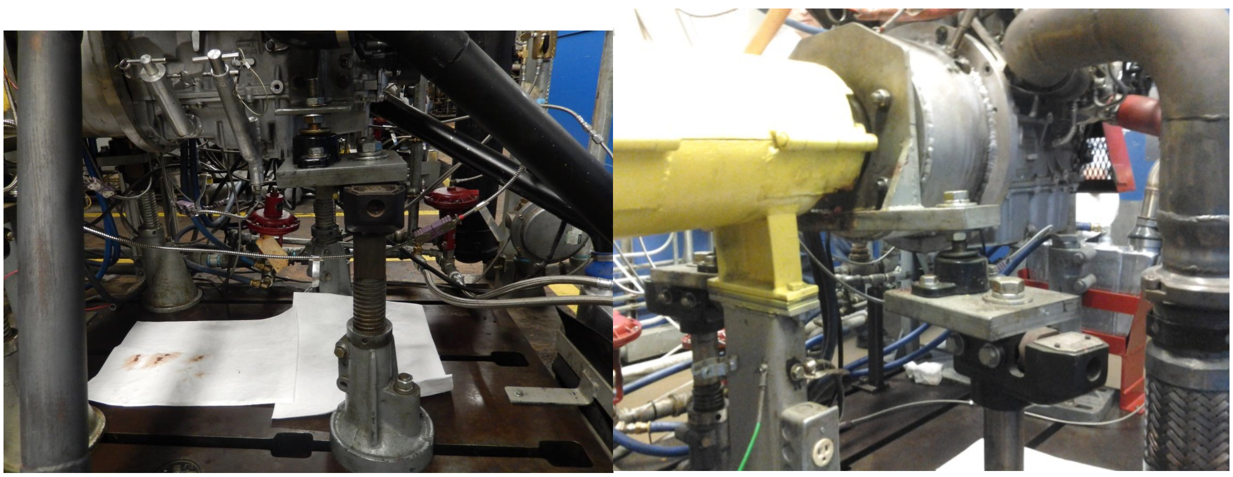


FIG. A9.20 Motor Mounts, Rear

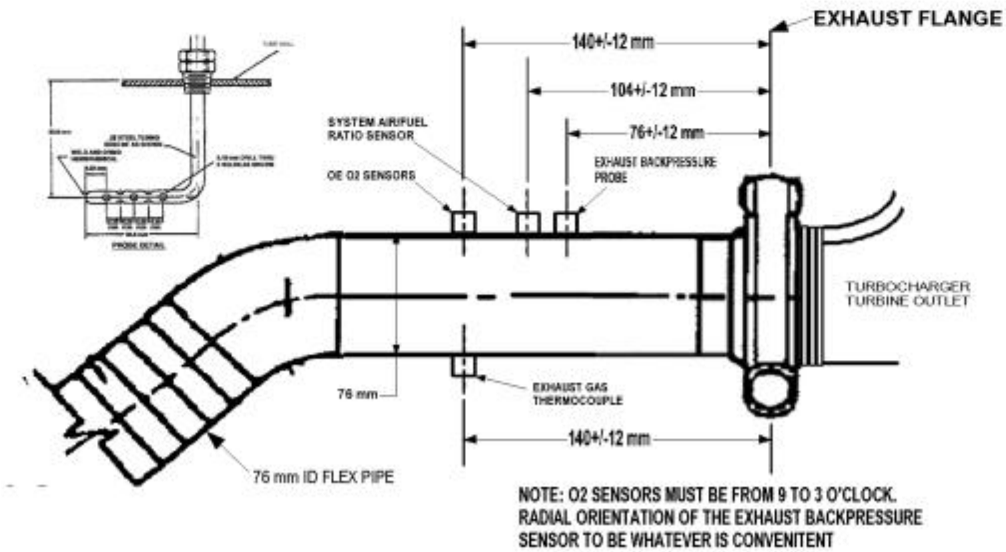


FIG. A9.21 Exhaust Measurements and Instrumentation

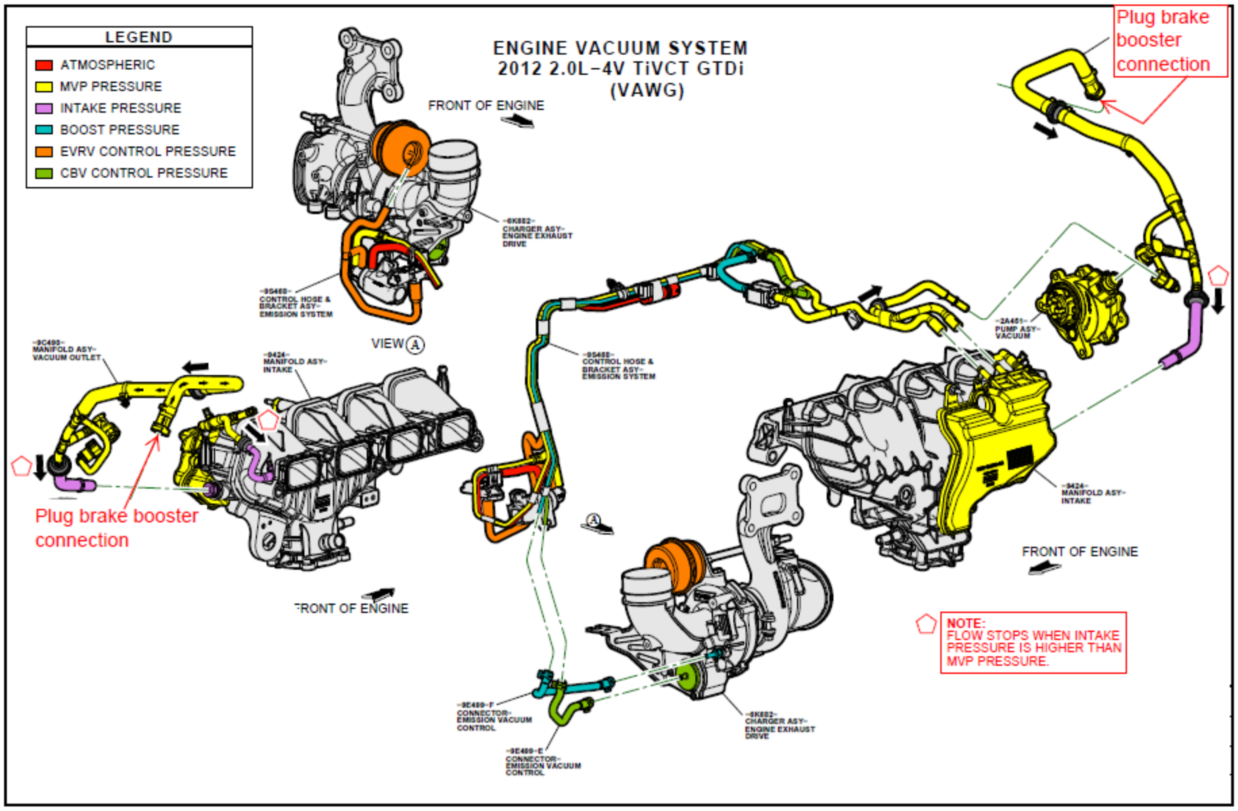


FIG. A9.22 Vacuum System

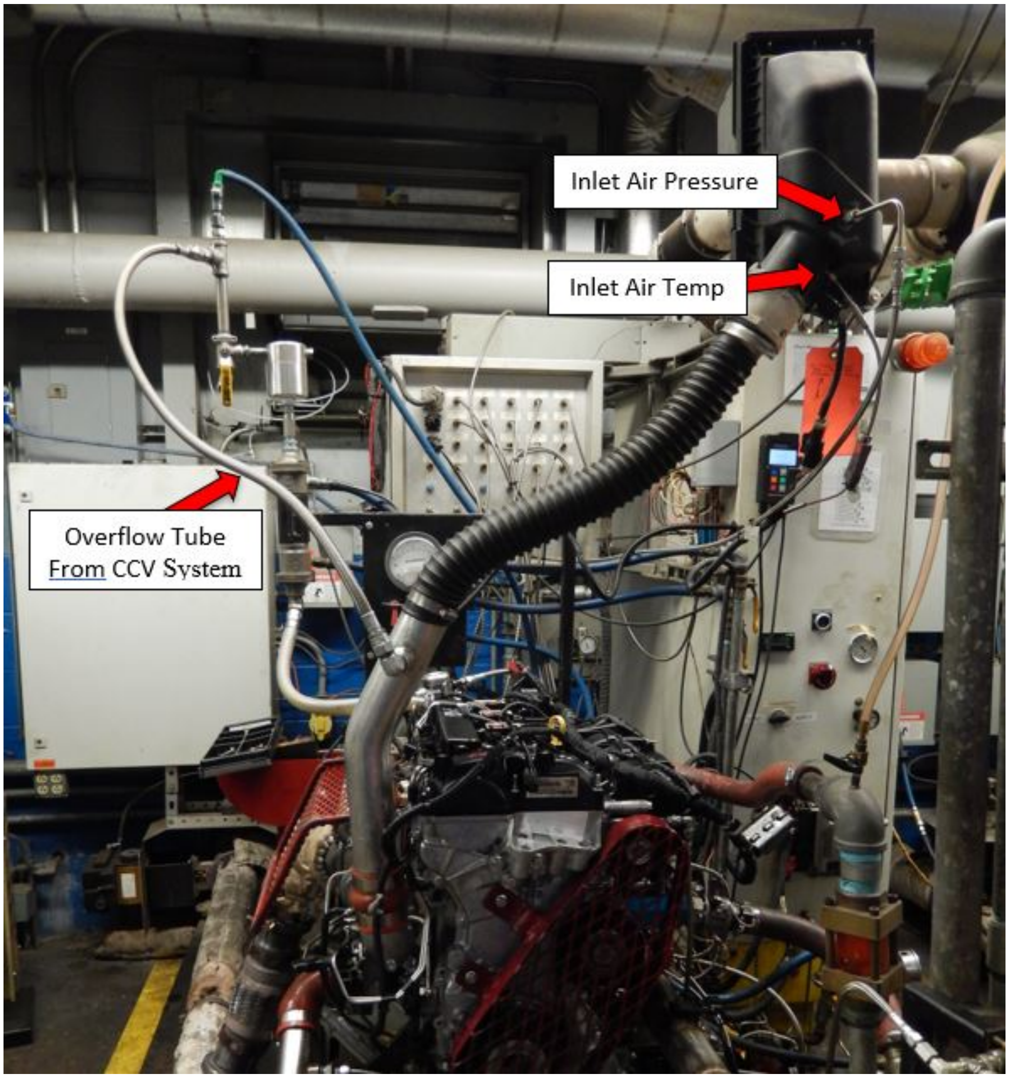


FIG. A9.23 Typical System for air intake

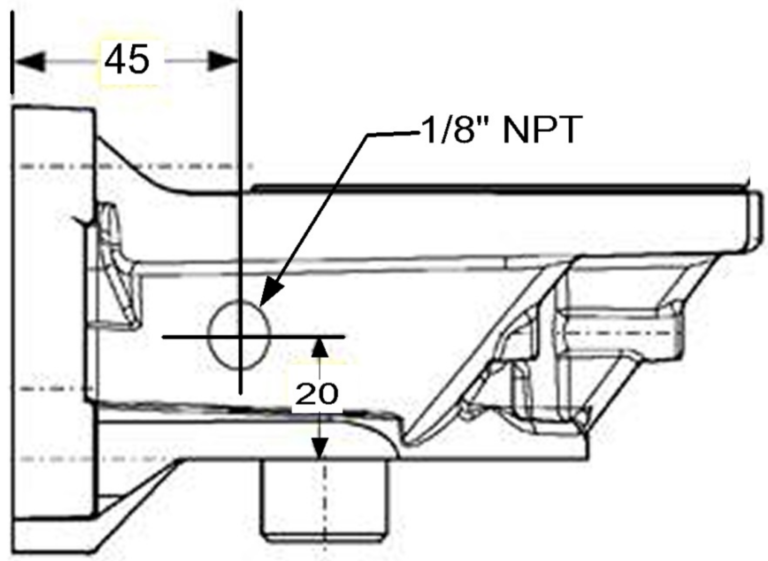
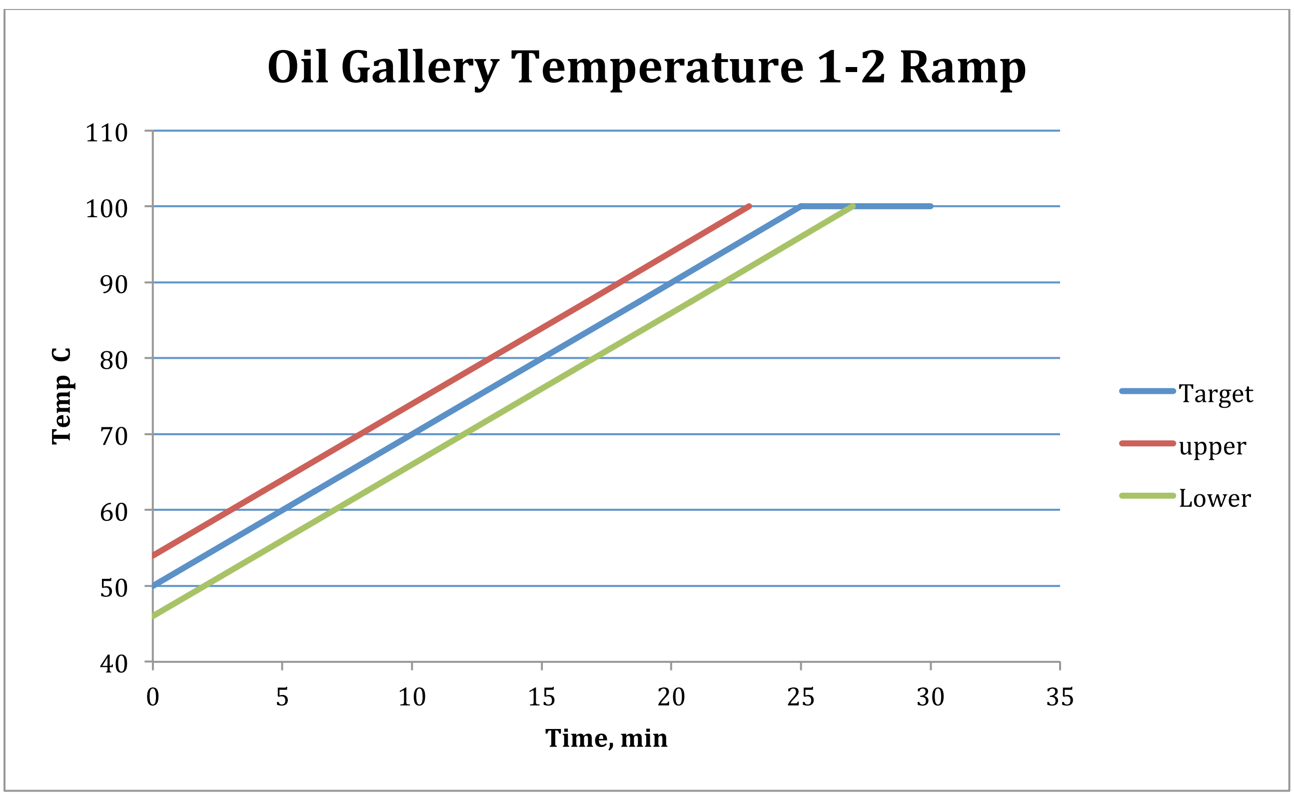


FIG. A9.24 Location of the Oil-Out Temperature Thermocouple in the Oil Filter Adapter (dimensions in mm)



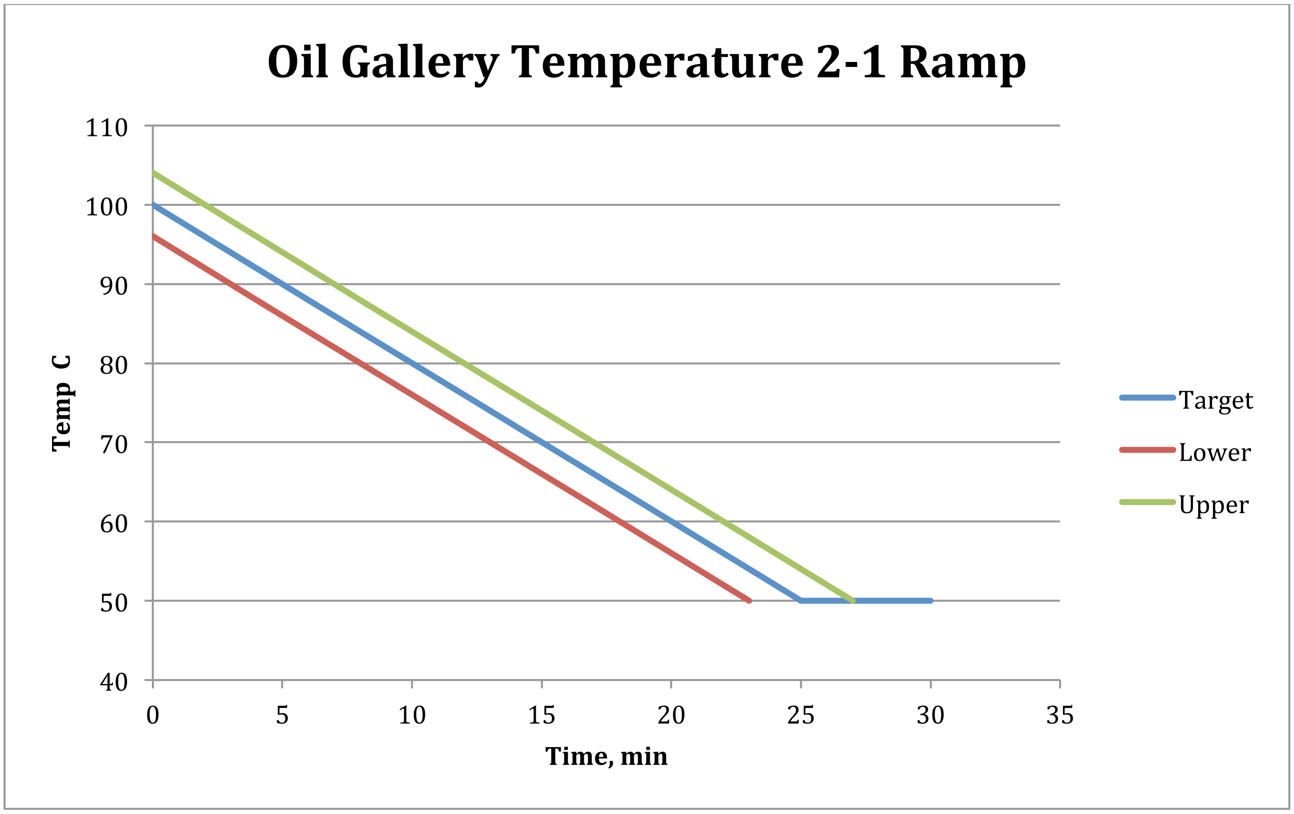
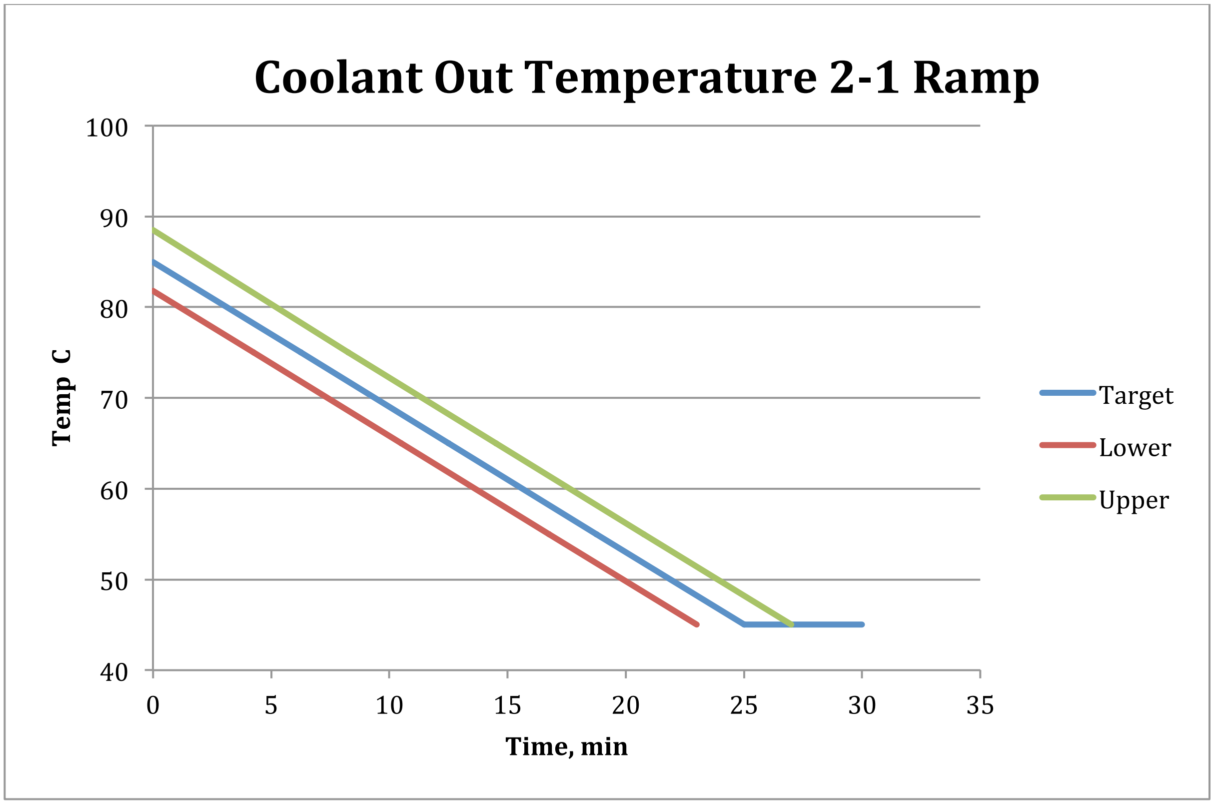


FIG. A9.25 Typical Oil Gallery Temperature Ramps



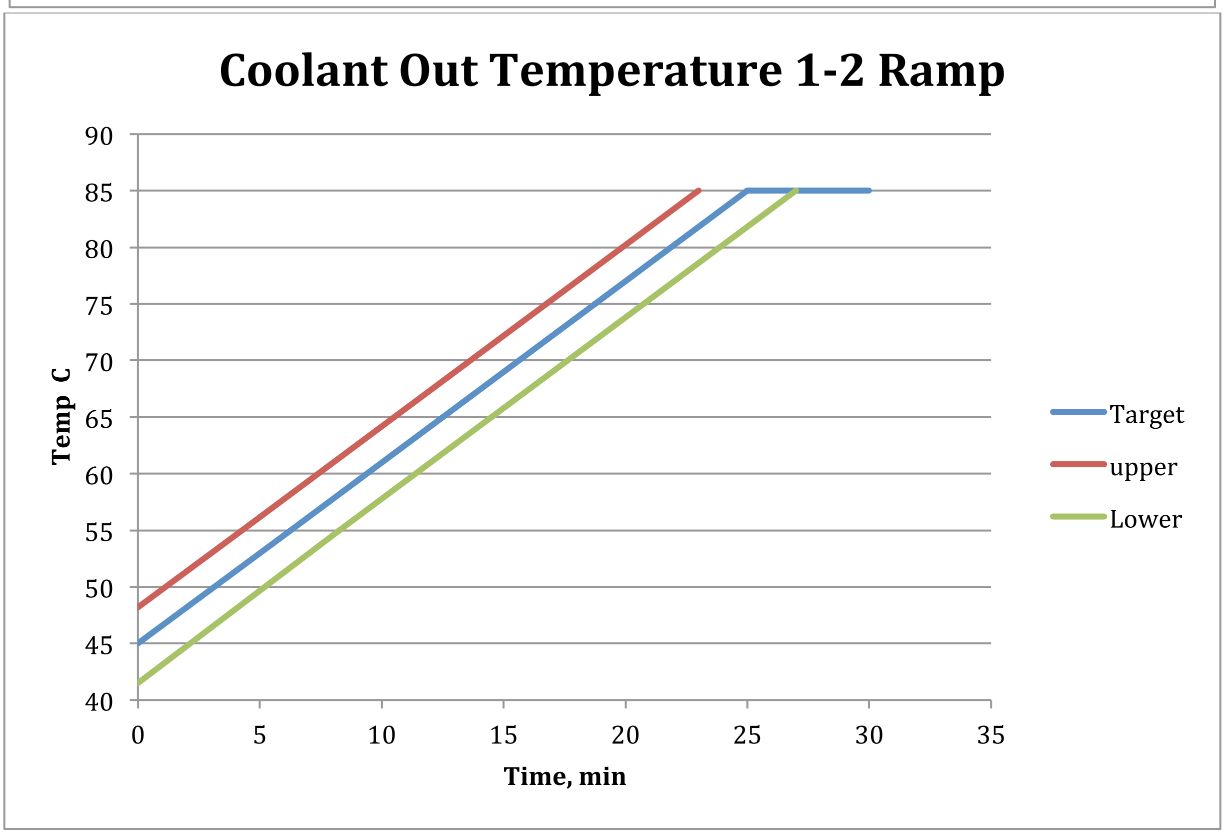


FIG. A9.26 Typical Coolant Out Temperature Ramps

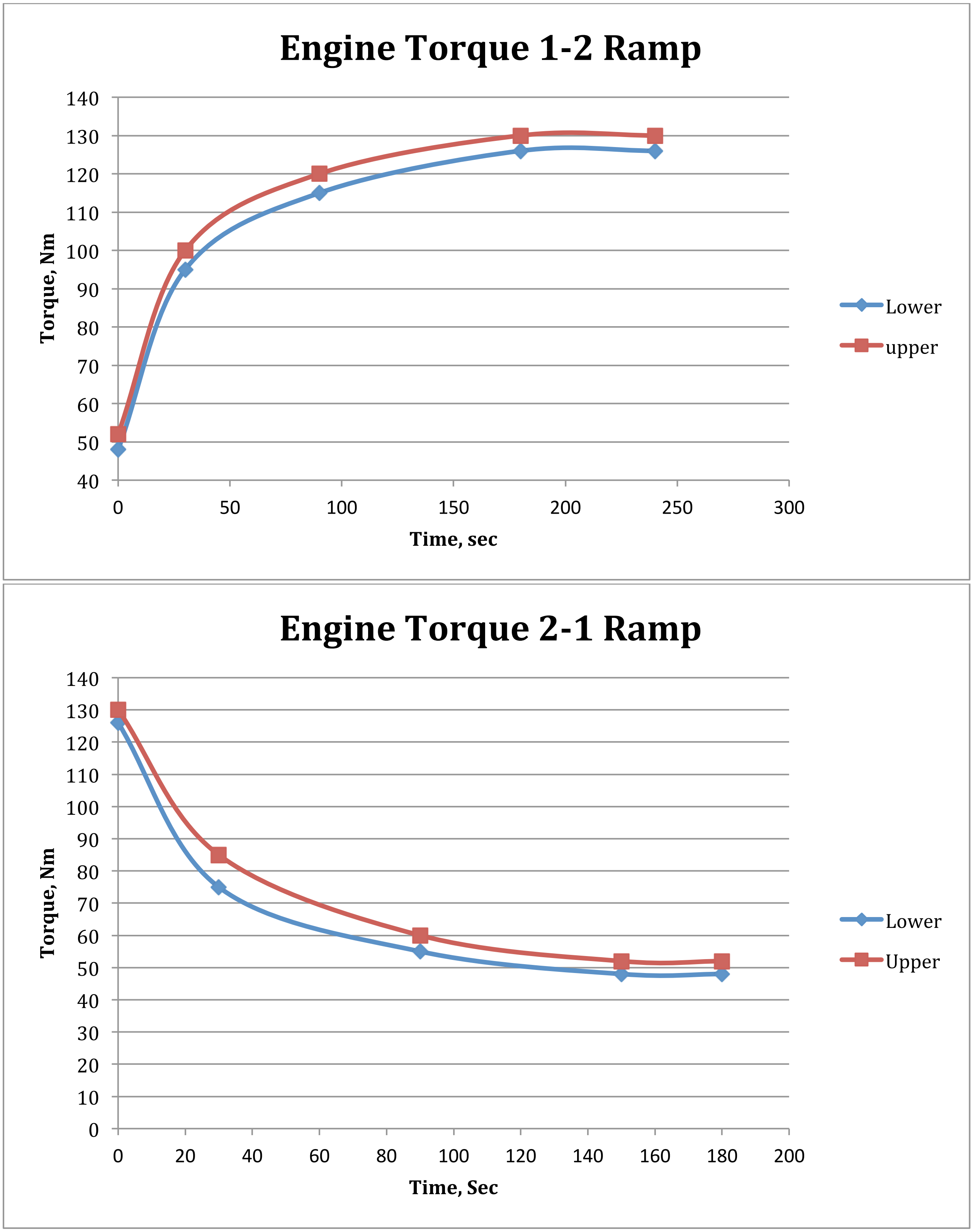
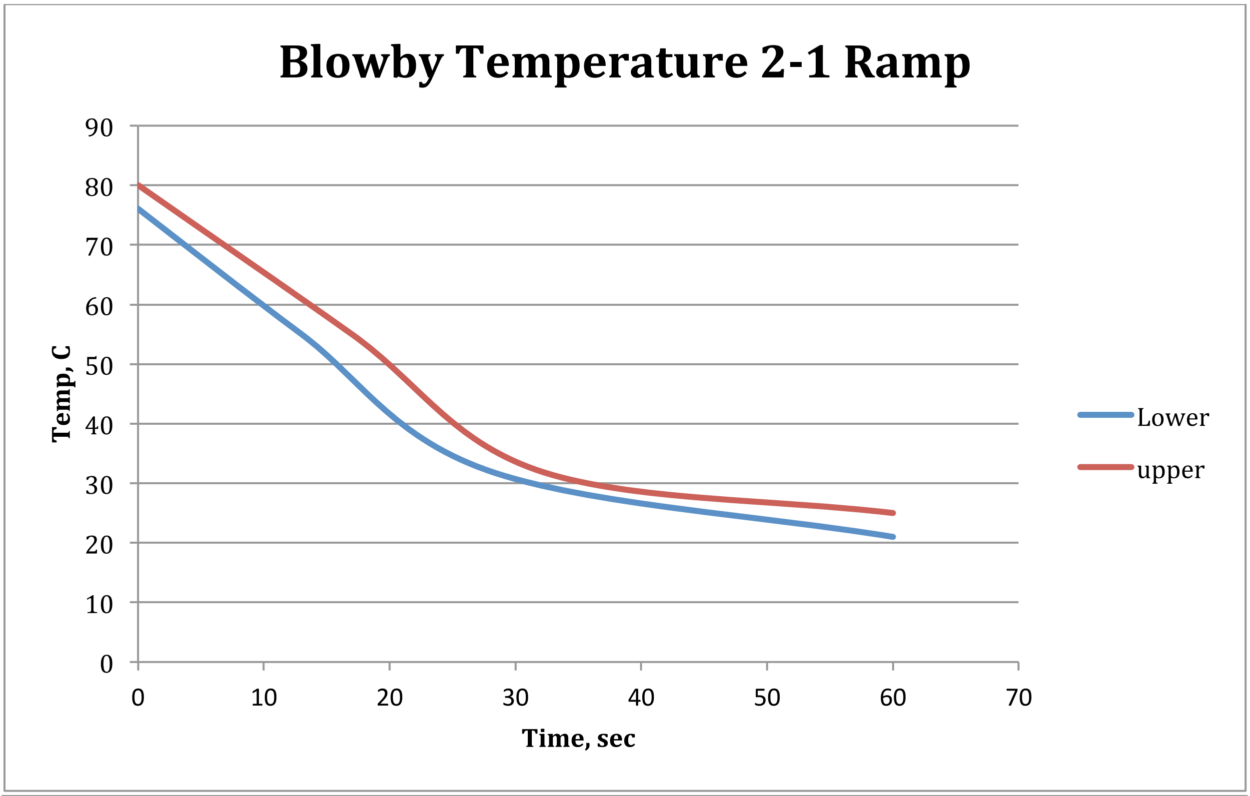


FIG. A9.27 Typical Engine Torque Ramps



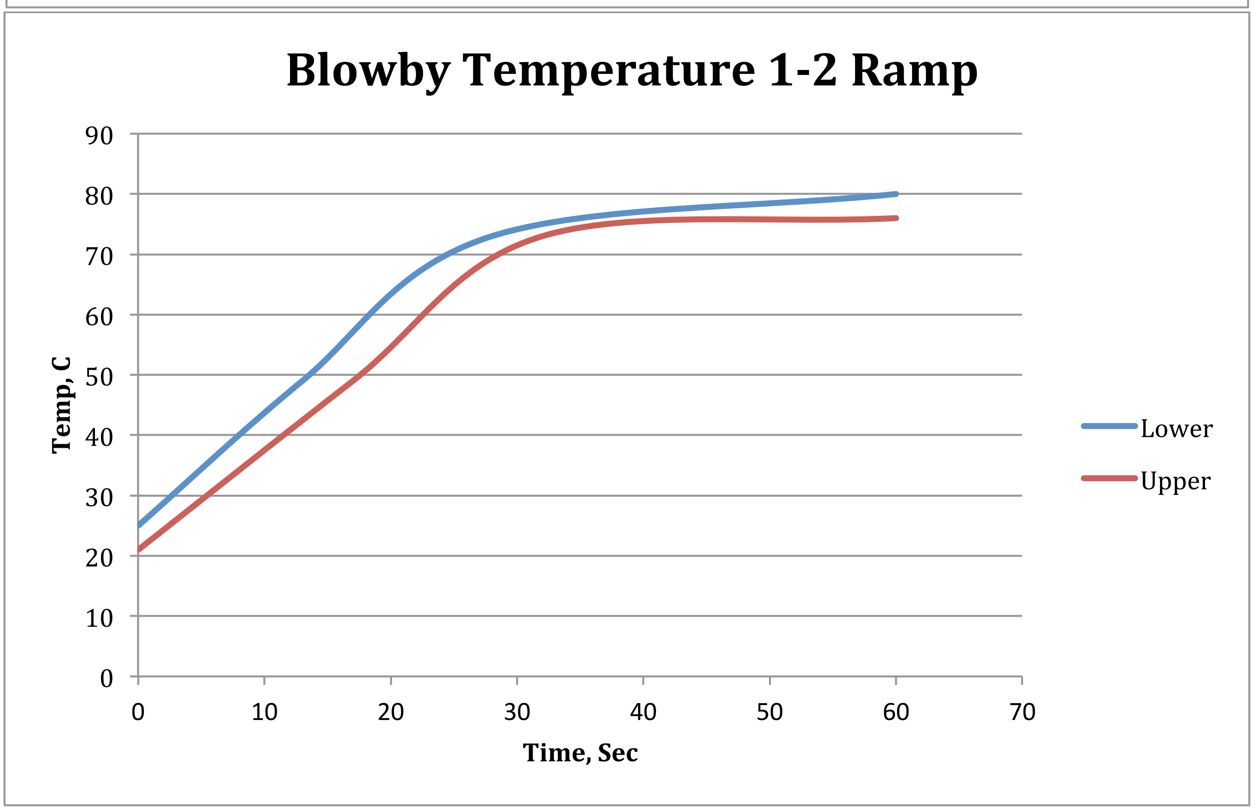


FIG. A9.28 Typical Blowby Temperature Ramps

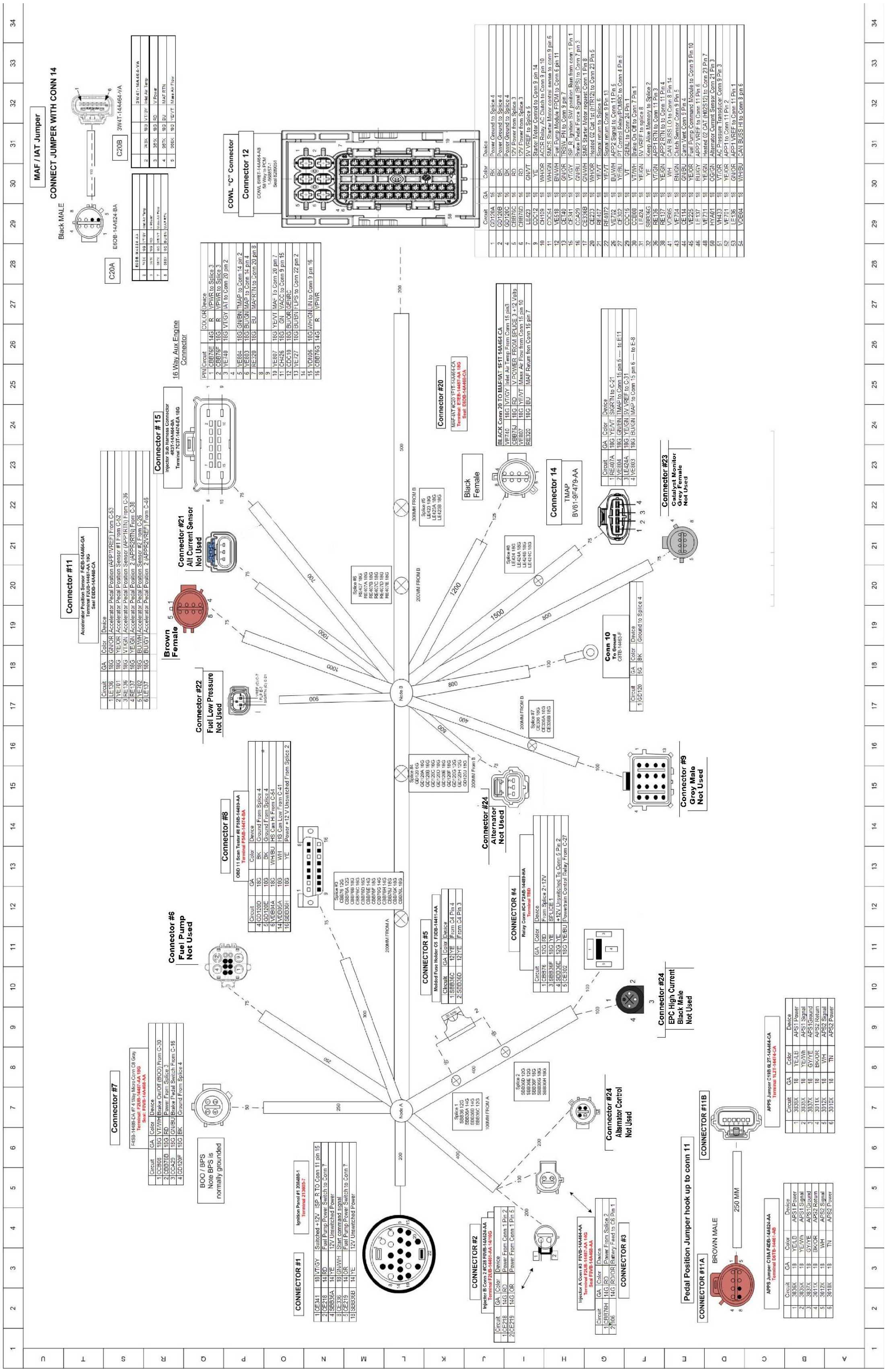
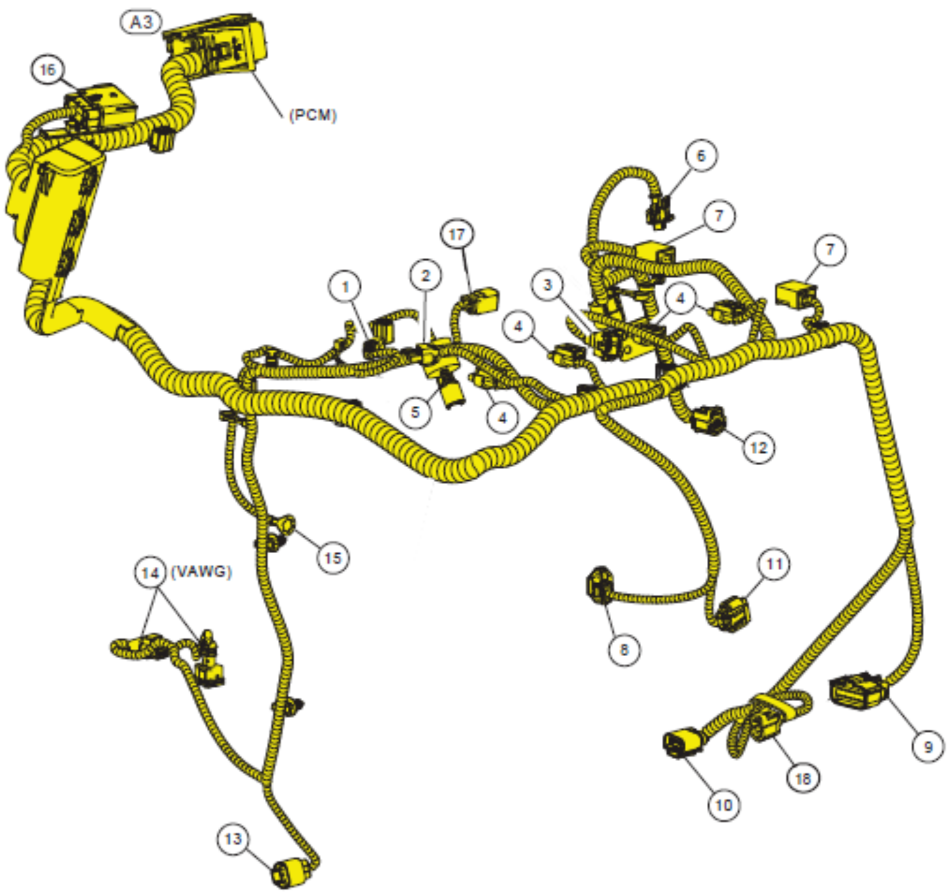


FIG. A9.29 Stand Wiring Harness

WIRING ASY ENGINE



1. TO CAMSHAFT VARIABLE TIMING HOUSING & VALVE ASY (EXHAUST)
2. TO CAMSHAFT VARIABLE TIMING HOUSING & VALVE ASY (INTAKE)
3. TO EMISSIONS SYSTEM CONTROL HOSE & BRACKET ASY / AIR VALVE
4. TO IGNITION COIL & BOOT ASY (4) PLACES
5. TO CYLINDER HEAD TEMP SENSOR ASY
6. TO HIGH PRESSURE FUEL PUMP ASY (SEE SHEET 73)
7. TO CAMSHAFT POSITION TRANSDUCER ASY (2) PLACES
8. TO FUEL PRESSURE SENSOR ASY
9. TO FUEL INJECTOR AND KNOCK SENSOR JUMPER
10. TO AIR INTAKE CHARGE THROTTLE BODY & MOTOR ASY
11. TO MAP SENSOR
12. TO ENGINE COOLANT TEMP SENSOR ASY
13. TO CRANKSHAFT TIMING SENSOR ASY
14. TO TURBOCHARGER ENGINE EXHAUST DRIVE (VAWG)
15. GROUND EYELET
16. ATTACH TO DYNO HARNESS CONNECTOR #15
17. NOT USED
18. NOT USED

FIG. A9.30 Engine Wiring Harness

A10. CONTROL AND DATA ACQUISITION REQUIREMENTS

A10.1 *General Description*:

A10.1.1 The data acquisition system shall be capable of logging the operational data in digital format. It is to the advantage of the laboratory that the system be capable of real time plotting of controlled quantities to help assess test validity. The systems shall be capable of calculating real time quality index *QI* for the controlled quantity as this will be monitored throughout the test.

A10.1.2 Control capability is not dictated by this procedure. The control system shall be capable of keeping the controlled quantities within the limits specified in Table 4..

A10.1.3 Design the control and data acquisition system to meet the requirements listed below. Use the recommendations laid out in the Instrumentation Task Force Report and Data Acquisition Task Force Report for any items not addressed in Annex A10.

A10.2 *Digital Recording Frequency*—The maximum allowable time period over which data can be accumulated is one second. This data can be filtered, as described in A10.6.1, and will be considered a reading.

A10.3 *Steady State Operation*:

A10.3.1 This portion of the test will be the entire time at Stage 1 and 2 conditions. Stage 1 and 2 conditions are reached by the end of the ramping periods. Calculate the quality index using values reported to the accuracy levels in Table A10.1.

TABLE A10.1 Accuracy Levels of Data Points to be Used in QI Calculations

Quantity, unit	Field Length
Engine speed, r/min	5.0
Humidity, g/kg	5.1
Temperature: Coolant Out, Oil Gallery, Blowby Outlet, °C	7.2
Engine Torque, N•m	5.1
Inlet Air Pressure, kPa	7.2
Exhaust back pressure, kPa	6.3
Coolant Outlet Pressure, kPa	6.1
Coolant Flowrate	6.1
Lambda	5.2

5.1

TABLE A10.2 L and U Constants and Over and Under-Range Values

Quantity, unit	Stages	L	U	Over-Range	Under-Range
Coolant flowrate, L/min	1	38	42	267	0
	2	68	72	267	0
Coolant-out temperature, °C	1	84.5	85.5	134	0
	2	45.5	44.5	134	0
Exhaust back pressure, kPa	1	102	106	304	0
	2	105	109	304	0
Humidity, g/kg	1, 2	10.4	12.4	109.9	0
Inlet-air pressure, kPa	1, 2	0.03	0.07	2	-1.9
Inlet-air	1, 2	31.5	32.5	81.2	0

temperature, °C					
Oil gallery temperature, °C	1	99.5	100.5	149.2	0.8
	2	49.5	50.5	149.2	0.8
Engine speed, r/min	1	2505	2495	2992	1058
	3	1555	1545	2992	1058
Torque, N•m	1	48	52	325	0
	2	128	132	325	0
Coolant pressure, kPa	1, 2	68	72	267	0
Air-charge temperature	1,2	29.5	30.5	79.2	0
Lambda	1	0.73	0.83	5.9	0
	2	0.95	1.05	5.9	0

TABLE A10.3 Maximum Allowable Time Constants

Control Quantity	Time Constant, s
Engine speed, r/min	0.5
Torque, Nm	0.7
Engine oil in temperature °C	0.6
Coolant out temperature, °C	0.6
Coolant flowrate, L/min	8.0
Blowby in, °C	0.6
Intake, air, °C	0.6
Intake air pressure, kPa	0.2
Exhaust back pressure, kPa	0.2
Coolant pressure, kPa	2.0

A10.3.2 The time intervals between recorded readings shall not exceed 1 min. Data shall be recorded throughout the length of each stage.

A10.4 *Transitions* :

A10.4.1 The ramp requirements are listed in Table 5.

A10.4.2 During the transition, the time intervals between all recorded readings shall not exceed 2 s.

A10.5 *Quality Index*:

A10.5.1 Calculate and record the quality index for each controlled quantity for the steady state portion of each test stage throughout the entire test.

A10.5.2 Update the quality index periodically throughout the test to determine the operational validity while the test is in progress. This could indicate if the test operational validity is in question before the test has completed.

A10.5.3 Use the following equation and the values listed in Table A10.2 to calculate the QI_q:

$$QI_q = 1 - \frac{1}{n}\sum_{i=1}^{n}\left(\frac{U_q+L_q-2q_i}{U_q-L_q}\right)^2 \qquad \text{(A10.1)}$$

where:

QI_q = the symbol for the quality index of quantity q

q = the quantity measured in the test,

q_i = the recorded value for the measured quantity at instant i,

U_q = the upper-specification limit for the measured quantity q,

L_q = the lower-specification limit for the measured quantity q, and

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

A10.5.4 Reset data that is greater than the over-range values listed in Table A10.2 with the over-range value listed in Table A10.2.

A10.5.5 Reset data that is lower than the under-range values listed in Table A10.2 with the under-range value listed in Table A10.2.

A10.5.6 Round the *QIq* values to the nearest 0.001.

A10.5.7 Report the *QIq* values on Form 5 of the test report.

A10.5.8 If the end-of-test QI_q value is below 0.000 for reference oil tests, review the test operations with the TMC. The TMC issues a letter to the laboratory and the test sponsor on its opinion.

A10.5.8.1 The laboratory documents its comments regarding the end-of-test QI_q values less than 0.000 for non-reference oil tests. The laboratory or test sponsor might request a TMC review of test operations for non-reference oil tests. The TMC issues a letter to document its opinion.

A10.6 *Time Constants*:

A10.6.1 Filtering can be applied to all control quantities. The amount of filtering applied shall not allow time constants to exceed the values listed in Table A10.3. This time constant shall pertain to the entire system, running from the sensor to the display and data acquisition.

A10.6.2 Maximum allowable system time constants for the controlled quantities are shown in Table A10.3.

A11. DIPSTICK OIL LEVEL TO CHARGE CONVERSIONS

A11.1 Use Table A11.1 to convert dipstick oil level to oil charge.

Dip Stick Level (mm)	Oil Charge (g)		Dip Stick Level (mm)	Oil Charge (g)		Dip Stick Level (mm)	Oil Charge (g)
160	4915		99	2577		38	1100
159	4866		98	2529		37	1084
158	4769		97	2505		36	1068
157	4720		96	2480		35	1060
156	4623		95	2431		34	1052
155	4574		94	2407		33	1044
154	4525		93	2383		32	1035
153	4501		92	2371		31	1027
152	4477		91	2359		30	1019
151	4379		90	2346		29	1011
150	4355		89	2334		28	1003
149	4331		88	2310		27	995
148	4233		87	2285		26	986
147	4185		86	2236		25	978
146	4136		85	2212		24	970
145	4087		84	2188		23	966
144	4038		83	2164		22	963
143	4014		82	2139		21	959
142	3990		81	2115		20	955
141	3965		80	2090		19	951
140	3940		79	2058		18	948
139	3916		78	2025		17	944
138	3892		77	1993		16	940
137	3844		76	1944		15	936
136	3795		75	1920		14	933
135	3746		74	1896		13	929
134	3697		73	1872		12	925
133	3673		72	1847		11	922
132	3649		71	1798			
131	3624		70	1774			
130	**3600**	**Full Mark**	69	1749			
129	3502		68	1733			
128	3454		67	1717			
127	3430		66	1701			
126	3405		65	1652			
125	3357		64	1628			
124	3308		63	1603			
123	3259		62	1587			
122	3235		61	1571			
121	3210		60	1555			
120	3162		59	1531			
119	3138		58	1506			
118	3113		57	1482			
117	3064		56	1457			
116	3016		55	1433			
115	2967		54	1409			
114	2943		53	1360			
113	2918		52	1344			
112	2870		51	1327			
111	2846		50	1311			
110	2821		49	1287			
109	2797		48	1262			
108	2772		47	1246			
107	2756		46	1230			
106	2739		45	1214			
105	2723		44	1198			
104	2699		43	1181			
103	2675		42	1165			
102	2659		41	1149			
101	2642		40	1132			
100	2626		39	1116			

A12. SEQUENCE X REPORT FORMS AND DATA ACQUISITION

A12.1 Download the standardized report form set and data acquisition from ASTM TMC[43] or obtain a hard copy from the TMC[2]. The contents of the report form set are as follows:

1. Title /Validity Declaration Page
2. Table of Contents
3. Summary of Test Method
4. Test Result Summary
5. Operational Summary
6. New and Used Oil Analysis
7. Oil Level and Blowby Measurements
8. Reference and Test Chain Measurements
9. Downtime Report Form Test Comments Report Form
10. American Chemistry Council Code of Practice Test Laboratory Conformance Statement

APPENDIXES

(Nonmandatory Information)

X1. SOURCES OF MATERIALS AND INFORMATION

X1.1 For convenience, some sources for materials and information are listed below:

X1.2 *Test Engine Parts*—Ford Component Sales, Ford Motor Co., 290 Town Center Dr, Dearborn, MI 48126.

X1.3 *ASTM Test Monitoring Center*—ASTM Test Monitoring Center, 6555 Penn Ave., Pittsburgh, PA 15206-4489.

X1.4 *Test Sponsor*—Ford Motor Company, 17225 Federal Drive, Allen Park, Ste. 200 Rm. P029, MI 48101.

X1.5 *Aeroquip Hose and Fittings*—Aeroquip Corp., 1225 W. Main, Van Wert, OH 45891.

X1.6 *Fuel Information and Availability*—Haltermann Products, 1201 S. Sheldon Rd., P.O. Box 249, Channelview, TX 79530-0429.

X1.7 *Intake-Air Humidity Instruments*—Alnor Dewpointer; also Dewpoint Meters by EG & G, Foxboro, Hy-Cal, General Eastern, Protimeter.

X1.8 *Heat Exchangers*—ITT Standard Heat Exchangers , Kinetics Engineering Corp., 2055 Silber Road, Suite 101, Houston, TX 77055.

X1.9 *Fuel Flowrate Measurement*—Mass fuel flowmeters, Micro Motion Corp., 7070 Winchester Circle, Boulder, CO 80301.

X1.10 *Parts Washer and Chemicals*—Better Engineering Manufacturing, 8361 Town Court Center, Baltimore, MD 21236-4964.

X1.11 *Crankcase and Intake Air Pressure Gauges*—Dwyer Instrument Co., Junction of Indiana State Highway 212 and U.S. Highway 12, P.O. Box 373, Michigan City, IN 46360.

X1.12 *Blowby Heat Exchanger Coolant*—Nacool 2000 Engine Cooling System Treatment , Nalco Chemical Co. Functional Chemicals Group, One Nalco Ctr., Naperville, IL 60566-1024.

X1.13 *Lubricant EF-411*—Local distributors of ExxonMobil products.

X1.14 *Tygon Hose*—Cadillac Plastic Co. distributors, or The Norton Co., 12 East Avenue, Tallmadge, OH 44278.

X1.15 *Brulin 815 GD and 815 QR-NF*—BHC (Formerly Brulin & Co, Inc.), 2920 Dr Andrew J Brown Ave, Indianapolis, IN 46205.

X1.16 *Flex Hone* —Model GB33432, W.W.Grainger, Inc., several locations, website www.grainger.com.

X1.17 *Pneumatic Honing Drill*—Westward 1/2 Reversible Air Drill, Model: 5ZL26G , W.W.Grainger, Inc., several locations, website www.grainger.com.

X1.18 *Sanford Piston Ring Grinder*—Sanford Mfg. Co., 300 Cox St., P.O. Box 318, Roselle, NJ 07203.

X1.19 *Carbide Ring Cutting* Burr 3/16 in.— P/N 74010020, M. A. Ford. Mfg. Co., Inc., 7737 Nothwest Blvd., Davenport, IA 52806. www.maford.com.

X1.20 *Sunnen Soft Stone*—No. JHU-820 Sunnen, Inc., 7910 Manchester, St. Louis, MO 63143.

X1.21 *Ford Camshaft Alignment Tool*—Ford P/N 303-1565. Ford or Lincoln dealer.

X1.22 *Crankshaft TDC Timing Peg*—Ford P/N 303-507. Ford or Lincoln dealer.

X1.23 *Dynamometer*—Dyne Systems, Inc., W209 N17391 Industrial Drive, Jackson, WI 53037.

X1.24 *Various Materials*—Oil pan and baffles, oil screen, flywheel, clutch, pressure plate, spacer, coolant inlet and outlet housings. bell-housing, dynamometer and engine wire harnesses, blowby orifice kit: OH Technologies, 9300 Progress Pkwy., Mentor, OH 44060, and/or Test Engineering, Inc.,12758 Cimarron Path, Ste. 102, San Antonio, TX 78249-3417.

X1.25 *Oil Separator*—Moroso, P/N MOR 85487, Summit Racing Equipment, PO Box 909, Akron, OH 44309-0909. Tel: +1800 2303030; www.summitracing.com.

X1.26 *Type 5 or Type 52Iintercooler*—FrozenBoost.com.

X1.27 *Motorized Chain Measurement Apparatus*—P/N MCMR 1000. Test Engineering, Inc., 12758 Cimarron Path, Ste. 102, San Antonio, TX 78249-3417.

X1.28 *Powertrain Control Module*—Ford Customer Service Division, Service Lubricants Technical Expert, Ford Motor Company, 17225 Federal Drive, Ste. 200 Room P029, Allen Park, MI 48101.

X1.29 *Shell Zone Dex-Cool*—Available from retailers and autoparts stores including Keller-Heartt Oil, 4411 S. Tripp Ave., Chicago, Ill. 60632.

X1.30 *Chemtool B-12*—Berryman Products, Inc., 3800 E. Randol Mill Rd., Arlington, TX 76011.

X1.31 *Ford Racing Balance Shaft Delete Kit*—Ford P/N M-6026-23-BSBP, Ford or Lincoln dealer.

X1.32 *Crankshaft Sensor Alignment Tool*—Ford P/N 303-1521. Ford or Lincoln dealer.

X1.33 *Driveshaft*—Machine Service Inc., 1000 Ashwaubenon St., Green Bay, WI 54304.

X1.34 *Coolant and Fuel Micromotion Flow Meter*—Emerson Automation Solutions, Micro Motion, 7070 Winchester Circle, Boulder, Co 80301. Tel: +1 800522 6277; www3.emersonprocess.com.

X1.35 *Blowby Heat Exchanger*— Standard Xchange, 175 Standard Pkwy, Buffalo, NY 14227-1233.

X1.36 *OTC Flywheel Holding Tool*—P/N 303-103. Bosch Automotive Service Solutions, 28635 Mound Road, Warren, MI 48092.

X1.37 *Chain Measurement Rig Parts:*
Cleveland Specialty Inspection Services, Inc., 8562 East Avenue, Meteor, Ohio 44060; www.cleavelandespeciality.com
MSC; www.mscdirect.com
Fastenal; Fastenal web support team. Tel: 877 507-7555; email: webhelp@fastenal.com; www.fastenal.com.
Grainger. Tel: 1-800-GRAINGER; www.grainger.com.
Parker. Parker Hannefin Corp. Tel: 1-800-272-7537; www.parker.com.
80/20, Ralph A. Hiller Company 6005 Enterprise Dr. Export, PA 15632.

X1.38 *J-TEC Blowby Flowmeter*—P/N VF563AA. J-TEC Automotive, Tel: +1 319 393 5200. www.jtecautomotive.com.

X2. Suggested Designs for Engine Fixing Brackets

X2.1 Suggested designs for left and right fixing brackets for installing the engine in the test stand are given in Figs. X2.1 and X2.2, respectively.

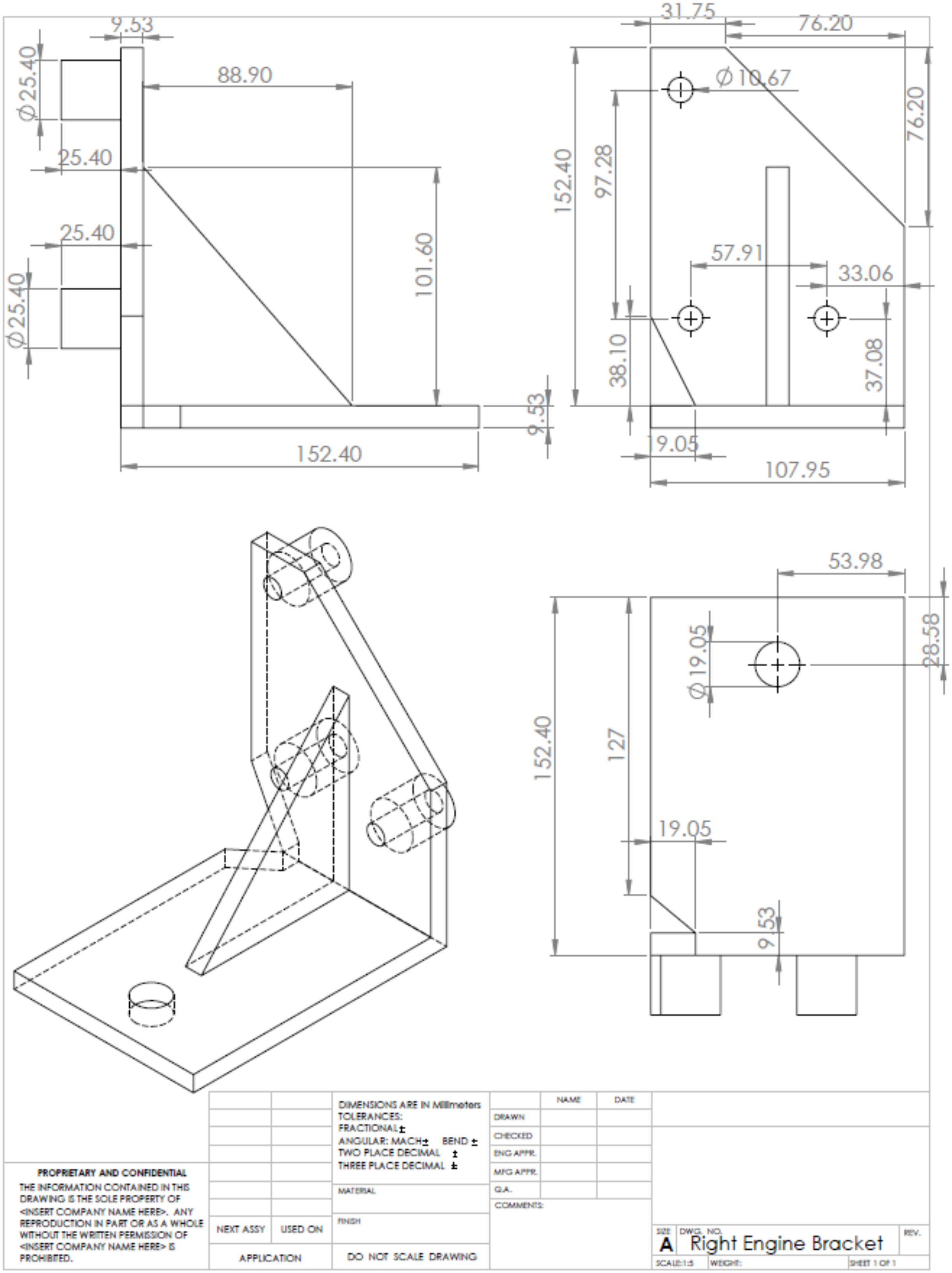
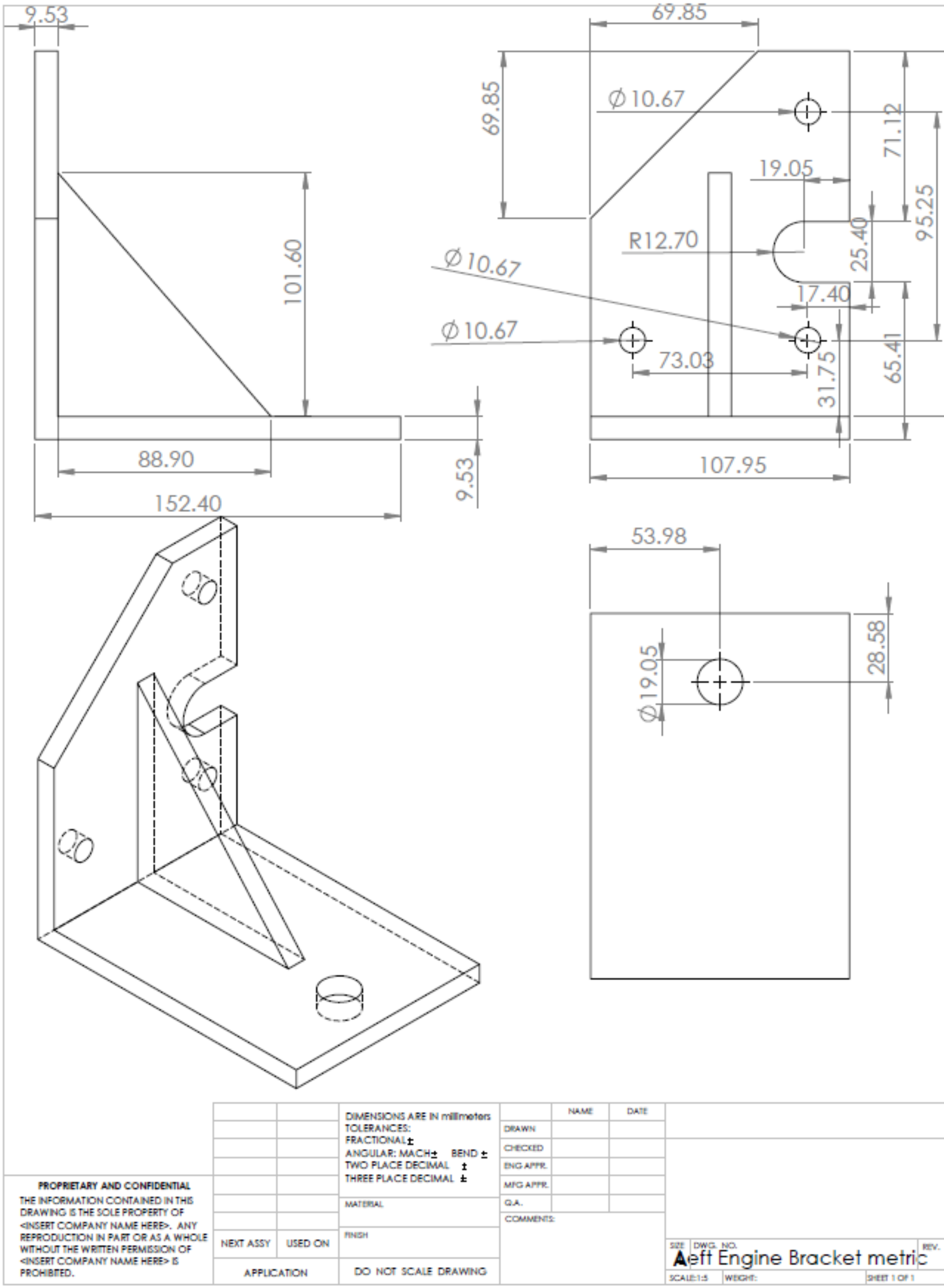


Fig. X2.1 Right Engine Bracket



X2.2 Left Engine Bracket