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

This standard is issued under the fixed designation D6891; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method measures the ability of crankcase oil to control camshaft lobe wear for spark-ignition engines equipped with an overhead valve-train and sliding cam followers. This test method is designed to simulate extended engine idling vehicle operation. The Sequence IVA Test Method uses a Nissan KA24E engine. The primary result is camshaft lobe wear (measured at seven locations around each of the twelve lobes). Secondary results include cam lobe nose wear and measurement of iron wear metal concentration in the used engine oil. Other determinations such as fuel dilution of crankcase oil, non-ferrous wear metal concentrations, and total oil consumption, can be useful in the assessment of the validity of the test results.[2]

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

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

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* See Annex A5 for specific safety precautions.

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D235 Specification for Mineral Spirits (Petroleum Spirits) (Hydrocarbon Dry Cleaning Solvent)
D287 Test Method for API Gravity of Crude Petroleum and Petroleum Products (Hydrometer Method)
D323 Test Method for Vapor Pressure of Petroleum Products (Reid Method)
D381 Test Method for Gum Content in Fuels by Jet Evaporation
D445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)
D525 Test Method for Oxidation Stability of Gasoline (Induction Period Method)
D3525 Test Method for Gasoline Diluent in Used Gasoline Engine Oils by Gas Chromatography
D4485 Specification for Performance of Engine Oils
D5185 Test Method for Determination of Additive Elements, Wear Metals, and Contaminants in Used Lubricating Oils and Determination of Selected Elements in Base Oils by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES)
D5302 Test Method for Evaluation of Automotive Engine Oils for Inhibition of Deposit Formation and Wear in a Spark-Ignition Internal Combustion Engine Fueled with Gasoline and Operated Under Low-Temperature, Light-Duty Conditions
D5844 Test Method for Evaluation of Automotive Engine Oils for Inhibition of Rusting (Sequence IID)
E230 Specification and Temperature-Electromotive Force (EMF) Tables for Standardized Thermocouples

2.2 *API Standard:*

API 1509 Engine Oil Licensing and Certification System[4]

2.3 *SAE Standards:*

SAE J183 Engine Oil Performance and Engine Service Classification[5]

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

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[2] The ASTM Test Monitoring Center will update changes in this test method by means of Information Letters. Information letters may be obtained from the ASTM Test Monitoring Center (TMC), 6555 Penn Ave., Pittsburgh, PA 15206-4489, Attention: Administrator. www.astmtmc.cmu.edu. This edition incorporates all Information Letters through No. ~~06–1.~~ 08–1.

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

[4] Available from The American Petroleum Institute (API), 1220 L. St., NW, Washington, DC 20005.

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

SAE J254 Instrumentation and Techniques for Exhaust Gas Emissions Measurement[5]

2.4 *ASME Standard:*

B46.1 Standard for Surface Texture (Surface Roughness, Waviness, and Lay)[6]

2.5 *JASO Standard:*

M 328-95 Valve-train Wear Test Procedure for Evaluating Automobile Gasoline Engine Oils[7]

2.6 *CEC Standard:*

CEC-L-38-A-94 Peugeot TU-3M/KDX Valve-train Scuffing Wear Test[8]

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. **D5302**

3.1.2 *calibration test stand*, *n*—a test stand on which the testing of reference material(s), conducted as specified in the standard, provided acceptable results. **Sub. B Glossary[9]**

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

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

3.1.3.1 *Discussion*—Reference oils are used to calibrate testing facilities, to compare the performance of other oils, or to evaluate other materials (such as seals) that interact with oils. **D5844**

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *assessment length*, *n*—the length of surface over which measurements are made.

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

3.2.3 *cam lobe wear*, *n*—the sum of the wear determined at the following locations (nose is zero location): (*1*) 14 cam degrees before the nose, (*2*) 10° before the nose, (*3*) 4° before the nose, (*4*) at the nose, (*5*) 4° after the nose, (*6*) 10° after the nose, (*7*) 14° after the nose.

3.2.4 *cam nose wear*, *n*—the maximum linear deviation of a worn nose profile from the unworn profile; the nose is the high lift point on the particular cam lobe.

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

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

3.2.6 *reference line*, *n*—a deduced, leveled, straight line drawn on the profilometer graph, from the front unworn average edge of a cam lobe to the rear unworn average edge of that cam lobe.

3.2.7 *valve-train*, *n*—a mechanical engine subsystem comprised of the camshaft, the rocker arms, hydraulic lash adjusters, the poppet valves, and valve-springs.

3.2.8 *waveness$_{total}$*, *n*—the maximum excursion of the worn surface as graphically measured normal to the reference line.

4. Summary of Test Method

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

AAAAA–BBBBB–CCCCC

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

4.2 *Test Engine*—This procedure uses a fired 1994 model Nissan KA24E, in-line 4-cylinder, 4-cycle, water-cooled, port fuel-injected gasoline engine with a displacement of 2.389 L.[10,11] The engine features a single overhead camshaft with sliding follower rocker arms, with two intake valves and one exhaust valve per cylinder, and hydraulic lash adjusters. The camshaft is not phosphate-coated or lubrited.

[6] Available from American Society of Mechanical Engineers (ASME), ASME International Headquarters, Three Park Ave., New York, NY 10016-5990.

[7] Available from Japanese Standards Organization (JSA), 4-1-24 Akasaka Minato-Ku, Tokyo, 107-8440, Japan.

[8] Available from the Coordinating European Council for the Development of Performance Tests Transportation Fuels, Lubes, and other Fluids, Madou Plaza , 25 Floor Place, Madou B-1210, Brussels, Belgium.

[9] Available from ASTM Test Monitoring Center (TMC), 6555 Penn Avenue, Pittsburgh, PA 15206-4489, Attention: Administrator.

[10] The sole source of supply of the apparatus known to the committee at this time is Nissan North American, Inc., P.O. Box 191, Gardena, CA 90248-0191.

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

4.3 *Test Stand*—Couple the test engine (devoid of alternator, cooling fan, water pump, clutch and transmission) to an eddy-current dynamometer for precise control of engine speed and torque. Specify the combined inertia of the driveline and dynamometer to ensure reproducible transient ramping of engine speed and torque. Control the intake air, provided to the engine air filter housing, for temperature, pressure, and humidity. Mount the engine similar to its vehicle orientation (tilted up 5.5° in front; sideways 10° up on intake manifold side; bottom of oil sump horizontal). Modify the engine ECM wiring harness, sensors, and actuators. The test stand plumbing shall conform to the diagrams shown in Annex A3. Install the engine on a test stand equipped with computer control of engine speed, torque, various temperatures, pressures, flows, and other parameters outlined in the test procedure (see Section 11).

4.4 *Test Sequence*—After engine break-in or after the completion of a previous test, install a new test camshaft and rocker arms. Charge the fresh test oil to the engine and conduct two flushes. After completing both flushes, drain the used oil, and weigh and install the fresh test oil and filter. Conduct the test for a total of 100 h, with no scheduled shutdowns. There are two operating conditions, Stage I and Stage II; Stage I for 50 min and Stage II for 10 min comprise one test cycle. The test length is 100 cycles.

4.5 *Analyses Conducted*—After test, measure the camshaft lobes using a surface profilometer. From these graphical profile measurements, determine the maximum wear at seven locations on the cam lobe. Determine individual cam lobe wear by summing the seven location wear measurements. Average the wear from the twelve cam lobes for the final, primary test result. After test completion, determine the oil consumption by the mass of used oil versus the fresh oil charged to the engine (including oil filter). Analyze the end of test used oil for fuel dilution, kinematic viscosity, and wear metals. Retain a final drain sample of 1 L for 90 days. Retain the camshaft and rocker arms for six months.

5. Significance and Use

5.1 This test method was developed to evaluate automotive lubricant's effect on controlling cam lobe wear for overhead valve-train equipped engines with sliding cam followers.

NOTE 1—This test method may be used for engine oil specifications, such as Specification D4485, API 1509, SAE J183, and ILSC GF 3.

6. Apparatus

NOTE 2—Coordination with the ASTM Committee D02, Subcommittee B, Sequence IVA Surveillance Panel is a prerequisite to the use of any equivalent apparatus. However, the intent is to permit reasonable adaptation of existing laboratory facilities and equipment. Figures are provided throughout the test method to suggest appropriate design details and depict some of the required apparatus.

6.1 *Test Engine*—This test method uses a fired 1994 model Nissan KA24E, in-line 4-cylinder, 4-cycle, water-cooled, port fuel-injected gasoline engine with a displacement of 2.389 L.[10,11]. See Annex A2 for a parts lists. Nominal oil sump volume is 3.5 L. The cylinder block is constructed of cast iron, while the cylinder head is aluminum. The engine features a single overhead camshaft with sliding follower rocker arms, with two intake valves and one exhaust valve per cylinder, and hydraulic lash adjusters. The camshaft is not phosphate-coated or lubrited. The rocker arm contact pad material is powdered metal. The engine compression ratio is 8.6 to 1. Rate the engine at 198 N·m torque at 4400 r/min. The ignition timing and multi-port fuel injection system is ECM. Fuel the engine with a specially blended, non-detergent unleaded reference gasoline. Make the EGR non-operable.

6.1.1 *Engine Buildup and Measurement Area*—The ambient atmosphere of the engine buildup and measurement areas shall be reasonably free of contaminants and maintained at a uniform temperature. Maintain the specific humidity at a uniform level to prevent the accumulation of rust on engine parts. Use uniform temperatures to ensure repeatable dimensional measurements. Use a sensitive surface profilometer instrument to measure the wear of the cam lobes, and place the profilometer on a base-plate free of external vibrations.

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

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

6.2 *External Engine Modifications*—Modify the test engine for the valve-train wear test. Make the exhaust gas recirculation non-operable. Disable the swirl control actuator. Disable the fast idle system and the auxiliary air control (AAC) valve. Replace the engine coolant temperature sensor by a fixed resistor. Modify the engine water-pump to incorporate an external electric-driven water-pump. Do not use the water-pump fan blade and cooling radiator. Remove the alternator. Install an oil cooler (water-to-oil heat exchanger) at the oil filter housing, as shown in Annex A3. Modify the engine wiring harness. Install fittings for various temperature and pressure measurements as required by the test method. Place the Nissan production rocker cover with a specially manufactured aluminum jacketed rocker cover. Route the engine coolant through this jacket. Install a fitting in the front engine cover to allow a portion of the crankcase ventilation air to bypass the rocker cover. Install fittings for various temperature and pressure measurements as required by this test method.

6.2.1 *Non-Operable EGR*—This test method does not use an EGR valve. Cover the EGR port with the supplied 3 mm thickness block-off (blind) plate (see Annex A3). Remove the hose from the exhaust manifold to the EGR. Plug the EGR supply port in the rear of the exhaust manifold with a pipe fitting.

6.2.2 *Swirl Control Actuator*—Disable the swirl control actuator by removing the harness connector and vacuum line. Plug the vacuum line source.

6.2.3 *Fast Idle Disabling*—To disable the fast idle system, remove the fast idle cam on the throttle body.

6.2.4 *Engine Coolant Temperature Sensor*—Substitute the variable input of the coolant temperature sensor to the ECM at the wiring harness of the ECM with a fixed resistance of 300 Ω.

6.2.5 *Utility Engine Water-pump*—Modify the engine water-pump shown in Fig. 1 to serve as a dummy housing on the engine, and use an electric motor-driven, external water pump for this test.

6.2.5.1 Support two surfaces, 180° apart, of the underside (non-machined surface) of the 77 mm diameter steel hub. Leave the shaft, body, and impeller free to be pressed out of the supported hub.

6.2.5.2 Using a press punch rod with the approximate diameter of 14 mm, press the shaft out of the hub.

6.2.5.3 Locate the copper wire clip in the slot on the side of the aluminum alloy pump body. Remove the U-shaped wire clip by pulling perpendicular to the longitudinal axis of the water-pump shaft.

6.2.5.4 Support the flat, machined face of the aluminum alloy pump body on two sides, 180° apart, leaving the impeller, bearings, seal, and shaft free to be pressed out of the aluminum alloy pump body.

6.2.5.5 Again using press punch rod with the approximate diameter of 14 mm, press the shaft, impeller, double bearing, and seal assembly out of the aluminum alloy pump body. Press in the direction of the internal cavity.

6.2.5.6 Clean and prepare the aluminum alloy pump body for contamination free welding.

6.2.5.7 Fabricate a water pump bore plug (see Annex A3) starting at the neck of the aluminum alloy pump body towards the internal cavity. In some instances, due to manufacturing tolerances, the pump body may need to be heated to approximately 200 °C and the fabricated bore plug cooled to approximately 0 °C. This will allow easy installation of the bore plug.

6.2.5.8 Preheat the aluminum alloy pump body (with plug installed) to approximately 200 °C.

6.2.5.9 Using an argon/tungsten-inert gas welder with pedal/rheostat-operated 220 A , 4043 aluminum 3 mm filler rod, and the approximate settings of AC and high frequency, weld the base perimeter of the plug to the internal cavity of the aluminum pump body.

6.2.5.10 Allow to cool, then perform final cleaning before installation on the engine.

6.2.6 *Coolant Bypass Hose*—Disconnect the coolant bypass hose at the intake manifold. The connection ends are plugged to prevent bypass flow. Remove the thermostat.

6.2.7 *Oil Cooler*—Insert a water-to-oil heat exchanger (see Annex A3) between the engine oil filter adapter block and the oil filter, using a gasket as shown in Annex A3. See Annex A3 for installation details. Plumb the water outlet to the cooler fitting and orient to the same axis as the oil filter. Orient the cooler for both water fittings to face the rear of the engine. To connect process water to the oil cooler, use flexible hoses (16 mm diameter) of approximately 500 mm length. Control the oil temperature by metering the flow of the process water outlet. A control system valve with Flow Coefficient (Cv) of 0.32 produces satisfactory control. Replace the oil cooler (see Annex A2) when the short-block is replaced. Replace all hoses to the oil cooler when installing a new cooler.

6.2.8 *Ignition Power Supply*—Use a 15 A dc power supply to provide (13.4 to 14.2) V dc to the ECM that powers the engine ignition system (a Lambda Electronics Corporation Model No. LFS-43-15 has been found useful).[11,12] Provide a separate power source for the starter motor circuit. Use an automotive battery equipped with a low-amperage battery charger.

6.2.9 *ECM Wiring Harness Modifications*—Remove the connectors and wires from the electronic control module wiring harness except those shown in Table 1.

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

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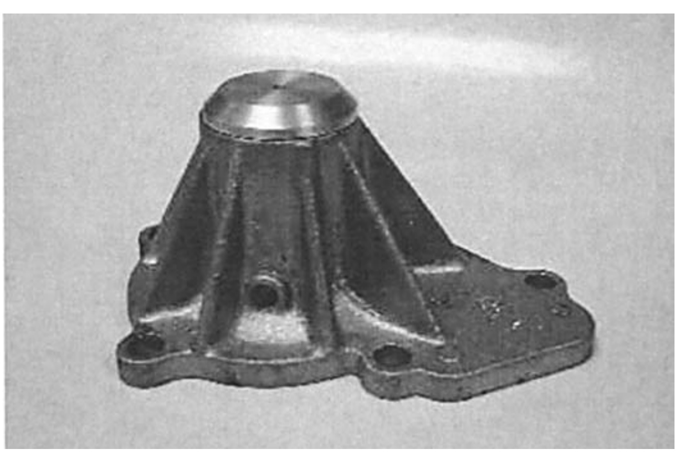

FIG. 1 Modified Water Pump

TABLE 1 ECM Wiring Harness Modifications[A]

Connector Description	Connector Number(s)
Camshaft Position Sensor	30M
Power Transistor	44M
Distributor	46M
Ignition Coil	47M, 97M
Oxygen Sensor	59M
Mass Air Flow Sensor	63M
Engine Coolant Temperature Sensor	65M (Install 300Ω resistor)
Throttle Position Sensor	66M
Injectors 1–4	72M, 73M, 74M, 75M
Intake Air Temperature Sensor	18M
Body Ground	275M
Engine Ground	60M, 61M
Connector Description	Connector Number(s)
Fuel Pump Relay[B]	5M
ECCS Relay[C]	6M
Resistor and Condenser	40M
Check Connector	208M
Joint Connector A	259M
ECM (ECCS Control Module)	262M
Fuel Pump	2C
Joint Connector C	212M (jumper hardwired)
Connector	260M (jumper hardwired)
EGR Temperature sensor	17M (retain, do not connect)
EGRC solenoid valve	88M (retain, do not connect)
IACV-AAC Valve and IACV-FICD Solenoid Valve	64M (retain, do not connect)
Ground Connector	(retain, do not connect)
Check Engine Light	add and utilize
30 amp fuse holder	add and utilize
Ground[D]	add and utilize
Keep-Alive wire	add and utilize
Ignition wire	add and utilize
Ground wire[D]	add and utilize

[A] See modified wiring diagram in Annex A3.
[B] Modify the fuel pump relay connector (5M) to provide a nominal 13 V to the fuel pump only when turning on the ignition power switch. See Annex A3 for the wiring details.
[C] The ECCS relay uses the 6M connector. Connect it to the battery through a fusible link.
[D] Attach the wiring harness grounds to the front engine-lifting bracket.

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

6.3.1 *Computer Data Acquisition System*—The procedure shown in 6.3.1.1-6.3.1.3 details the test stand log operational data with a computer data acquisition system using sensor configurations, and is in compliance with Data Acquisition and Control Automation II.[9] Consider a test that has greater than 2 h without data acquisition on any controlled parameter to be operationally invalid.

6.3.1.1 *Frequency of Logged Steady-State Data*—Log the Stage I steady-state (last 45 min of stage) operational conditions every 2 min or more frequently. Log the Stage II steady-state (last 5 min of stage) operational conditions every 30 s or more frequently.

6.3.1.2 *Frequency of Logged Transient Data*—Define the transient time as the first 5 min following operational stage changes. Computer log and plot the cycle 5 transient data. Log the critical parameters (engine speed, torque, oil gallery temperature, coolant out temperature) once per second or higher frequency. If cycle 5 transients are beyond the procedural limits defined in 11.2.6, document and confirm the corrective action with the next available transition plot.

6.3.1.3 *System Time Response for Logged Data*—Do not exceed the controlled operational parameters for system time response for measurement shown in Table 2. The system time response includes the total system of sensor, transducer, analog signal

TABLE 2 System Time Response

Parameters	Time Response, max (one time constant)
Temperatures	2.5 s
Pressures	1.6 s
Coolant Flow	2.5 s
Torque	2.0 s
Speed	1.8 s

attenuation, and computer digital filtering. Use single-pole type filters for attenuation.

6.3.1.4 *Quality Index*—The Quality Index (QI) is an overall statistical measure of the variation from test targets of the steady-state operational controlled parameters. The Sequence IVA Surveillance Panel has chosen the QI upper and lower control ~~limits; see~~limits, shown in Table 3~~, used in the QI calculation equation. If the QI calculation of a controlled parameter is less than zero, then the laboratory engineer shall investigate the reason, assess its impact on test operational validity, and document such finding in the final test report. It is recommended, for calibration tests, that the laboratory engineer and the TMC agree on the validity assessment.~~ .

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

where:

X_i = values of the parameter measured,
U = allowable upper limit of X,
L = allowable lower limit of X, and
n = number of data points used to calculate QI.

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

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

where:

Q = QI calculated without missing/BQD,
I = points,
n = number of data points used to calculate QI, and
N = number of data points for a complete data set.

If the QI calculation of a controlled parameter is less than zero, investigate the reason, assess its impact on test operational validity, and document such finding in the final test report. For calibration tests, review the operational validity assessment with the TMC.

6.3.2 *Test Stand Configuration*—Mount the engine on the test stand similar to its vehicle orientation (tilted up 5.5° in front; sideways 10° up on intake manifold side; bottom of oil sump horizontal). This orientation is important to the return flow of oil in the cylinder head, and ensures reproducible oil levels. Directly couple the engine flywheel to an eddy-current dynamometer through a driveshaft. The driveshaft design shall minimize vibration at the test operating conditions. The dynamometer system shall have inertia of (0.75 ± 0.15) kg·m^2 to ensure satisfactory control of engine speed at 800 r/min, stable air-to-fuel ratio control, and enable reproducible transient control of engine speed and torque during stage changes. Do not use hydraulic type dynamometers, as they exhibit residual loads at low speed operation. Do not use the engine to drive any external engine accessory. Recommend the area above and to the left of the rocker arm cover be left unobstructed to allow for easier on-site replacement of valve-train wear parts while the engine rests on the test stand. See Annex A5 for Safety Precautions.

6.3.3 *Dynamometer Speed and Torque Control System*—To improve laboratory reproducibility for transient control of engine speed and torque, the driveline system inertia, excluding engine, shall be (0.75 ± 0.15) kg·m^2. Control the engine power for evaluating the lubricant in a repeatable manner by:

6.3.3.1 Measuring and controlling engine speed and dynamometer torque,

6.3.3.2 Controlling exhaust absolute pressure by exhaust pipe throttling, and

6.3.3.3 Controlling the supply of intake air temperature, humidity, and pressure differential above barometer pressure.

NOTE 3—The dynamometer speed and torque control systems shall be capable of maintaining the steady state operating set points within the performance envelope (that is, quality index established by the industry matrix testing program).

TABLE 3 Upper and Lower Control Limits

Parameter	L	U
Coolant Flow	29.8	30.2
Coolant Out Temperature,	49.81	50.19
Stage I and II	54.81	55.19
Exhaust Back-pressure	103.34	103.66
Intake Air Humidity	10.8	12.2
Intake Air Pressure	0.047	0.053
Intake Air Temperature	31.71	32.29
Oil Cylinder Head Temperature,	48.7	49.3
Stage I and II	58.7	59.3
Speed,	793.5	806.5
Stage I and II	1493.5	1506.5
Torque	24.5	25.5
Rocker Cover Air Flow	9.5	10.5

NOTE 4—Two types of full closed-loop speed and torque control systems have been successfully utilized. One typical closed-loop system maintains speed by varying dynamometer excitation and maintains torque by varying the engine throttle. This arrangement may provide satisfactory steady-state control. Another closed-loop speed and torque control system maintains torque by varying dynamometer excitation and controls speed using the engine throttle. This arrangement may provide satisfactory transient control during stage changes.

6.3.4 *Intake-air Supply System*—The supply system shall be capable of delivering a minimum of 600 L/min (2000 L/min preferred) of conditioned and filtered air to the test engine during the 100 h test, while maintaining the intake-air parameters detailed in Annex A1. A humidifying chamber controls the specific humidity and provides a positive air pressure to an intake air supply duct. Annex A3 shows a general schematic of the intake air system.

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

6.3.4.2 *Intake Air Filtering*—Use the production intake air cleaner assembly (Annex A2), with filter, at the engine. Use a snorkel adapter, functionally equivalent to that shown in Annex A3, to connect the controlled air duct to the air cleaner. Modify the top of the air cleaner assembly for the installation of the intake temperature sensor and for the intake pressure sensor line. Refer to 6.3.4.5.

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

6.3.4.4 *Intake Air Temperature*—For final control of the inlet air temperature, install an electric air heater strip within the air supply duct. The duct material and heater elements design shall not generate corrosion debris that could be ingested by the engine. To provide sufficient duct flow for adequate air temperature control, it is recommended that excess air be dumped just prior to the air cleaner snorkel. An air dump area of approximately 60 mm^2 will provide sufficient flow without stagnation. If additional airflow is required to stabilize air temperature, it is permissible to install a nominal 10 mm bleed hole in the air filter housing. Install the inlet temperature sensor in the air cleaner, centered at the inlet to the air cleaner (see Annex A3). Attach a support brace to the air cleaner assembly mounting stud and wing nut, if vibration of the temperature sensor is a problem.

6.3.4.5 *Intake Air Supply Pressure*—Install a disc type valve in the controlled air system supply duct to control the engine inlet air gage pressure. Locate the sensing tube for inlet air pressure in the topside of the air cleaner assembly ((50 ± 10) mm left and (80 ± 10) mm in front of the right rear corner of the assembly). This location senses the pressure before the air enters the air cleaner element.

6.3.5 *Fuel Supply System*—This test method requires approximately 200 L of unleaded Haltermann KA24E Green test fuel[11,13] per test (100 cycles). Ensure a sufficient fuel supply at the start of test to conduct the test without a shutdown. Use the production port fuel injection system, including fuel pump (see Annex A3), fuel injector rail, and fuel pressure regulator. Use recirculated fuel within the system using a non-production heat exchanger to maintain fuel temperature ranging from (15 to 30) °C. Measure fuel consumption using a mass flow meter (MicroMotion[11, 14] model D-6 is suitable). Install a fuel filter assembly (see Annex A3) upsteam of the fuel pump. Ensure proper fuel filtration to maintain precise air-fuel ratio control during the test.

6.3.5.1 *Fuel Temperature*—Measure fuel temperature through one of the ports in a cross fitting located in the line between the fuel pump and the fuel rail. Maintain the fuel temperature to the fuel rail below 50 °C.

6.3.5.2 *Fuel Pressure*—Measure the fuel pressure through one of the ports in a cross fitting located in the line between the fuel pump and the fuel rail inlet.

6.3.5.3 *Fuel Flow*—Install a mass fuel flow meter for measuring the fuel consumption rate in the fuel supply system, prior to the fuel recirculating loop. A MicroMotion model D-6 fuel flow meter has been found to be suitable.

6.3.6 *Exhaust System*—Use a production cast iron exhaust manifold, without insulation, for the test. Plug the rear of the manifold (EGR supply) with a pipefitting. Do not use an EGR for this test. Use and install a production exhaust gas oxygen sensor (one-wire EGO) in the original location in the exhaust manifold. Mount an industrial cooling blower with a nominal air flow rating within 10 000 L/min to 14 000 L/min to blow air vertically over the cast iron exhaust manifold and the manifold exhaust gas oxygen (EGO) sensor. This cooling air is essential to proper EGO operation. Ensure this cooling air is not directed to the engine oil pan or rocker arm cover. Use a deflector shield to prevent air currents at the oil pan. See Annex A5 for Safety Precautions. Use the production exhaust pipe front length (minimum 500 mm), including tube collector with shield, leading from the manifold. Route the exhaust from the test cell using accepted laboratory practices. Install an exhaust pressure control valve at any point after the production exhaust pipe to enable the exhaust to be controlled to an absolute pressure. Use of a catalytic converter, or exhaust attenuator, or pipe cooling is optional, provided these devices are installed after the production exhaust pipe front length and specified absolute pressure is maintained. Remove the unused exhaust pipe production fitting, and weld a plate over the opening (see Annex A3). Because this test method is continuously operated at low engine speeds and torque, the water vapor in the exhaust gas tends to condense in the exhaust piping. Install a low point drain in the exhaust piping to remove accumulated water before the start of each test. Depending on the exhaust piping arrangement, if exhaust pressure fluctuations are observed, remove water periodically throughout the 100 h test.

[13] The sole source of supply of the apparatus known to the committee at this time is Dowell Chemical Company, 1201 South Sheldon Road, Channelview, TX 77530-0429.

[14] The sole source of supply of the apparatus known to the committee at this time is Micromotion, 7070 Winchester Circle, Boulder, CO 80301.

6.3.6.1 *Air-To-Fuel-Ratio Sensor*—Install a Universal Exhaust Gas Oxygen (UEGO) sensor in the production exhaust pipe to monitor the air-to-fuel ratio. Make a port (30 ± 10) mm downstream of the collector. Orient the UEGO to the front side of the exhaust pipe using the appropriate weld fitting. It is not necessary to direct cooling air over the UEGO sensor.

6.3.6.2 *Exhaust Gas Temperature*—Measure the exhaust gas temperature using a 6 mm diameter thermocouple. Install the thermocouple in a welded fitting attached to the exhaust pipe at a location (50 ± 10) mm downstream from the end of the collector. Insert the sensor tip to the center of the exhaust pipe (see Annex A3).

6.3.6.3 *Exhaust Absolute Pressure*—Attach the exhaust pressure sensor tube to a welded fitting installed on the exhaust pipe at a location (50 ± 10) mm downstream from the end of the tube collector. Orient this fitting circumferentially (60 to 90)° from the exhaust temperature sensor.

6.3.6.4 *Exhaust Sample Probe*—It is optional to install an exhaust sampling probe for emission analyses (percent O_2, CO_2, CO, HC). If used, locate the exhaust sampling probe 100 mm downstream from the end of the collector on the exhaust pipe. Extend the probe into the center of the exhaust pipe, with the tip of the probe cut to a 45° angle (longest portion facing upstream).

6.3.7 *Air-to-Fuel Ratio Control*—Control the air-to-fuel ratio (AFR) at a stoichiometric mixture (14.4 ± 0.3) by the engine ECM, using feedback from the production exhaust gas oxygen sensor installed in the exhaust manifold.

6.3.7.1 *AFR Measurement*—To monitor the reliability of the AFR control, use an AFR analyzer with a separate wide range-sensing element (UEGO) sensor to compute the AFR. Use a Horiba model MEXA 110 lambda analyzer,[11,15] or the ETAS Lambda Meter LA3.[11,16] These analyzers are configured to read directly the air-to-fuel ratio. Program the Mexa 110 AFR analyzer with the information shown in Table 4 for the Haltermann KA24E Green test fuel. Input the Mexa 110 analyzer with sensor calibration documentation received with the sensor. It is recommended that a periodic verification of the calibration be performed by exposing the sensor to a 4.0 % O_2, N_2 balance certified gas. Follow the manufacturer's calibration procedures for the AFR analyzer used.

6.3.8 *Ignition System*—Do not modify the ignition system for this test method.

6.3.8.1 *Monitoring Ignition Timing*—Use an automotive timing light (strobe) to visually check the ignition timing.

6.3.9 *Engine Coolant System*—A schematic diagram of the external coolant system is shown in Annex A3. Use a 50 % deionized water and antifreeze solution, using an extended life ethylene glycol based engine coolant. Texaco Havoline Dex-Cool[11,17] has been found to meet this requirement (see Annex A4). Configure the plumbing such that the total coolant system capacity, including engine and normal reservoir capacity, is (25 to 30) L. Regulate the system pressure by a 100 kPa radiator-type pressure cap onto the reservoir tank. Plumb the coolant to enter the engine at the thermostat housing (remove the thermostat). Coolant exits the engine at the front of the intake manifold. Circulate a portion of the engine coolant through the specially manufactured jacketed rocker cover (see Annex A3).

6.3.9.1 *External Coolant Pump*—Use an electric motor-driven centrifugal bronze body pump with a nominal minimum rating of 150 L/min at 100 kPa head pressure. The actual flow range during the test (including break-in) is (20 to 70) L/min.

6.3.9.2 *Coolant Heater*—Use a nominal 8 kW electric heater, or equivalent external heating source, in the coolant system. This allows engine coolant soak temperatures to be maintained while the engine is not running. Because the ECM coolant temperature sensing system is non-operable, smooth running of the engine upon start-up depends on maintaining the coolant soak temperature.

6.3.9.3 *Coolant Heat Exchanger*—Use a conventional shell-and-tube heat exchanger for cooling. Flow the engine coolant through the tube side, and use process water on the shell side. A nominal 150 mm diameter by 1200 mm long exchanger has been found to be suitable. Position the heat exchanger vertically, and the coolant inlet at the top of the exchanger. Plumb the high point bleed to remove system air during initial circulation of coolant. Install a sight-glass in the coolant line upstream of the external coolant pump. Plumb a low point drain to allow complete coolant removal.

6.3.9.4 *Coolant Control*—For control of the coolant out temperature, install an automatic control valve in the process water outlet of the heat exchanger. Use a control valve with a Cv rating of 1.25 for the recommended heat exchanger size.

6.3.9.5 *Coolant Flow Control*—Measure the coolant flow using a volumetric flow sensor installed in the coolant line between the heat exchanger and the coolant inlet to the engine. A Barco venturi[11,18] metering element is recommended. Control the flow by an automatic flow control valve on the discharge side of the external pump. A control valve with a Cv rating of 16 is recommended.

6.3.9.6 *Jacketed Rocker Cover Coolant System*—Route a portion of total coolant system flow through the jacketed rocker cover. Install a tee fitting at the exit of the coolant heat exchanger to allow the coolant flow to split into two circuits (main circuit to the

[15] The sole source of supply of the apparatus known to the committee at this time is Horiba Instruments, 17671 Armstrong Avenue, Irvine, CA 92714.

[16] The sole source of supply of the apparatus known to the committee at this time is ETAS, 2155 Jackson Avenue, Ann Arbor, MI 48103.

[17] The sole source of supply of the apparatus known to the committee at this time is Texaco Lubricants Company, P.O. Box 4427, Houston, TX 77210-4427.

[18] The sole source of supply of the apparatus known to the committee at this time is Barco, Hyspan Precision Products, 1685-T Brandwine Avenue, Chula Vista, CA 91911.

TABLE 4 AFR Analyzer Parameters[A]

Fuel Properties	Value
Hydrogen to Carbon ration of the fuel	1.800
Oxygen Content	0.000

[A] Stoichiometric air-to-fuel ratio for the test fuel is 14.4 to 1.

engine thermostat housing and secondary circuit to the jacketed rocker cover (see Fig. 2). The secondary circuit enters the front of the jacketed cover and exits the rear of the cover. Install an automatic air bleed vent near the front of the rocker cover. Limit the secondary circuit flow rate at the exit by installing a two-way control valve, 13 mm nominal internal diameter size, with a flow coefficient rating (Cv) of 1.25. Configure the control valve in the fail-safe open position. The secondary flow joins the primary flow at the suction of the coolant system-circulating pump. Refer to the schematic of the cooling system located in Annex A3.

6.3.10 *Crankcase Ventilation System (*Fig. 3*)*—Alter the Nissan production routing of the crankcase gasses to ensure that a certain mass flow rate of fresh air is supplied to the valve-train underneath the jacketed rocker cover. Take humidity-conditioned air from the bottom, left rear of the air cleaner housing and route to the rear right side of the rocker arm cover and to the engine front cover. Draw the crankcase off-gas from the engine at the production breather and oil separator. From the breather, the crankcase gas flows through the Positive Crankcase Ventilation (PCV) valve to the bottom plenum of the intake manifold (see Annex A3) for a drawing of the ventilation system plumbing. Use a mass flow meter to measure the 10.0 L/min (SLPM, Standard Litres per Minute) fresh airflow to the rocker cover. This meter, corrected to standard conditions, shall have an accuracy of ± 0.25 L/min (SLPM) at 10 L/min (SLPM). Full scale of the meter shall be a minimum of 20 L/min (SLPM). Time response of the measurement shall be less than or equal to 1.0 s. One model that meets these specifications is Sierra Mass Flow Meter, model 730-N2-1E0PV1V4 (air; 20 SLPM).[11,19] Prior to the meter is a three-way control valve. This valve should have a nominal size of 13 mm, with a flow coefficient rating of 2.5 Cv. Configure the valve so that loss of control power routes all air to the rocker cover. A Badger Meter ½ in. research valve with Trim A meets these requirements.[11,20] Use a surge at the exit of the flow meter. It should have a nominal capacity of 20 L. The plumbing from the 3-way valve to the engine front cover is a nominal diameter of 10 mm; see Fig. 4. The plumbing from the 3-way valve, through the flow meter and surge chamber, and on to the rear of the rocker cover, is a nominal diameter of 16 mm.

6.3.10.1 *Diversion for Blowby Measurement*—To facilitate the periodic measurement of engine blowby, install a 3-way valve in the hose between the engine PCV and the intake manifold vacuum source. Use a longer hose to connect the rocker cover to the air cleaner housing. During blowby measurement, position the 3-way valve and hoses to route blowby from the rocker cover (bypassing the air cleaner), through the blowby meter, through the 3-way valve, then to the intake manifold vacuum source. Monitor crankcase pressure at the dipstick tube. During blowby measurement, adjust the blowby measurement apparatus for zero crankcase pressure.

6.3.11 *Temperature Measurement*—Temperature measurement equipment and locations for the required temperatures are specified in 6.3.11.1-6.3.11.7. The TMC shall approve alternative temperature measurement equipment. The accuracy and resolution of the temperature measurement sensors and the complete temperature measurement system shall follow the guidelines in Specification E230.

6.3.11.1 *Thermocouples*—All thermocouples except the intake-air thermocouple shall be premium, sheathed, types with premium wire. The intake-air and ambient air thermocouples may be an open-tip type. Grounded thermocouples may provide a more accurate reading, in situ, when immersion depths are limited. Using grounded thermocouples requires the incorporation of signal conditioning modules for providing electrically isolated inputs to digital computer systems. Use thermocouples of 3.2 mm or 6.4 mm diameter in specific locations. The 3.2 mm thermocouples are specified at locations, which require short immersion depths to prevent undesirable temperature gradients. For exhaust gas temperature, the 6.4 mm diameter thermocouple is recommended. Match thermocouples, wires, and extension wires to perform in accordance with the special limits of error as

[19] The sole source of supply of the apparatus known to the committee at this time is Sierra Instruments, 5 Harris Court, Monterey, CA 93940.

[20] The sole source of supply of the apparatus known to the committee at this time is Badger Meter, Inc., Precision Products Division, 6116 East 15th Street, Tulsa, OK 74112.

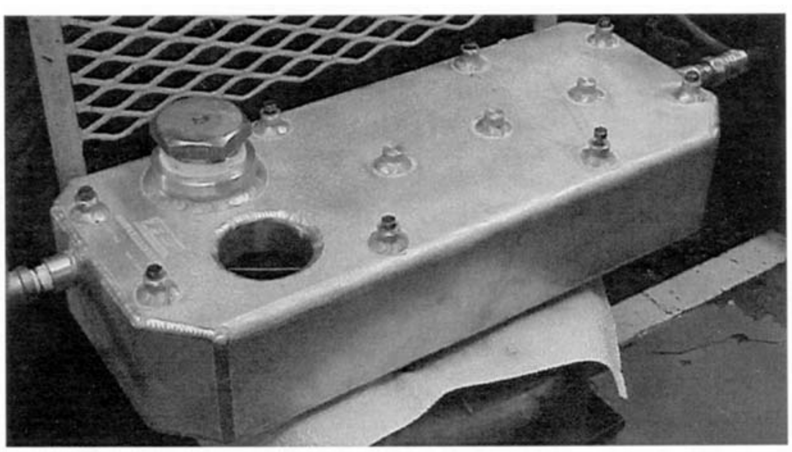

FIG. 2 Jacketed Rocker Cover

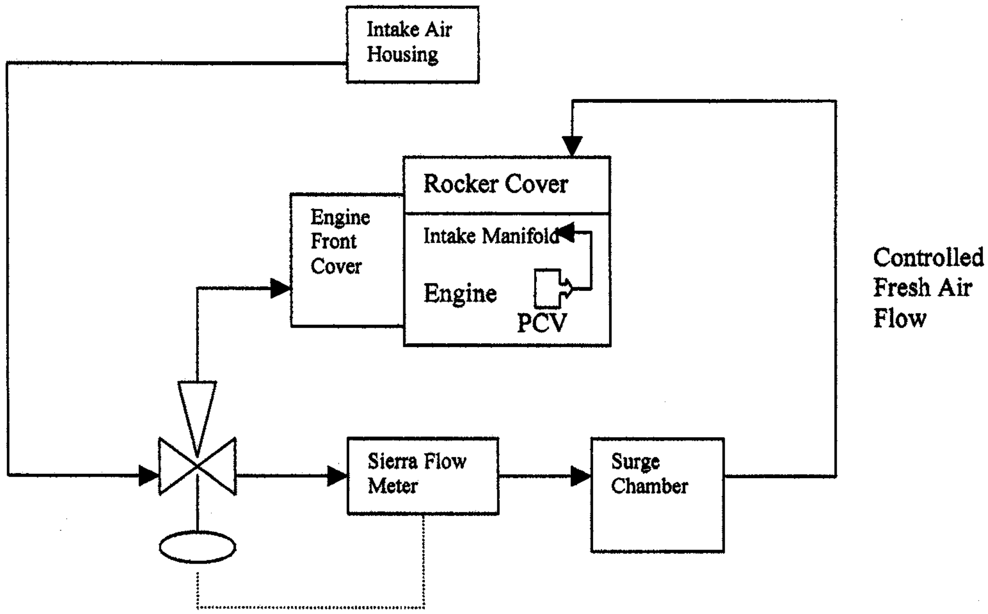

FIG. 3 Crankcase Ventilation System Flow Diagram

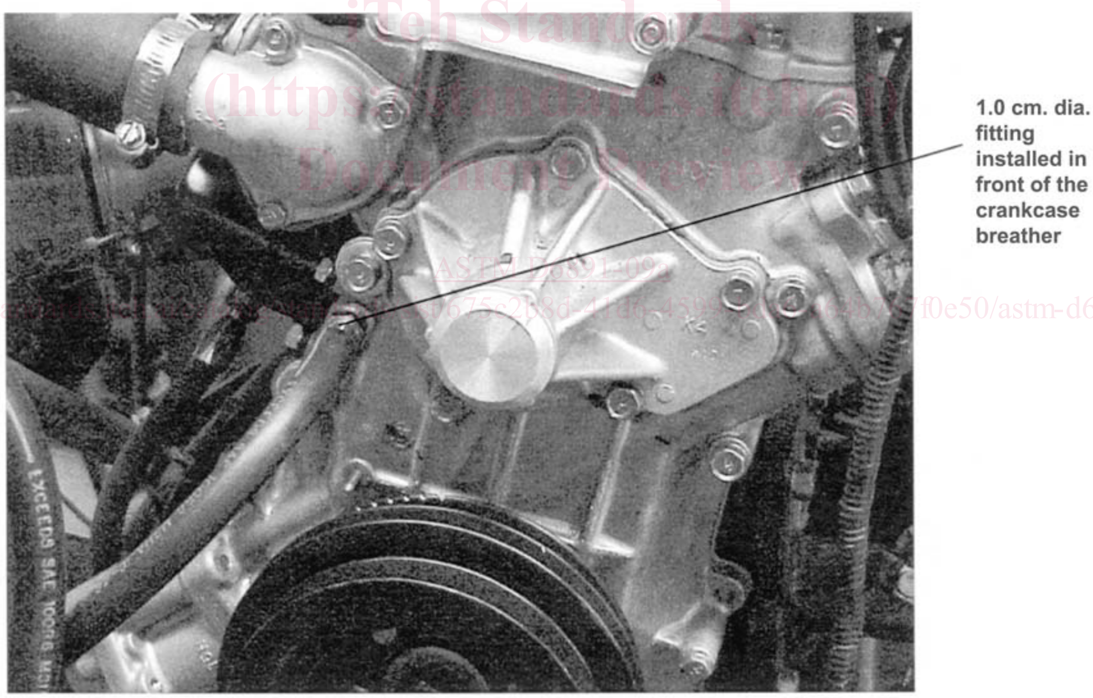

FIG. 4 Location of Crankcase Ventilation Port to Engine Front Cover

defined by Specification E230. Either Type J (Iron-Constantan) or Type T (Copper-Constantan) or Type K (Chromel-Alumel) thermocouples are acceptable; Type J is preferred.

6.3.11.2 *Resistance Thermometer Detectors*—Do not use Resistance Thermometer Detectors (RTDs) as alternatives to thermocouples, due to inherent signal attenuation characteristics that are different from sheathed, grounded thermocouples.

6.3.11.3 *Engine Coolant Inlet*—Install the engine coolant inlet temperature sensor at the inlet pipe, (200 ± 20) mm from the end of the thermostat-housing nipple. Locate the sensor tip at the center of the pipe inner diameter.

6.3.11.4 *Engine Coolant Outlet*—Install the engine coolant outlet temperature sensor at the coolant water outlet passage at the front end of the intake manifold. Locate the existing port at the top of the manifold, (50 ± 10) mm from the intake gasket surface.

Locate the sensor tip in the center of flow. The recommended thermocouple diameter is 3.2 mm. This temperature is the coolant control point.

6.3.11.5 *Engine Oil Gallery Temperature*—Precisely weld a thermocouple fitting to the oil filter block (see Fig. 5). A 3.2 mm diameter thermocouple, or equivalent is recommended. Position the sensor tip in the center of the oil passageway. Do not use the engine oil gallery temperature for oil temperature control.

6.3.11.6 *Engine Oil Sump Temperature*—Sense the engine oil sump temperature by modifying the drain plug location of the oil pan for a thermocouple fitting, as shown in Fig. 6. Insert the sensor tip (50 ± 5) mm inside the interior surface of the oil pan. Only monitor this temperature. It is not used for oil temperature control.

6.3.11.7 *Cylinder Head Oil Temperature*—Assess the cylinder head oil gallery from the intake side of the head through the vertical passage, centered front-to-rear (see Fig. 7). Drill an access port in a bossed area of the head, and locate 10 mm upward from the deck surface of the head. Drill and tap the access port to accept a 3.2 mm close pipe nipple. Connect a 3.2 mm pipe tee to the nipple. Use a straight-through tee connection for the temperature sensor. Insert the sensing tip into the center of the oil gallery passage. Orient the right angle tee connection downward and use for the measurement of cylinder head gallery pressure. The cylinder head oil temperature is the primary control point.

6.3.11.8 *Dynamometer Load Cell Temperature*—Measure the dynamometer torque using a strain-gage transducer attached to the moment arm; it is recommended that the environment surrounding the transducer be maintained at a constant temperature. Strain-gage transducers are very sensitive to temperature changes. Use a temperature sensor located near the transducer to monitor ambient variations.

6.3.12 *Pressure Measurement Equipment*—The seven required pressure measurement parameters are shown in 6.3.11.2-6.3.11.7. This test method does not specify specific measurement equipment. This allows reasonable opportunity for adaptation of existing test stand instrumentation. The accuracy and resolution of the pressure measurement sensors and the complete pressure measurement system shall follow the guidelines detailed in ASTM research report D02-1218.[21]

6.3.12.1 *Allowance for Pressure Head Deviations*—Use tubing between the pressure tap locations and the final pressure sensors and incorporate condensate traps. This is important in applications where low air pressures are transmitted through lines passing through low-lying trenches between the test stand and the instrument console. Locate the pressure transducer at the same elevation as the measurement location, or account for the pressure head. Design the oil pressure sensor / tubing lines to minimize the trapped oil volume in the tubing lines.

6.3.12.2 *Intake Manifold Vacuum*—Measure the intake manifold vacuum on the throttle body, at an existing port located just below the throttle plate.

6.3.12.3 *Engine Oil Pressure*—Sense the engine oil pressure at the production location on the oil filter block (see Fig. 5). Route the sensing line to a tee fitting, allowing ports to a pressure transducer and an analog pressure gage.

6.3.12.4 *Cylinder Head Oil Gallery Pressure*—Assess the cylinder head oil gallery from the intake side of the head through the vertical passage, centered front-to-rear. Drill this access port in a bossed area of the head that is located 10 mm upward from the head deck surface. Drill and tap the access port to accept a 3.2 mm close pipe nipple. Connect a 3.2 mm pipe tee into the nipple. Orient and use the right angle tee connection downward for the measurement of cylinder head gallery pressure.

6.3.12.5 *Fuel Pressure*—Measure the fuel pressure through a cross-fitting port located in the line between the fuel pump and the fuel rail inlet.

[21] The ASTM Test Monitoring Center will update changes in this test method by means of Information Letters. Information letters may be obtained from the ASTM Test Monitoring Center (TMC), 6555 Penn Ave., Pittsburgh, PA 15206-4489, Attention: Administrator. www.astmtmc.cmu.edu. This edition incorporates all Information Letters through No. 08–1.

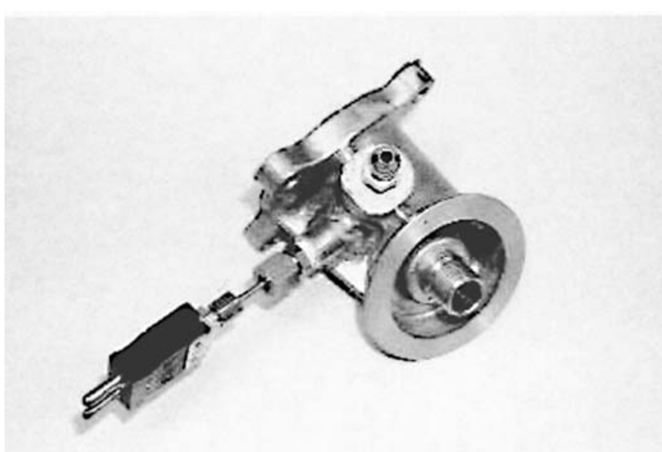

FIG. 5 Oil Filter Block

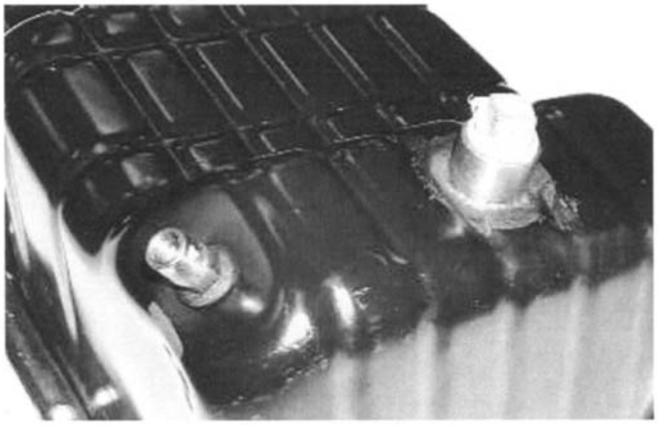

FIG. 6 Oil Pan

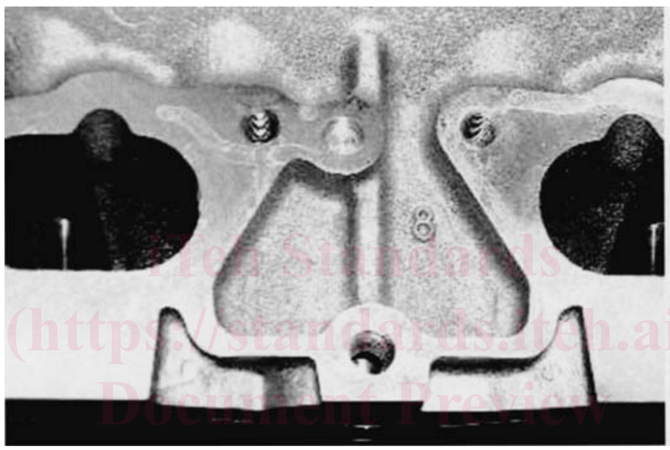

FIG. 7 Cylinder Head

6.3.12.6 *Crankcase Pressure*—Attach the crankcase pressure sensing line to a fitting welded to the dipstick tube. Locate this fitting approximately (80 ± 10) mm from the top of the dipstick tube (see Fig. 8). The sensor shall be capable of measuring positive and negative pressure. If using a manometer, install a liquid trap to prevent manometer fluid from entering the crankcase.

6.3.13 *Flow Rate Measurement Equipment*—Measure the engine coolant, fuel, and blowby flow rate. The accuracy and resolution of the flow rate measurement sensors and the complete flow rate measurement system shall follow the ASTM research report D02-1218.[21]

6.3.13.1 *Engine Coolant Flow Rate*—Determine the engine coolant flow rate by measuring the differential pressure drop across a venturi flowmeter. A Barco #70523 is suitable. Calibrate a differential pressure transducer to provide an output (litres per minute).

FIG. 8 Dipstick Tube