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STANDARD TEST METHOD FOR EVALUATION OF AUTOMOTIVE ENGINE OILS IN THE SEQUENCE IVA SPARK-IGNITION ENGINE[1]

1. Scope

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 method is designed to simulate extended engine idling vehicle operation. The Sequence IVA Test Method uses a Nissan KA24E engine[2]. 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[3].

1.2 The values stated in either SI units or in other units shall be regarded separately as standard.

1.3 *This standard does not purport to address all 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 specific Safety Precautions.*

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2. Referenced Documents

2.1 *ASTM Standards*

D 287 Test Method for API Gravity of Crude Petroleum and Petroleum Products (Hydrometer Method)[4]
D 323 Test Method for Vapor Pressure of Petroleum Products (Reid Method)[4]
D 381 Test Method for Existent Gum in Fuels by Jet Evaporation[4]
D 445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and the Calculation of Dynamic Viscosity)[4]
D 525 Test Method for Oxidation Stability of Gasoline (Induction Period Method)[4]
D 3525 Test Method for Gasoline Diluent in Used Gasoline Engine Oils by Gas Chromatography[5]
D 4485 Specification for Performance of Engine Oils[5]
D 5185 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[6]
D 5302 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[6]
D 5844 Test Method for Evaluation of Automotive Engine Oils for Inhibition of Rusting (Sequence IID)[6]
E 29 Practice for Indicating Which Places of Figures are to be Considered Significant In Specifying Limited Values[7]

G 40 Standard Terminology Relating to Wear and Erosion[8]
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RR D02-1218 Instrumentation Task Force Report to the ASTM Technical Guidance Committee[9]

2.2 *API Standards*
API 1509 Engine Oil Licensing and Certification System[10]

2.3 *SAE Standards*
SAE J183 Engine Oil Performance and Engine Service Classification[11]
SAE J254 Instrumentation and Techniques for Exhaust Gas Emissions Measurement[11]

2.4 *ANSI Standards*
MC96.1 Temperature Measurement - Thermocouples, 1975[12]

2.5 *ASME Standards*
B46.1 Standard for Surface Texture (Surface Roughness, Waviness, and Lay)[13]

2.6 *JASO Standards*
M 328-95 Valve-train Wear Test Procedure for Evaluating Automobile Gasoline Engine Oils[14]

2.7 *CEC Standards*
CEC-L-38-A-94 Peugeot TU-3M/KDX Valve-train Scuffing Wear Test[15]

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 (**D 5302**).

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[16])**.

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 **(D 5844)**.

3.2 *Definition(s) of Term(s) 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. An example is: 6-10-175 represents the 175th Sequence IVA test conducted on test stand 6 and the 10th 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. An example is: 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 2.389-L, in-line 4-cylinder, 4-cycle, water-cooled, port fuel-injected gasoline engine.[17] 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.

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. 50-min of Stage I and 10-min of Stage II 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 weight of used oil vs. 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 1-L final drain sample for 90-days. Retain the camshaft and rocker arms for 6-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 4485, API 1509, SAE J183, and ILSC GF 3.

6. Apparatus

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 2.389-L, in-line 4-cylinder, 4-cycle, water-cooled, port fuel-injected gasoline engine[17], 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 @ 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 Build-up and Measurement Area*
The ambient atmosphere of the engine build-up 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 re-circulation 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 A2. 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 A2. Remove the hose from the exhaust manifold to the EGR. Plug the EGR supply port in the rear of the exhaust manifold with a pipefitting.

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 with a fixed resistance of 300-Ω at the wiring harness of the ECM.

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 the approximate settings of: AC, high frequency, pedal/rheostat-operated 220-A, and 4043 aluminum 3-mm filler rod, 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.

Fig. 1 - Modified Water Pump

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 A2, between the engine oil filter adapter block and the oil filter, using a gasket as shown in Annex A2. 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. Use flexible hoses (16-mm diameter) of approximately 0.5-m length to connect process water to the oil cooler.

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 assembly is replaced. Normally, this allows sixteen tests to be conducted using the same oil cooler. Recommend replacing any hoses to the oil cooler when installing a new oil cooler.

6.2.8 *Ignition Power Supply*

Use a 15A direct-current 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 works[18]).

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:

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 Temp Sensor	65M (Install 300-Ω resistor)
Throttle Position Sensor	66M
Injectors 1 - 4	72M, 73M, 74M, 75M

Intake Air Temp 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 the sensor configurations, and compliance with Data Acquisition and Control Automation II.[16]

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 attenuation, and computer digital filtering. Use single-pole type filters for attenuation. Only use grounded thermocouples for temperature sensors.

TABLE 2
SYSTEM TIME RESPONSE

Parameters	**Maximum Time Response (one time constant)**
Temperatures	2.5-s
Pressures	1.6-s
Coolant Flow	2.5-s
Torque	2.0-s
Speed	1.8-s

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 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.

TABLE 3
UPPER AND LOWER CONTROL LIMITS

PARAMETER	L	U
Coolant Flow	29.8	30.2
Coolant Out Temperature,	49.88	50.12
Stage I & II	54.88	55.12
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, Stage	48.7	49.3
I & II	58.7	59.3
Speed,	793.5	806.5
Stage I & II	1493.5	1506.5
Torque	24.5	25.5
Rocker Cover Air Flow	9.5	10.5

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 an inertia of 0.75 ± 0.15-kg-m^2 to ensure satisfactory control of engine speed at 800-rpm, 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 A6 for Safety Precautions.

6.3.3 *Dynamometer Speed and Load Control System*

To improve laboratory reproducibility for transient control of engine speed and torque, the drive-line 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.

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

The dynamometer speed and load control systems shall be capable of maintaining the steady state operating set points within the performance envelope (i.e. quality index established by the industry matrix testing program).

Two types of full closed-loop speed and load 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 load 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, see 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 and 6.3.11.8.

6.3.4.3 *Intake Air Flow*
Do not measure for intake air flow.

6.3.4.4 *Intake Air Temperature*
For final control of the engine 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 6-cm^2 will provide sufficient flow without stagnation. If additional airflow is required to stabilize air temperature, it is permissible to install a nominal 1-cm bleed hole in the air filter housing. Install the inlet temperature sensor in the air cleaner, centered at

the inlet to the air cleaner, 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 (approximately 5-cm left and 8-cm front of the right rear corner of the assembly). This location senses the pressure before entering the air cleaner element.

6.3.5 *Fuel Supply System*
This test method requires approximately 200-L of unleaded Haltermann KA24E Green test fuel[19] 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 re-circulated 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 model D-6 is suitable[20]). 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 between 15 and 30°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 re-circulating 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 A6 for Safety Precautions.

Use the production exhaust pipe front length (minimum 0.5-m), 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 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, remove water periodically throughout the 100-h test if exhaust pressure fluctuations are observed.

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 approximately 3-cm 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 grounded thermocouple. Install the thermocouple in a welded fitting attached to the exhaust pipe at a location 5-cm 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 5-cm 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 (% O_2, CO_2, CO, HC). If used, locate the exhaust sampling probe 10-cm 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 stochiometric 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 (Universal Exhaust Gas Oxygen sensor) to compute the AFR. Use a Horiba model MEXA 110 lambda analyzer[21], or the ETAS Lambda Meter LA3[22]. 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:

TABLE 4
AFR ANALYZER PARAMETERS[A]

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

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

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 that 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% de-ionized water and antifreeze solution, using an extended life ethylene-glycol based engine coolant. Texaco Havoline Tex-Cool[23] has been found to meet this requirement, see Annex A5. Configure the plumbing such that the total coolant system capacity, including engine and normal reservoir capacity, is 25-30-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 startup 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[24] 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 engine thermostat housing and secondary circuit to the jacketed rocker cover, 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 2-way control valve, ½-in. nominal internal diameter size, with a flow coefficient rating (C_v) 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 the Annex A3.

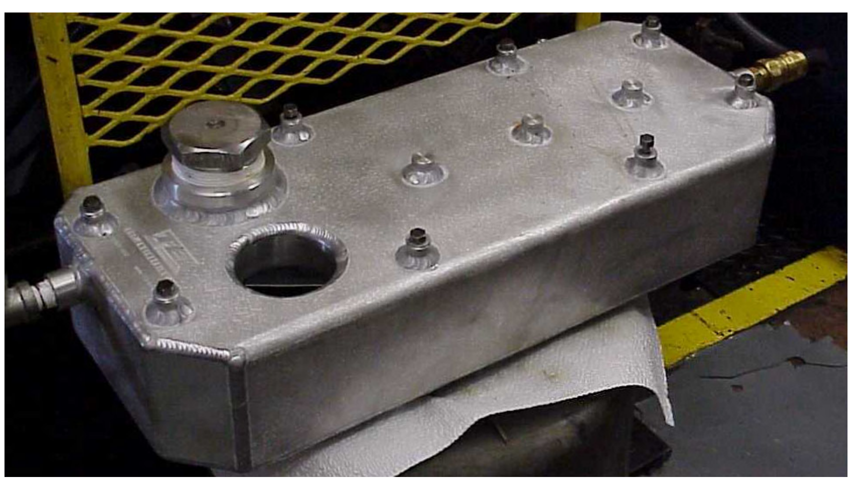


Fig. 2 - Jacketed Rocker Cover

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.

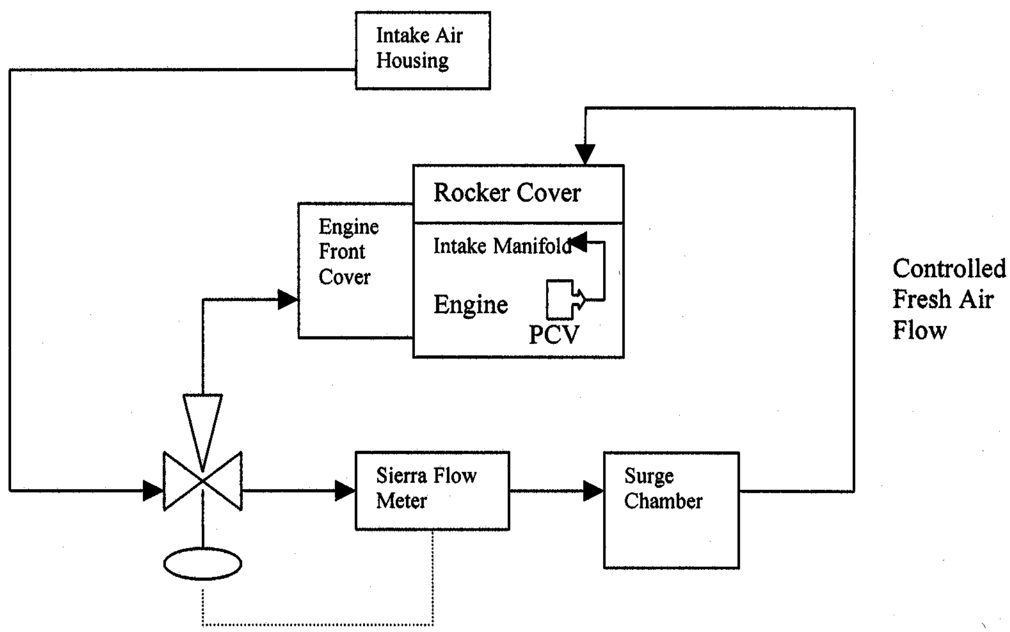


Fig. 3 – Crankcase Ventilation System Flow Diagram

Use a mass flow meter to measure the 10.0 Standard Liters per Minute (SLPM) fresh airflow to the rocker cover. This meter, corrected to standard conditions, shall have an accuracy of +/- 0.25-SLPM @ 10-SLPM. Full scale of the meter shall be a minimum of 20-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)[25]. Prior to the meter is a 3-way control valve. This valve should have a nominal size of 1.25-cm, with a flow coefficient rating of 2.5-C_v. 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.[26] 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 1.0-cm, 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 1.6-cm.

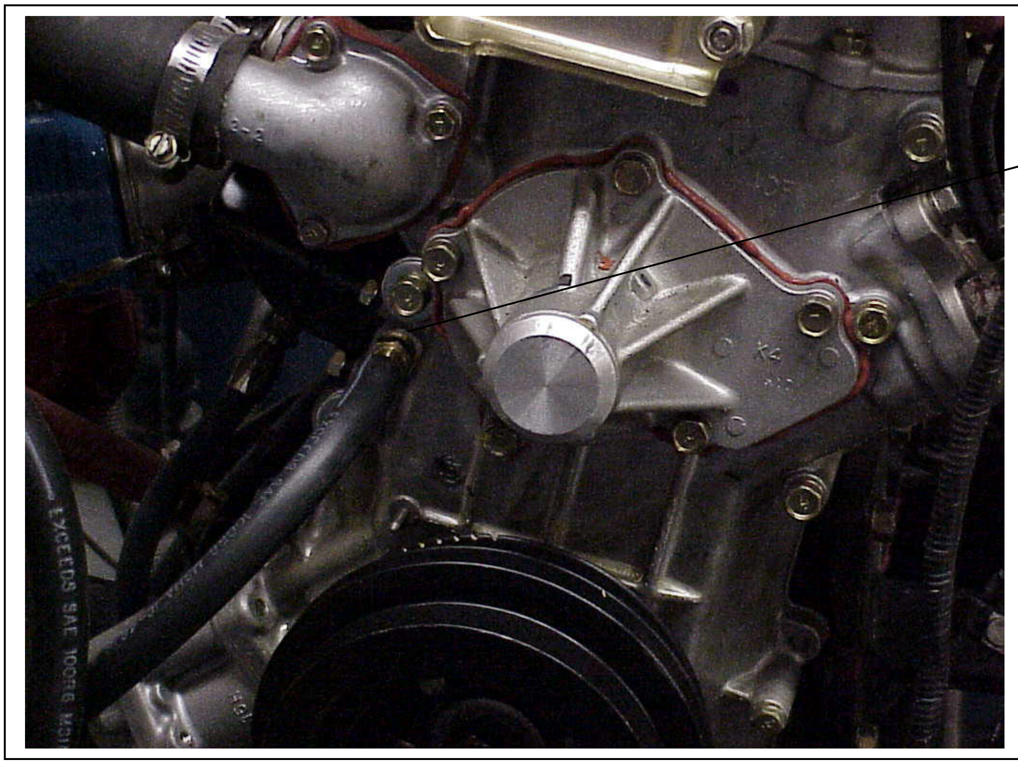


Fig. 4 - Location of Crankcase Ventilation Port to Engine Front Cover

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 6.3.11.1-6.3.11.11. 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 ANSI MC 96.1[12].

6.3.11.1 *Thermocouples*

All thermocouples except the intake-air thermocouple shall be premium, sheathed, and *grounded* 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 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 defined by ANSI MC96.1[12] . 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 (RTD's) 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-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, 5-cm from the intake gasket surface. Locate the sensor tip at 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*

Use the oil gallery temperature for monitoring the oil 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.

Fig. 5 - Oil Filter Block

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-mm inside the interior surface of the oil pan. Only monitor this temperature. It is not used for oil temperature control.

Fig. 6 - Oil Pan

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 1/8-in. close pipe nipple. Connect a 1/8-in. 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.

Fig. 7 - Cylinder Head

6.3.11.8 *Rocker Cover Gas Temperature*

Insert the rocker cover gas temperature sensor through the rear cylinder head rubber gasket (half moon rubber plug). Drill a 2-mm diameter hole in the rear rubber plug, 4-mm down from the top, flat surface, centered horizontally. Press fit a 3.2-mm diameter closed tip type J thermocouple, 4-cm length, into the drilled hole so that the tip of the sensor is 12-mm from the inside surface of the rubber plug.

6.3.11.9 *Intake-air*

Install the inlet temperature sensor in the air cleaner, centered at the inlet to the air cleaner as shown in Annex A1. If vibration of the temperature sensor is a problem, a support brace may be attached to the air cleaner assembly mounting stud and wing nut.

6.3.11.10 *Exhaust Temperature*

Measure the exhaust gas temperature using a 6-mm diameter grounded thermocouple installed in a welded fitting attached to the exhaust pipe at a location 5-cm downstream from the end of the collector. Install the sensor tip to the center of the exhaust pipe, see Annex A3.

6.3.11.11 *Fuel Temperature*

Measure the fuel temperature through one of the ports in a cross fitting located in the line between the fuel pump and the inlet of the fuel rail. Maintain the fuel temperature at this location between 15°C and 30°C.

6.3.11.12 *Dynamometer Load Cell Temperature*

Measure the dynamometer torque using a strain-gage transducer attached to the moment arm, and 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 through 6.3.11.8. 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 the Instrumentation Research Report 1218[9].

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 cross fitting, allowing ports to a pressure transducer, an analog pressure gauge, and to an oil sampling valve.

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 1/8-in. close pipe nipple. Connect a 1/8-in. 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.

6.3.12.6 Intake-air Pressure

To control the engine inlet air gauge pressure, install a disc type valve in the controlled air system supply duct. Locate the inlet air pressure sensing tube in the topside of the air cleaner assembly (approximately 5-cm left and 8-cm front of the right rear corner of the assembly). This location senses the pressure before entering the air cleaner element.

6.3.12.7 Crankcase Pressure

Attach the crankcase pressure sensing line to a fitting welded to the dipstick tube. Locate this fitting approximately 8-cm 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.

Fig. 8 - Dipstick Tube

6.3.12.8 *Exhaust Absolute Pressure*
Attach the exhaust pressure sensor tube to a welded fitting installed on the exhaust pipe located 5-cm downstream from the tube collector end. Orient this fitting circumferentially 60° to 90° from the exhaust temperature sensor. Install a condensate trap between the probe and sensor to accumulate water present in the exhaust gas.

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 Instrumentation RR 1218.

6.3.13.1 *Engine Coolant Flow Rate*
Determine the engine coolant flow rate by measuring the differential pressure drop across a venturi flow- meter. A Barco #705[24] is suitable. Calibrate a differential pressure transducer to provide an output (L/min). Take precautions to prevent air pockets from forming in the lines to the pressure sensor. Transparent lines or bleed lines or both are beneficial in this application.

6.3.13.2 *Fuel Consumption Rate*
Determine the fuel consumption rate using a mass flow-meter installed in the makeup fuel line. The flow-meter output shall allow real-time measurement of fuel rate (kg/h) and total fuel consumed (kg). A MicroMotion Model D-6 is satisfactory.

6.3.13.3 *Blowby Flow Rate Measurement System*
Use the apparatus shown in Annex A3 for measurement of the blowby flow rate. The measurement system routes the blowby through an external, sharp-edge orifice and into the engine intake manifold via an auxiliary PCV valve. Maintain the crankcase gage pressure at 0.0 - 0.025-kPa during system operation to minimize crankcase leakage.

Determine the blowby flow rate by measuring the differential pressure drop across the sharp-edge orifice. Use an inclined manometer or differential pressure sensor for the orifice differential pressure measurement. The crankcase pressure sensor shall have a 0-1-kPa range and be adequately damped to indicate a zero gage pressure.

The sharp-edge orifice is specifically designed for blowby flow rate measurement and shall be fabricated in strict compliance with the specifications available from the TMC. The assembly contains five orifices. Use a 3.175-mm orifice for the range (5 to 12-L/min) of blowby flow rate. The flow rate measurement orifice fabrication location and the blowby flow rate measurement may be obtained from the TMC.

6.3.14 *Process Cooling Water*
Provide the engine jacket coolant heat exchanger, the oil cooler, and the eddy-current dynamometer with process cooling water to maintain proper operating temperatures.

6.3.14.1 *Dynamometer Cooling System*

Water cool the eddy current electric dynamometer. Provide provisions for automatic test shutdown in the event the dynamometer cooling water is shutoff.

6.3.15 *Miscellaneous Apparatus Related to Engine Operation*

6.3.15.1 *Volumetric Graduates*

Use volume to measure the test oil quantity. Do not use weight, converted to a calculated volume. Recommend using a 1000-mL graduate and 500-mL graduate for volumetric determinations. All volumetric graduates shall be accurate to 2% of full scale. The large graduate resolution shall be 100-mL, and the small graduate resolution shall be 25-mL.

6.4 *Test Engine Hardware*

This section specifies the hardware required to build the test engine.

Use a new engine short block assembly for 16 tests, and a new a kit cylinder head assembly for the first test and the ninth test on that short-block. Conduct the engine break-in procedure prior to the first test and the ninth test on that short-block. The new engine is a long-block, as received. Use the camshaft and rocker arms in the new engine for break-in purposes only. Remove and modify the new cylinder head for the cylinder head oil gallery temperature and pressure measurement port, and for valve spring force calibration. Clean and reassemble the head using the break-in camshaft and rocker arms. Use the break-in procedure shown in 11.1.3. After break-in, replace the break-in camshaft and rocker arms with the new, camshaft and rocker arms parts.

6.4.1 *Nissan Supplied Component Kits*

Obtain the test parts and engines for this test method from Nissan North America[17], see Annex A2.

6.4.1.1 *Test Engine Long-Block*

Order the test engine long-block assembly (also called bare engine assembly) as shown in Annex A2. The test engine includes the block, pistons, rods, crankshaft, oil pan, front cover, cylinder head, and rocker arm cover final assembly. Use the camshaft and rocker arms during engine break-in only, but they are *not* official test parts. Use the short-block shown in Annex A2 for 16 tests. Use the original cylinder head for tests 1 through 8 of the 16 conducted on the short-block.

6.4.1.2 *Stand Set-Up Kit*

There are four component kit parts that comprise the *stand set-up kit*, see Annex A2. These four component kits include crankshaft pulleys, flywheel, intake and exhaust manifolds, air cleaner, fuel injection system, EGR block-off plate, ignition distributor, wiring, starter motor, fuel pump, exhaust pipe, and oil cooler.

Use one of each of the four component kit parts to configure one test installation.

6.4.1.3 *Test Kit*

For every official test conducted, use 1 test kit. This kit includes a camshaft, 2 rocker shafts, 12 rocker arms, 3 oil filters, and 4 spark plugs. The test kit camshaft and rocker arms are considered critical test parts. Do not substitute critical test parts with any other dealer, or after-market supplied hardware.

6.4.1.4 *Cylinder Head Replacement Kit*

Every engine short-block is used for 16 tests. Use the original cylinder head for tests 1 through 8 on that short-block. After the 8th test, install a new replacement cylinder head for tests 9 through 16 on that short-block. To assemble and install the bare cylinder head, use 1 gasket and seal kit. Install new calibrated valve springs, intake and exhaust valves with the replacement head, see Annex A2. When the replacement head is installed onto the engine, use the original supplied camshaft and rocker arms for conducting another *break-in* prior to test number 9.

6.4.2 *Procurement of Critical Parts*

The test camshaft and rocker arms are Critical Engine Parts for this test method. Obtain these parts by annual orders placed through Nissan North America. Do not use dealer, service, or after-market camshafts and rocker arms for this test method.

6.4.3 *Required New Engine Parts*

This test method is a flush-and-run type test. For each test, the camshaft and rocker arms are replaced. Use all the parts in test kit number 13000-40F85 as shown in Annex A2.

6.4.4 *Reusable Engine Parts*

Replace the engine short-block and oil cooler every 16 tests, and the cylinder head every eighth test. If the engine demonstrates deterioration (excessive blowby or oil consumption or fuel dilution; poor compression; low oil pressure; clearances beyond service limits; stripped fasteners) prior to this expected life, replace the engine and break-in and acceptable calibration test(s) conducted prior to official non-reference oil testing. Only conduct 16 tests on a short-block or the oil cooler, and no more than eight tests allowed on a cylinder head.

Replace the PCV valve, fuel filters, rocker cover gaskets, and air filter element after eight tests (when a new engine or a new cylinder head is installed). Replace the ignition distributor when a new engine is installed.

Replace the spark plugs for each test, just prior to the oil flush, see 9.8.2. Gap the spark plug at 0.99-mm (0.03-in.).

Reuse the jacketed rocker arm cover, oil pan, oil cooler, flywheel, intake and exhaust manifolds, throttle body, modified dummy water pump, spark plug wires, fuel injection system components, and engine sensors, as long as they continue to function properly.

6.5 *Special Measurement and Assembly Equipment*

This section describes the special apparatus, tools, and equipment required for engine measurement and assembly. Routine laboratory and workshop items are not included. Specific engine tools are shown in Table 5.

TABLE 5
TEST TOOLS

Item
3/8-in. Drive Impact Gun
3/8-in. Drive Speed Handle
3/8-in. Drive Rachet
3/8-in. Drive 4-in. Extension
3/8-in. Drive Rachet
Medium Flat Head Screwdriver
Large Flat Head Screwdriver
5/8-in. Wrench, Combination
5/8-in. Spark Plug Socket, 3/8-in. Drive
27-mm Deep Socket, 3/8-in. Drive
24-mm Impact Deep Socket, 3/8-in. Drive
12-mm Deep Socket, 3/8-in. Drive
10-mm Deep Socket, 3/8-in. Drive
Digital Bore Gauge w/ Metric Head
Dial Indicator Set w/ Magnetic Base
Mounting Plate for Dial Indicator
1-2-in. Digital Micrometer
Spark Plug Gapping Tool
Suction Device (Syringe and Tubing)
Wooden Wedge Tool (see Annex A4)
Utility Rocker Shafts
Pin Vise and 1.17-mm Diameter Drill Bit

6.5.1 *Camshaft Lobe Measurement Equipment*
Trace the camshaft lobes with a surface texture profilometer system. Use a surface measurement profilometer with real time digital display and graphical output capability. The vertical scale graphical resolution shall be capable of 1-micrometer per graph division. The profilometer shall be capable of traversing at least 100-mm, with a straightness accuracy equal to or less than 1-μm per 100-mm of traversed length. Use the profilometer pickup without a skid. Use a conical or spherical diamond tip stylus, with a nominal radius of 5-μm. The nominal traversing speed is 0.50-0.75-mm/s. A computer interface is recommended.

The Precision Devices, Inc. - MicroAnalyzer 2000 system[27], see Fig. 9, a computer-driven profilometer, may be used. Equip the profilometer with custom V-blocks, see Annex A2, for holding the work-piece (the camshaft on its journals), and an optical angle encoder for determining the cam shaft angular position see Annex A2. View the data from the trace in the profile mode, allowing an analysis of the texture and waviness of the trace. Configure the instrument software for a 2-point line texture leveling at the unworn edges of the cam lobe. Use this reference line for wear measurements. Display the profile waviness, using the Gaussian smoothing filter, set at 0.25-mm cutoff length, and do not remove the filter width at the ends of the texture. Base the lobe wear measurement upon the vertical dimension between the horizontally positioned, 2-point leveling line (reference line) and the lowest point in the waviness profile.

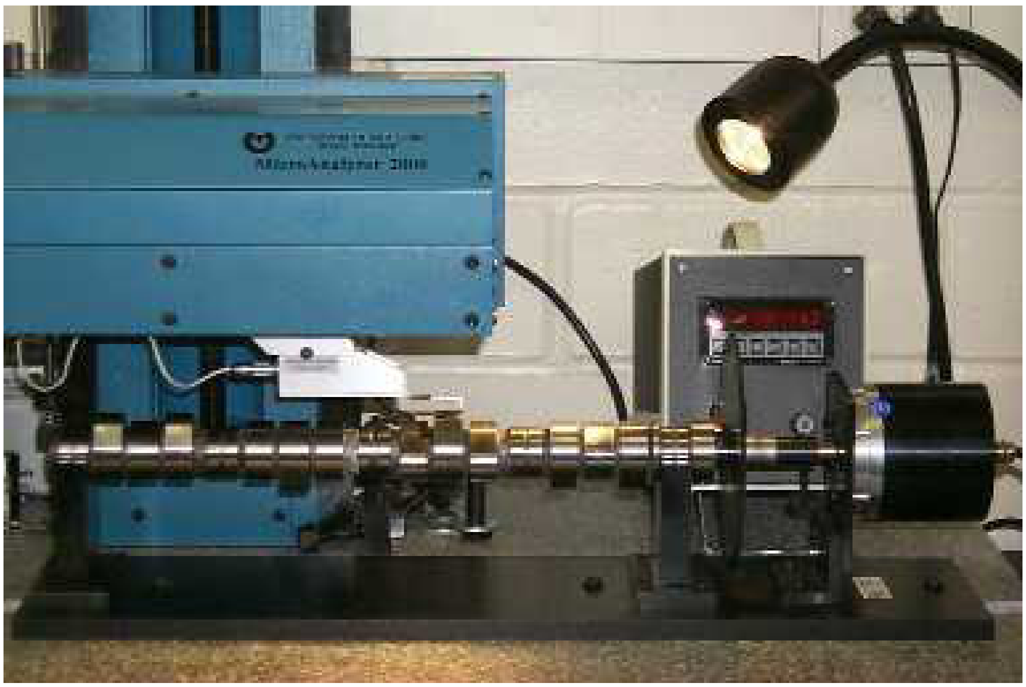


Fig. 9 - Cam Lobe Measurement Apparatus

6.5.2 *Unassembled Valve Spring Calibration Device*

Use a device to screen inner and outer valve springs before assembly in the cylinder head. Measure the individual spring loading at various compressed heights according to Annex A4. The tester shall be accurate to 2% and a resolution of 5-N.

7. Reagents and Materials

Use 13-L of the non-reference test oil sample to perform the 100-h Valve-train Wear test.

7.1 *Coolant for Engine and Rocker Arm Cover*

De-mineralize (less than 0.29-g/kg) the coolant or use distilled water mixed with an extended-life ethylene glycol antifreeze/coolant at a 50% volume ratio.

7.2 *Fuel*

Use Haltermann KA24E Green test fuel for this test method as shown in Annex A5. It is dyed green to preclude unintentional contamination with other test fuels. Use approximately 200-L of fuel for each test (100-cycles). This fuel has a hydrogen-to-carbon ratio of 1.80 to 1.

7.2.1 *Fuel Approval Requirements*

The TMC approves the fuel. Base fuel batch acceptance upon the physical and chemical specifications given in Annex A5. Engine validation tests are not necessary for fuel batch acceptance.

7.2.1.1 *Authorization*

The TMC issues a memorandum authorizing the use of a new Haltermann KA24E Green test fuel batch.

7.2.2 *Fuel Analysis*

Monitor the test fuel using good laboratory practices. Analyze each fuel shipment to determine the value of each parameter for existent gum as described in Test Method D 381, RVP as described in Test Method D 323, and API Gravity as described in Test Method D 287. Compare the results to the original values supplied by the fuel supplier. The analytical results shall be within the tolerances shown in parentheses beside each parameter. This provides a method to determine if the fuel batch is contaminated or has aged prematurely. If any analytical result falls outside the tolerances, the laboratory shall contact the fuel supplier for problem resolution.

7.2.2.1 *Fuel Deterioration*

Analyze the fuel semi-annually to ensure the fuel has not deteriorated excessively or been contaminated in storage.

7.2.2.2 Analyze the fuels using Test Methods D 287, D 323, D 381, and D 525.

7.2.3 *Fuel Shipment and Storage*

Ship the fuel in containers with the minimum allowable venting as dictated by all safety and environmental regulations, especially when shipment times are anticipated to be longer than one week. Store the fuel in accordance with all applicable safety and environmental regulations. If the *run* tank has more than one batch of fuel, document the most recent batch in the test report. Do not *top-off* the *run* tank with the new fuel batch unless the tank is *less than 10% full*.

7.3 *Lubricating Oils*

7.3.1 *Break-in Lubricating Oil*

An engine break-in procedure, see section 11.1.3, is immediately conducted following the replacement of new, major engine components (i.e. engine short-block and/or cylinder head). Use the proper reference oil, REO 926-2, from the TMC for the break-in procedure. Use approximately 3.5-L of this reference oil for each break-in procedure.

7.3.2 *Lubricant for Hydraulic Lash Adjusters*
The rocker arms hydraulic lash adjusters may ingest air during shipping and handling. Prior to installing the rocker arms in the test engine, prime the lash adjusters with an SAE 20 API *SA* grade oil, as shown in SAE J183[11]. Place the rocker arms on their side, for a minimum of 1-hour, in a container filled with the *SA* grade oil to allow trapped air to bleed out. If using a vacuum chamber, reduce the minimum soak time from 1-h to 5-min. Immediately install the rocker arms in the engine after the rocker arms are removed from the oil-filled container. Do not allow the rocker arms to lay on their side after air has been bled.

7.3.3 *Short-block Assembly Lubricant*
For engine short-block inspection and reassemble, use SAE 20 API *SA* grade oil as the assembly lubricant.

7.4 *Miscellaneous Materials*

7.4.1 *Solvents and Cleansers*
Use only the solvents and cleansers Aliphatic Naphtha, Ethyl Acetate, Pentane, Cylinder Block and RAC Cleaning Detergent - tri-sodium phosphate detergent, and any commercial coolant cleanser for this test method, see 6.1.3.

7.4.2 *Sealing Compounds*
Use a silicone based gasketing compound during engine assembly (e.g. oil pan). Use only the silicone gasket shown in Annex A2.

8. Oil Blend Sampling Requirements

8.1 *Sample Selection and Inspection*
The non-reference oil sample shall be uncontaminated and representative of the lubricant formulation being evaluated.

Note 2: If the test is registered using the American Chemistry Council[28] protocols, the assigned oil container formulation number shall match the registration form.

8.2 *Non-reference Oil Sample Quantity*
Use a minimum of 13-L of new oil to complete the Sequence IVA test, including the oil flushes. Normally the supplier provides a 15-L new oil sample to allow for inadvertent losses.

8.3 *Reference Oil Sample Quantity*
The TMC provides a 15-L reference oil sample for each stand calibration test.

9. Preparation of Apparatus
This section details those recurring preparations necessary for test operation. This section assumes the engine test stand facilities and other hardware described in 6 are in place.

9.1 *Test Stand Preparations*

9.1.1 *Instrumentation Calibration*
Calibrate all sensors and indicators before or during the test for the type instrumentation used. See Section 10 for the calibration requirements.

9.1.2 *Oil Cooler Cleaning*
Use clean aliphatic naphtha followed by forced-air drying to clean the oil cooler, if required, see 6.1.3.

9.1.3 *Air Cleaner Filter*
Replace the air cleaner filter element every eight tests, or more frequently if intake air pressure is insufficient.

9.1.4 *Draining Exhaust Piping*
Prior to the start of each test, drain the low point of the exhaust piping to eliminate water accumulation. Drain water during a test if exhaust pressure control becomes unstable.

9.1.5 *External Hose Replacement*
Inspect all external hoses used on the test stand and replace any hoses that have become unserviceable. Check for internal wall separations that could cause flow restrictions. Inspect and replace the oil cooler coolant hoses when the oil cooler is replaced (every 16 tests).

9.1.6 *Stand Ancillary Equipment*
Service the dynamometer and drive-line components, as required. The dynamometer torque measurement shall be accurate (no unaccounted forces from hoses; load cell temperature gradients; or trunnion bearing hysteresis).

9.2 *General Engine Assembly Preparations*
Follow and complete the assembly preparation functions shown in Table 6. Different laboratories and engine assemblers may complete the functions in slightly different sequences. Perform the functions in a specific manner or at a specific time in the assembly process as shown in Table 6. Complete any assembly instructions not detailed below according to the instructions in Annex A4. Follow the bolt torque specifications shown in Table 6:

TABLE 6
BOLT TORQUES

Bolt Types	Torques
Cylinder head bolts	82° beyond 29-N·m
Camshaft Sprocket bolt	137-N·m
Intake Manifold bolts	19-N·m
Camshaft cap bolts	39-N·m

Exhaust Manifold bolts	22-N·m
Rocker Cover bolts	9-N·m

9.3 *Cylinder Head Preparations*

Modify, clean, assemble, and calibrate new test engine cylinder heads before using the cylinder head for testing purposes. A cylinder head may be used for eight tests. The measurements shown in 9.3.3 are recorded on the appropriate report form.

9.3.1 *Cylinder Head Modification*

Assess the cylinder head oil gallery from the intake side of the head through the vertical passage, centered front-to-rear. This access port is drilled in a bossed area of the head, and located 10-mm upward from the deck surface of the head. The access port is drilled and tapped to accept a 1/8-in. close pipe nipple.

9.3.2 *Cylinder Head Cleaning*

Complete the modification shown in section 9.3.1, then thoroughly clean the cylinder head using aliphatic naphtha spray. Clean the valve guide bores and oil passages using a nylon bristle brush in conjunction with the aliphatic naphtha spray, see 6.1.3. Then rinse the head with a clear water spray, and dry with forced-air.

9.3.3 *Camshaft Journal Clearance*

Use only the vertical measurements to determine the overall cam journal to bearing clearance (front and rear). This clearance may not exceed 0.120-mm. Replace the cylinder head and/or camshaft, if the clearance exceeds 0.120-mm.

9.3.3.1 *Camshaft Bearing Bore Measurements*

Install cam-bearing caps, without the camshaft, with rocker shafts and tighten the lubricated cap bolts to 39-N·m.

(a) When the cylinder head is new, perform a comprehensive set of measurements of the five cam bearing bores to ensure the bores are sized to specification, and that the bores are round and not tapered. Measure the front and rear of each cam bore in three directions - vertical, and two measurements at 45° from vertical. This results in six measurements for each cam bore. The standard inner diameter specification is 33.000 to 33.025-mm. Run-out and taper shall not exceed 0.025-mm.

(b) After the first test on a cylinder head, use only the vertical dimension of the front and rear of each cam bore to determine the cam journal to bearing bore clearance before subsequent tests.

9.3.3.2 *Camshaft Journal Measurements*

Measure the front and rear outer diameters of each of the 5 camshaft journals. The standard outer diameter is 32.935 to 32.955-mm. Use these measurements to calculate cam journal to bearing bore clearance.

9.3.3.3 *Camshaft End Play*
With the camshaft installed in the cylinder head, measure the camshaft end play with a dial indicator. If the endplay exceeds 0.07 to 0.20-mm, do not use that cylinder head/camshaft combination.

9.3.4 *Cylinder Head Assembly*
Assemble the cylinder head using the instruction in Annex A4. Lap the valve faces to their respective valve seats to ensure a proper seal. Using a new cylinder head precludes replacing or machining the valves, valve guides, and valve seats. Use SAE 20 API *SA* lubricant to lubricate the valve stems and valve guides upon assembly.

9.3.5 *Initial Valve Spring Screening*
Measure and record the valve spring free length and out-of-square dimensions. Table 7 illustrates the springs specifications. If the springs are within the specifications for free length and out-of-square dimensions, measure the load on the unassembled valve spring calibration device. The valve spring parameters shall be within the specifications shown in Table 7. Determine the final valve spring load with the valve springs installed in the cylinder head, then springs slightly outside the load specification may be within the load specification when installed in the cylinder head, and using shims.

TABLE 7
VALVE SPRING SPECIFICATIONS

Parameters	**Intake**	**Exhaust**
Free Height		
outer	57.44-mm	53.21-mm
inner	53.34-mm	47.95-mm
Pressure		
outer	604.1 N @ 37.6-mm	640.4 N @ 34.1-mm
inner	284.4 N @ 32.6-mm	328.5 N @ 29.1-mm
Out-of-Square		
outer	2.5-mm	2.3-mm
inner	2.3-mm	2.1-mm

9.3.6 *Installed Valve Spring Calibration*
Lubricate each valve seal and valve stem with SAE 20 API *SA* oil. Install the valve seal over the

end of the valve stem with a plastic installation cap in place. Carefully seat the seals fully on the guides. Install pre-screened valve springs and retainers. When installing the valve springs and retainers, do not compress the springs excessively. Excessive spring compression may damage the valve seals.

9.3.6.1 *Assembled Force Calibration*
Measure and record the assembled valve spring loading with the valve spring head calibration fixture shown in Fig.10 and the part number in Annex A2.

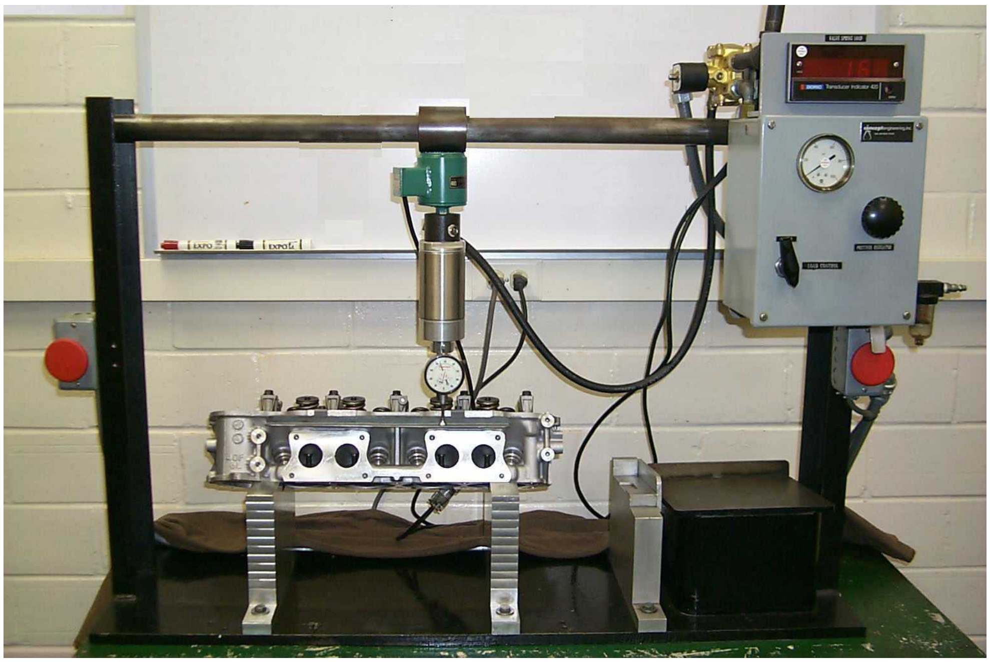


Fig. 10 - Head Calibration

The procedure detailed below includes measuring each installed valve spring at two deflection points, see Table 8.

(a) Check the apparatus load cell calibration for accuracy.

(b) Install the cylinder head holding fixtures Annex A3 for the test cylinder head.

(c) Position the test cylinder head in the holding fixture with intake valve springs accessible.

(d) Install the rocker cover gasket rail extension bracket on the test cylinder head.

(e) Starting with the intake valve spring No. 1 (far right), position the air cylinder and load cell on valve tip to allow compressing of the valve spring.

(f) Position the dial indicator with the plunger on the rocker cover gasket rail extension bracket.

(g) With no air pressure to the cylinder, the dial indicator shall read between 2.5-mm and 5.00-mm deflection pre-load against the rocker cover gasket rail extension bracket. This will allow determination of positive or negative valve displacement.

(h) Adjust the dial indicator face to position the needle at the zero mark with no air pressure to the air cylinder.

(i) Adjust the air regulator to provide enough air pressure to the air cylinder for compression of the valve spring to occur. If a valve spring has already been measured, then the air regulator should already be adjusted.

(j) Actuate and discharge the air cylinder in a rapid and consistent manner, several times, to compress the valve spring and assure proper movement of the valve-train components.

(k) Actuate the air cylinder and adjust the air regulator to decrease the air pressure to allow the valve to close to the fully seated position.

(l) Adjust the air regulator to gradually apply force to achieve exactly 1.27-mm valve opening. Record the indicated load (N) at 1.27-mm.

(m) Continue to adjust the air regulator to gradually apply force to achieve exactly 9.86-mm valve opening. Record the indicated load (N) at 9.86-mm.

(n) Discharge the air cylinder without adjusting the air regulator, and allow the intake valve to close to the fully-seated position. Position the air cylinder / load cell to check the remaining seven intake valve springs. Conduct steps e) through m) above for each remaining intake valve spring.

(o) Position the test cylinder head in the holding fixture with the exhaust valves accessible.

(p) Install the rocker cover gasket rail extension bracket on the cylinder head, and position the air cylinder and load cell to check the four exhaust valve springs. Conduct steps e) through m) for each exhaust valve spring.

(q) Replace any springs that are too strong. Use shims to adjust springs to a higher installed force. Recheck spring calibration and record indicated load of any replaced or shimmed springs.

TABLE 8
SPRING SPECIFICATIONS

Intake Valve Spring		Exhaust Valve Spring	
Force	**Deflection**	**Force**	**Deflection**

889 ± 35 N	9.86-mm	969 ± 35 N	9.86-mm
438 ± 35 N	1.27-mm	447 ± 35 N	12.7-mm

9.4 *Short Block Preparations*
Not normally required.

9.5 *Short Block Assembly*
Use SAE 20 API *SA* grade oil as the assembly lubricant for inspection and reassemble the engine short-block.

9.6 *Final Engine Assembly*
Use the engine short-block assembly as received from Nissan. Alternatively, disassemble, inspect, and reassemble the engine short- block according to Annex A4. For this test, maintain the piston ring end gaps to factory specifications. Do not increase the ring end gaps to elevate engine blowby. Observe the corrected blowby rate at 6.0 to 10.0-L/min during the Stage I operating condition.

9.6.1 *Cylinder Head Installation*
The parts kit, see Annex A2, include the assembled new cylinder head. The valve seats and valve faces are machined to Nissan production specifications. Laboratory inspection may reveal the need to lap the valve seat and valve faces. Perform the following before assembling the cylinder head:

9.6.1.1 Stamp with a laboratory specific identification code.

9.6.1.2 Modified for measurement access to the cylinder head oil gallery, see 6.3.11.7.

9.6.1.3 Measured for cam bearing bore diameter, specification 33.000 - 33.025-mm.

9.6.1.4 Cleaned with aliphatic naphtha and forced-air dried, see 6.1.3.

9.6.1.5 Reassembled according to Annex A4. Use SAE 20 API *SA* grade oil to lubricate valve guides and valve stems. Install new valve seals.

9.6.1.6 Measure and adjust installed valve spring force to test specifications, see 9.3.5.

Install the modified and measured cylinder head on the short-block using a new cylinder head gasket, see Annex A2. Torque the head bolts in proper sequence, and in five stages according to Annex A4. Use an angle-meter torque wrench to properly torque the cylinder head bolts.

9.6.2 *Pre-Test Cam Shaft Inspection and Measurement*

9.6.2.1 Visually inspect the pre-test camshaft lobes and bearing journals for rust, scratches, gouges, chipped areas, and other surface defects. Reject camshafts that are judged unsuitable for test.

9.6.2.2 Check the pre-test camshaft for straightness. With the camshaft supported by Vee-blocks at journal No(s). 1 and 5, measure the camshaft run-out at the center journal. Reject the camshaft if the total indicator reading of the run-out exceeds 20-µm.

9.6.2.3 Using a micrometer or profilometer traces, perform pre-test measurements across the nose of each camshaft lobe. Reject any camshaft that exhibits taper, concavity, or convexity of more than the 10-µm variation.

9.6.3 *Camshaft Installation*

After modifying, cleaning, assembling and calibrating the cylinder head, install the measured test camshaft. Clean the camshaft with aliphatic naphtha and force-air dry, see 6.1.3. Coat the lobes and journals with clean *test oil* only. Do not use REO 926-2 or SAE 20 API *SA* to lubricate the test camshaft.

9.6.3.1 Install the test camshaft, camshaft journal caps and dummy rocker shafts, and torque to 39-N·m. Install the camshaft sprocket and snug the sprocket bolt (do not torque to specification).

9.6.3.2 Measure and record the camshaft end-play and the camshaft sprocket run-out, see Annex A4.

9.6.3.3 Temporarily remove the test camshaft, camshaft sprocket, camshaft journal caps, and utility rocker shafts.

9.6.3.4 Pre-fill the cavities of the cylinder head under the camshaft with new test oil.

9.6.3.5 Oil the camshaft and journal bores with new test oil and install the test camshaft.

9.6.3.6 Install the camshaft journal caps in their proper positions.

9.6.3.7 Install the rocker shaft assemblies and loosely screw the bolts. Do not tighten the bolts.

9.6.3.8 Install the camshaft sprocket and timing chain, aligning the punch-mark with the glaring link. Torque the camshaft bolt to 135-N·m using the appropriate cam sprocket holding tool.

9.6.3.9 Center each individual rocker arm on its respective cam lobe, and then snug the ten rocker shaft bolts and torque to 39-N·m using the torque sequence in Annex A4.

9.6.3.10 Once installed, pour new test oil over the rocker arms, rocker shafts and camshaft. Excess oil will drain through the open oil pan drain-plug.

9.7 *Replacement of Valve-train Wear Parts*

The valve-train wear tests is a flush-and-run type procedure, except replace the valve-train test parts for each test. Use the following procedure when replacing these parts:

9.7.1 *Removal of Valve-train Wear Parts*

9.7.1.1 Disconnect wiring or hoses that hinder access to the rocker cover.

9.7.1.2 Remove the crankshaft pulley guard.

9.7.1.3 Remove the blowby fresh airline and the spark plug wire loom from the rocker cover.

Note 3: At Southwest Research Institute (SwRI), client test oil is poured over valve-train parts at test start before Flush 1, *NOT* during parts installation.

9.7.1.4 Remove the rocker cover.

9.7.1.5 Remove all four spark plugs.

9.7.1.6 Rotate the engine by hand to set piston No. 1 at *top dead center* on its compression stroke (align the timing indicator with 0° at the yellow mark on the crankshaft pulley). Position the dowel pin on camshaft front at the 12:00 position and align the punch-mark on the camshaft sprocket with the glaring link on the timing chain. This may require rotating the engine several times until the mark and glaring link line up.

9.7.1.7 Remove the front hoist bracket from the cylinder head. It may hang from the ground straps.

9.7.1.8 Remove the half-moon rubber plug from the front of the cylinder head.

9.7.1.9 Install the timing chain wooden wedge tool between timing chain at the tensioner using a large screwdriver to set in place.

9.7.1.10 Remove the camshaft bolt and sprocket using a 24-mm impact deep socket.

9.7.1.11 Remove the ten rocker shaft bolts according to Annex A4.

9.7.1.12 Carefully remove the rocker shafts and rocker arms. Avoid touching the rocker arm pads. The rocker arms shall remain assembled on the rocker shafts.

9.7.1.13 Remove the five camshaft journal caps. Number the caps for their location.

9.7.1.14 Carefully remove the test camshaft without damaging the lobes. Avoid touching the camshaft lobes.

9.7.1.15 Using a suction device, remove the used test oil that is trapped in the cavities of the cylinder head under the camshaft. Do not add this oil to the drained test oil. Properly discard this oil.

9.7.1.16 Bring the end-of-test parts, including the assembled rocker shaft assemblies to the engine disassembly area. Before disassembling the used rocker shaft assemblies, properly label the rocker arms.

9.7.1.17 Disassemble the rocker shaft assemblies.

9.7.1.18 Remove the reusable retainer clips from the used rocker shafts.

9.7.1.19 Clean the end-of-test camshaft and rocker arms with aliphatic naphtha solvent and pentane if necessary, then force-air dry, see 6.1.3. Deliver the cleaned camshaft to the measurement room, and the cleaned rocker arms to the rating area or place them in a desiccator.

9.7.2 *Installing New Valve-train Test Parts*

9.7.2.1 Obtain the new test parts, including the pre-measured test camshaft. See Annex A2 for a new parts listing with their corresponding part numbers for each turn-around.

9.7.2.2 Number the new rocker arms E1 – E4 and I1 – I8.

9.7.2.3 Clean the new camshaft, rocker shafts and rocker arms, as well as the used retainer clips, camshaft journal caps, camshaft sprocket, rocker cover and all bolts with aliphatic naphtha solvent and force-air dry, see 6.1.3.

9.7.2.4 Perform and record camshaft bearing journal diameter measurements.

9.7.2.5 Perform a bleed down of the rocker arms with built in hydraulic lash adjusters. Place the rocker arms in a container or vacuum chamber, fully submerging them in SAE 20 API *SA* grade oil. Using a vacuum chamber reduces the minimum soak time from 1-h to 5-min. Once the rocker arms are air bled, do not place them on their sides. Orient the rocker arms in their natural engine position.

9.7.2.6 Assemble the new rocker arms and used retainer clips on the new rocker shafts according to Annex A4.

9.7.2.7 Install and torque to 39-N·m the five camshaft journal caps and bare rocker shafts using the designated utility rocker shafts.

9.7.2.8 Perform and record camshaft bearing bore diameter measurements.

9.7.2.9 Remove the camshaft journal caps and utility rocker shafts.

9.7.2.10 Install the test camshaft, camshaft journal caps and dummy rocker shafts, and torque to 39-N·m. Install the camshaft sprocket and snug the sprocket bolt, and do not torque to specification.

9.7.2.11 Measure and record the camshaft end-play and the camshaft sprocket run-out according to Annex A4.

9.7.2.12 Remove the test camshaft, camshaft sprocket, camshaft journal caps, and dummy rocker shafts.

9.7.2.13 Pre-fill the cavities of the cylinder head under the camshaft with new test oil.

9.7.2.14 Oil the camshaft and journal bores with new test oil and install the test camshaft.

9.7.2.15 Install the camshaft journal caps in their proper positions.

9.7.2.16 Install the rocker shaft assemblies and loosely screw the bolts. Do not yet tighten the bolts.

9.7.2.17 Install the camshaft sprocket and timing chain, aligning the punch-mark with the glaring link. Torque the camshaft bolt to 135-N·m using the appropriate cam sprocket holding tool.

9.7.2.18 Center each individual rocker arm on its respective cam lobe, then snug the ten rocker shaft bolts and torque to 39-N·m using the torque sequence as shown in Annex A4.

9.7.2.19 After installation, pour new test oil over the rocker arms, rocker shafts and camshaft. Excess oil will drain through the open oil pan drain-plug.

9.7.2.20 Inspect the half-moon rubber plugs found on the front and rear of the cylinder head. Replace the plugs if necessary.

9.7.2.21 Install the half-moon rubber plug on the front of the cylinder head. Apply the proper amount of the Nissan silicone gasket maker to the bottom of the plug. Repeat for the half-moon rubber plug found on the rear of the cylinder head.

9.7.2.22 Inspect the rocker cover gasket and replace if necessary.

9.7.2.23 Install the rocker cover and torque in sequence to 8-N·m as shown in Annex A4.

9.7.2.24 Re-install the blowby fresh air line on to the rocker cover and tighten the clamp.

9.7.2.25 Install spark plug wire loom and reconnect any other wiring or hoses.

9.7.2.26 Install the front hoist bracket and torque the nuts to 20-N·m.

9.7.2.27 Install new spark plugs, see Annex A2. Gap the plugs to 0.99-mm and torque to 14-N·m.

9.7.2.28 Install the front pulley guard.

10. Test Stand Calibration and Maintenance

Verify the calibration status of the test laboratory and test engine with reference oils, which are supplied by the TMC. Conduct test stand calibration tests periodically to verify that proper severity level and precision are being achieved. A prerequisite to the conduct of reference oil calibration tests is the proper processing of computer acquired operational data, ensuring accuracy of measurements, and test stand preventative maintenance.

10.1 *Computer Data Acquisition*

The test stand log operational data using a computer data acquisition system with sensor configurations process is shown in 10.1.1 – 10.1.3.

10.1.1 *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 4-min of stage) operational conditions every 30-s or more frequently.

10.1.2 *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, cylinder head 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 corrective action with the next available transition plot.

10.1.3 *Signal Conditioning*

Do not exceed the controlled operational parameters for system time response as shown in Table 2. The system time response includes the total system of sensor, transducer, analog signal attenuation, and computer digital filtering. Use single-pole type filters for attenuation. For temperature sensors, grounded thermocouples are preferred, although ungrounded thermocouples are acceptable.

10.1.3.1 *Isolated Inputs*

If using grounded and sheathed thermocouples, use signal-conditioning modules to provide isolated inputs to the digital computer.

10.2 *Instrumentation Calibration*

Perform a thorough re-calibration adjustment of all instrumentation and transducers, including computer channels, whenever the test engine is replaced (normally after 16 tests), or not to exceed 180 days since the previous re-calibration. Perform a calibration check for critical parameters after the 8th test following a re-calibration adjustment. These critical parameters are:

10.2.1 Oil Gallery temperature

10.2.2 Coolant Out temperature

10.2.3 Intake Air temperature

10.2.4 Dynamometer torque

Perform additional calibration checks whenever operational data indicates an abnormality. Standards used for instrumentation calibration, shall be traceable to that countries National Standards Organization. Standard's accuracy shall be a minimum of four times better than the test stand instrumentation accuracy.

10.2.5 *Engine Load Measurement System (Torque)*
Scale the final readout of engine load in torque (N·m). Calibrate the load measurement and readout system with deadweights. Coolant flow through the dynamometer, reaction forces due to coolant plumbing, brinnelled trunnion bearings of the dynamometer, and may affect calibration by temperature excursions of the dynamometer electronic load transducer. The torque measurement accuracy shall be ± 0.2-N·m.

10.2.6 *Coolant Flow Measurement Systems*
Check the venturi flow-meter for calibration using a 50% water/glycol fluid controlled at 50°C. Calibrate the flow-meter as installed in the system at the test stand. Alternatively, the flow-meters may be detached from the test stand and calibrated, providing the adjacent upstream and downstream plumbing remain intact during the calibration process. Calibrate the flow-meters with a turbine flow-meter or by a total volume per unit time method. The coolant flow measurement accuracy shall be ± 0.3-L/min.

10.2.7 *Fuel Consumption Measurement Calibration*
Check the mass flow-meter or gravimetric systems for calibration when the test engine is replaced (normally after 16 tests), or not to exceed 180-days since the previous re-calibration. The fuel flow measurement accuracy shall be ± 0.05-kg/hr.

10.2.8 *Air-to-Fuel Sensor Calibration*
Re-calibrate the AFR meter per the instrument manufacturers recommended procedure when the universal (or wide-range) exhaust gas oxygen sensor is replaced.

10.2.9 *Temperature Measurement Calibration*
Check the engine oil-gallery, engine coolant-out, and intake-air temperature measurement sensors for calibration after eight tests. Check the other temperature sensors at least after 16 tests. The temperature measurement system accuracy shall be within ± 0.5°C of the laboratory calibration standard. The calibration standard shall be traceable to national standards.

10.2.10 *Pressure Measurement Calibration*
Check the pressure measurement systems for calibration when the test engine is replaced (normally after 16 tests), or not to exceed 180-days since the previous re-calibration. The exhaust pressure measurement accuracy shall be ± 1.0-kPa.

10.2.11 *Humidity of Induction Air Calibration*

10.2.11.1 Calibrate the primary laboratory measurement system at each test stand on a semi-annual basis using a hygrometer with a minimum dew point accuracy of ± 0.55°C @ 16°C. Locate the sample tap on the air supply line to the engine, between the main duct and 1-m upsteam of the intake air cleaner. The calibration consists of a series of paired humidity measurements comparing the laboratory system with the calibration hygrometer. The comparison period lasts from 20-min to 2-h with measurements taken at 1 to 6-min intervals, for a total of 20 paired measurements. The measurement interval shall be appropriate for the time constant of the humidity measurement instruments.

10.2.11.2 Verify that the flow rate is within the equipment manufacturer's specification, and that the sample lines are non-hygroscopic. Correct dew point hygrometer measurements to standard conditions (101.12-kPa) using the appropriate equation. Compute the difference between each pair of readings and calculate the mean and standard deviation of the twenty-paired readings. The absolute value of the mean difference shall not exceed 1.43-g/kg, and the standard deviation shall be not be greater than 0.714-g/kg. If these conditions are not met, investigate the cause, make repairs, and recalibrate. Maintain calibration records for 2-years.

10.3 *Apparatus Calibration and Maintenance*

10.3.1 *Cam Lobe Profilometer Calibration*
Follow the manufacturer's instruction for calibration and verification checks of the profilometer. The profilometer shall be calibrated at least annually.

10.3.2 *Head Fixture Calibration*
Calibrate the head fixture at least once every three months. The testing laboratory shall determine the calibration technique.

10.3.3 *Blowby Flow Rate Measurement System Maintenance*
Clean the blowby measurement apparatus at least weekly. Exercise particular care when cleaning the orifice meter assembly. Clean the 3-way valve by soaking the valve in solvent, see 6.1.3. Inspect the port passages and remove any carbonaceous deposits by scraping. When disassembling the valve for cleaning, properly seat the core upon re-assembly.

Note 4: Internal leakage within the 3-way valve may cause some of the blowby gas to pass directly to the intake manifold from the test PCV valve and result in erroneous blowby flow rate measurements.

10.4 *Test Stand Maintenance*

10.4.1 *Periodic Cleaning of Coolant System Plumbing*
Internally clean the engine coolant system plumbing every 16 tests by a chemical flushing method. Use any commercial radiator cleaner/flush chemical that is safe for vehicle use. After using the cleaner, flush the test stand coolant plumbing with fresh water, until clear. If using a flush cart, stronger chemicals may be used provided the engine coolant pumps are bypassed and the instrument transducers are not included in the flush, see 6.1.3.

10.4.2. *Oil Cooler Replacement*
Replace the oil cooler; see Annex A2, when replacing the short-block assembly. Normally, this

allows 16 tests to be conducted using the same oil cooler. Replace all hoses to the oil cooler, when installing a new oil cooler.

11. Procedure

When installing a new engine and cylinder head or both, conduct a break-in procedure, see 11.1.3, before running official 100-h tests. After completing the break-in, install the official test valve-train parts as shown in 9.7. Then conduct a double oil-flush procedure as shown in 11.2.2. After performing the double oil-flush, conduct the 100-h test as shown in 11.2.3. Use Annex A1 for Operational Conditions.

11.1 *Pre-test Procedure*

11.1.1 *Engine Coolant System Flushing*

When replacing the engine short-block (normally every 16 tests), clean the coolant system (including heat exchanger) before conducting the engine break-in. By using an external electric-driven coolant-circulating pump, the installed engine does not have to be running during the flush-cleaning process. Exclude sensitive components of the coolant flow meter from the flushing chemicals. Check the calibration of the coolant flow meter after flushing the coolant system.

11.1.1.1 Circulate the cooling system cleanser for 30-min at a target temperature of 50°C using the electric heating element for the coolant system.

11.1.1.2 Following the 30-min cleaning process, turn off the electric heater for the coolant system. Open the coolant system drain valves, add fresh water until the drains are clear, and the pH of the incoming and outgoing fresh water is unchanged. Fully drain the system.

11.1.1.3 Fill coolant system with a pre-mixed coolant consisting of 50/50 volume % mixture of the specified extended-life ethylene-glycol anti-freeze and deionized, de-mineralized, or distilled water. Operate the coolant pump to bleed air from the coolant system. Use this coolant charge for eight tests, or until replacing the engine or cylinder head.

11.1.2 *Engine Pre-lubrication*

The oil pump drive is directly connected to the engine crankshaft, which make it impractical to pressure lubricate the engine prior to startup. Build oil pressure quickly by pre-filling the oil filter with 325-mL of the appropriate lubricant. Bleed air from the rocker arm lash adjusters before installing these components in the engine. Immerse the rocker arms in a container of SAE 20 API *SA* grade oil while laying on their side. After soaking, keep the rocker arms straight up until installing to prevent air from entering the lash adjusters.

11.1.3 *Engine Break-in Procedure*

Conduct the break-in procedure, prior to lubricant evaluation testing, when installing a new engine short-block, new long-block, or new cylinder head on the test stand. The break-in allows setting the ignition-timing, purging air from the coolant system, checking for leaks in the various systems, and monitoring engine performance and tests stand instrumentation.

Follow the prescribed break-in conditions in Annex A1.1. Use the engine short-block assembly for 16 tests and the cylinder head assembly for eight tests. Perform new engine break-in once every eight tests. Use the following break-in steps:
11.1.3.1 Install the new test engine assembly with break-in test parts (camshaft, rocker arms, rocker shafts that come with pre-assembled cylinder head) onto the test stand.

11.1.3.2 Remove the oil drain plug and pre-fill the cavities of the cylinder head under the camshaft with break-in oil REO 926-2. Replace the oil drain plug.

11.1.3.3 Install the rocker cover.

11.1.3.4 Charge the coolant system with a 50/50 mixture of deionized water and extended life coolant. The coolant system capacity is 25-L.

11.1.3.5 Connect the stand to a fuel tank containing the test fuel.

11.1.3.6 Measure by volume, 3.5-L of break-in oil REO 926-2.

11.1.3.7 Install a new oil filter onto the engine. Perform the following steps to help the oil pressure build quicker during initial start-up. Do not install a dry oil filter on a test engine.

(a) Obtain a new break-in oil filter and remove it from its packaging.

(b) Measure out 325-mL of oil from the new break-in oil charge.

(c) Holding the oil filter upright; pre-fill the filter with the 325-mL of new break-in oil.

(d) Tilt the filter and slowly rotate it a full 360° several times to let the oil absorb into the entire fiber filter element.

(e) Install the filter onto the engine. By letting the oil absorb into the entire filter element, no oil should spill out when tilting the filter to install it.

11.1.3.8 Fill the engine with the remainder of the 3.5-L break-in oil charge.

11.1.3.9 Circulate and preheat the engine coolant to 50°C and then warm soak the engine for 10-min before initial startup.

11.1.3.10 Start the engine and crack the throttle open 5-10% to raise the engine speed, not to exceed 1500-r/min, to help the oil pressure build quicker. Once oil pressure has started to build control engine speed to 800-r/min, control torque to 10-N·m and ramp oil temperature to 50°C.

11.1.3.11 Once the engine achieves 800-r/min, use a timing light to set the ignition timing to 10° Before Top Dead Center (BTDC).

11.1.3.12 Start the break-in sequence and run through all 8 steps. Total running time is 95-min.

11.1.3.13 After completing the compression check, drain the engine oil for 30-min and remove the used oil filter.
11.1.3.14 Remove the rocker cover.

11.1.3.15 Using a suction device, remove the used break-in oil that is trapped in the cylinder head cavities under the camshaft.

11.1.3.16 Examine the used engine oil for unusual amounts of metal particles.

11.1.3.17 Remove the break-in test parts (camshaft, rocker arms, rocker shafts).

11.1.3.18 After completing break-in, check the engine assembly for anything unusual.

11.1.3.19 If acceptable, the engine is ready for test work.

11.2 *Engine Operating Procedure*
The Valve-train Wear test is a double-flush and run test. Conduct the oil flush and test operations as shown in 11.2.2 – 11.2.3, and in Annex A1.

11.2.1 *Preparation of Test*

11.2.1.1 Obtain the test oil and remove a 237-mL sample of new test oil for chemical analyses of the 0-h test oil. Use a 237-mL plastic container.

11.2.1.2 Install the test parts (camshaft, rocker arms, rocker shafts) according to procedure.

11.2.1.3 Remove the oil drain plug and pre-fill the cavities of the cylinder head under the camshaft with new test oil. Replace the oil drain plug once completed.

11.2.1.4 Re-install the rocker cover. Inspect and replace rocker cover gasket if necessary.

11.2.1.5 Connect the stand to a fuel tank containing the test fuel.

11.2.2 *Double Oil Flush*

11.2.2.1 Measure by volume, 3.5-L of new test oil.

11.2.2.2 Install a new oil filter onto the engine, see Annex A2. Perform the following steps to help the oil pressure build quicker during initial startup. Do not install a dry oil filter on the test engine.

(a) Obtain a new flush oil filter and remove it from its packaging.

(b) Measure out 325-mL of oil from the new flush oil charge.

(c) Holding the oil filter upright, pre-fill the filter with the 325-mL of new flush oil.

(d) Tilt the filter and slowly rotate it a full 360° several times to let the oil absorb into the entire fiber filter element.

(e) Install the filter onto the engine. By letting the oil absorb into the entire filter element, no oil should spill out when tilting the filter to install it.

11.2.2.3 Fill the engine with the remainder of the 3.5-L flush oil charge.

11.2.2.4 Circulate and preheat the engine coolant to 50°C and then warm soak the engine for 10-min before initial startup.

11.2.2.5 Start the engine and crack the throttle opened 5-10% to raise the engine speed, not to exceed 1500-r/min, to help the oil pressure build quicker. During engine startup, target 1200-r/min. Once oil pressure has started to build and within 30-s of engine start, control engine speed to 800-r/min, control torque to 10-N·m and ramp oil temperature to 50°C.

11.2.2.6 Once the oil temperature has reached 50°C run *Flush 1* according to the prescribed flush conditions Annex A1.2. *Flush 1* is a 20-min flush operating the engine at 800-r/min and 10-N·m of torque.

11.2.2.7 Check ignition timing with timing light during *Flush 1* to verify it to be set at 10° BTDC. Correct if not set at 10° BTDC.

11.2.2.8 Shutdown the engine at the end of the 20-min flush. Proceed to drain the engine oil and remove the used oil filter. Drain used oil for 30-min. Maintain coolant flow at 30-L/min and coolant temperature at 50°C during the oil drain period.

11.2.2.9 After draining the *Flush 1* oil, measure by volume, 3.5-L of new test oil.

11.2.2.10 Install a new oil filter onto the engine, see Annex A2. Perform the following steps to help the oil pressure build quicker during initial startup. Do not install a dry oil filter on the test engine.

(a) Obtain a new flush oil filter and remove it from its packaging.

(b) Measure out 325-mL of oil from the new flush oil charge.

(c) Holding the oil filter upright, pre-fill the filter with the 325-mL of new flush oil.

(d) Tilt the filter and slowly rotate it a full 360° several times to let the oil absorb into the entire fiber filter element.

(e) Install the filter onto the engine. By letting the oil absorb into the entire filter element no oil should spill out when tilting the filter.

11.2.2.11 Fill the engine with the remainder of the 3.5-L flush oil charge. If the engine coolant pump was shut off during the oil drain period (for maintenance or diagnostic work) circulate and preheat the engine coolant to 50°C and then warm soak the engine for 10-min before initial startup.

11.2.2.12 Start the engine and crack the throttle opened 5-10%, to raise the engine speed, not to exceed 1500-r/min, to help the oil pressure build quicker. Once oil pressure has started to build within 30-s of engine start, control engine speed to 1500-r/min, control torque to 10-N·m and ramp oil temperature to 60°C.

11.2.2.13 Once the oil temperature has reached 60°C run *Flush 2* according to the prescribed flush conditions, Annex A1. *Flush 2* is a 20-min flush operating the engine at 1500-r/min and 10-N·m of torque.

11.2.2.14 Shut down the engine at the end of the 20-min flush. If a problem is suspected with the test engine, perform a compression check on all 4 cylinders before draining the engine oil; otherwise no compression check is required. Record the data on the sheet provided. If the compression on any cylinder is below 900-kPa or is lower than 20% from the median value for that engine, then investigate the cause before proceeding with a test.

11.2.2.15 Drain the engine oil and remove the used oil filter. Drain the used oil for 30-min.

11.2.3 *Test*

11.2.3.1 Once both 20-min flushes and the 30-min oil drain have been completed, obtain the tare weight of a container to measure the test oil charge.

11.2.3.2 Measure by volume, 3.00-L of new test oil.

11.2.3.3 Weigh and record the 3.00-L oil sample before charging the engine.

11.2.3.4 Obtain a new test oil filter, see Annex A2, weigh it dry and record for use in calculating oil consumption in 11.5.1.

11.2.3.5 Install the weighed, new oil filter onto the engine. Perform the following steps to help the oil pressure build quicker during initial startup. Do not install a dry oil filter on the test engine.

(a) Measure out 325-mL of oil from the new test oil charge.

(b) Holding the oil filter upright, pre-fill the filter with the 325-mL of new test oil.

(c) Tilt the filter and slowly rotate it a full 360° several times to let the oil absorb into the entire fiber filter element.

(d) Install the filter onto the engine. By letting the oil absorb into the entire filter element, no oil should spill out when tilting the filter for installation.

11.2.3.6 Fill the engine with the remainder of the 3.00-L test oil charge.

11.2.3.7 If the coolant pump was shut down during the oil drain period following the double flush procedure (for maintenance or stand repair), circulate and preheat the engine coolant to 50°C and then warm soak the engine for 10-min before initial startup. If coolant flow was maintained during the oil drain period, the coolant preheat and soak period may be omitted.

11.2.3.8 Start the engine and crack the throttle opened 5-10%, to raise the engine speed, not to exceed 1500-r/min, to help the oil pressure build quicker. Once oil pressure has started to build and within 30-s of engine start, control engine speed to 800-r/min, control torque to 25-N·m and ramp oil temperature to 50°C.

11.2.3.9 Once the oil temperature has reached 50°C, initiate the 100-h test. Follow the prescribed test conditions, Annex A1.

11.2.3.10 Check while running the engine for any coolant or oil leaks. The engine will run for the entire 100-cycles (100-h) without any scheduled shutdowns, but unscheduled shutdowns for repair may occur.

11.2.3.11 Drain condensation traps once every 8-h.

11.2.4 *Unscheduled Engine Shutdown Procedure*
Follow the procedure detailed in 11.2.4.1 – 11.2.4.2 when performing an unscheduled engine shutdown. Document the shutdown duration, shutdown reason, and the action taken. Document this information in the appropriate report form. The test time requirement does not include any shutdown time.

11.2.4.1 *Emergency Shutdown*
An emergency shutdown usually precludes an organized shutdown. Prevent the test lubricant from overheating and prevent excessive fuel dilution. Avoid excessive engine cranking, if it will not start. Excessive cranking may affect camshaft lobe wear.

11.2.4.2 *Restart After Unscheduled Shutdown*
Preheat the coolant to 50°C. Start the engine and crack the throttle open 5-10% to raise the

engine speed, not to exceed 1500-r/min, to help the oil pressure build quicker. During engine startup, target to 1200-r/min. Once oil pressure has started to build and within 30-s of engine start, bring speed up to 1500-r/min and 25-N·m torque. Stabilize for 5-min. Then use 5-min ramp to intended stage of test. This ensures each startup will take 10-min before the test is resumed.

11.2.5 *Cyclic Schedule, General Description*
See Annex A1 for the steady-state operating test conditions (specification targets). The actual test operational conditions are summarized in the appropriate report form.

11.2.6 *Transient Ramping of Parameters*
Engine speed ramping, temperatures, and torque fluctuations between stages influence wear severity. Therefore, the importance of ramping rates. Record a plot of cycle 5 transitions in the appropriate report form.

11.2.6.1 *Oil Temperature Transitions*
After Stage I, increase the cylinder head oil gallery temperature from a nominal 49°C to the Stage II oil gallery temperature target of 59°C. The transitory time is defined as the first 5-min of Stage II, following the end of Stage I. At 1-min into the ramp, the cylinder head oil gallery temperature shall range from 51-53°C. At 2-min into the ramp, the cylinder head oil gallery temperature shall range from 54-56°C. At 3-min into the ramp, the cylinder head oil gallery temperature shall be at or above 57.0°C. By the end of the 5-min ramp, stabilize the cylinder head oil gallery temperatures at 59 ± 0.5°C.

After Stage II, decrease the cylinder head oil gallery temperature from a nominal 59°C to the Stage I cylinder head oil gallery temperature target of 49°C. The transitory time is defined as the first 5-min of Stage I, following the end of Stage II. At 1-min into the ramp, the cylinder head oil gallery temperature shall range from 55-57°C. At 2-min into the ramp, the cylinder head oil gallery temperature shall range from 52-54°C. At 3-min into the ramp, the cylinder head oil gallery temperature shall be at or below 51.0°C. By the end of the 5-min ramp, stabilize the cylinder head oil gallery temperature at 49 ± 0.5°C.

11.2.6.2 *Coolant Temperature Transitions*
After Stage I, increase the coolant out temperature from a nominal 50°C to the Stage II coolant out temperature target of 55°C. The transitory time is defined as the first 5-min of Stage II, following the end of Stage I. At 1-min into the ramp, the coolant out temperature shall range from 51-52°C. At 3-min into the ramp, the coolant out temperature shall be at or above 54°C with minimal overshoot. By the end of the 5-min ramp, stabilize the coolant out temperature at 55 ± 0.5°C.

After Stage II, decrease the coolant out temperature from a nominal 55°C to the Stage I coolant out temperature target of 50°C. The transitory time is defined as the first 5-min of Stage I, following the end of Stage II. At 1-min into the ramp, the coolant out temperature shall range from 53-54°C. At 3-min into the ramp, the coolant out temperature shall be at or below 51°C with minimal undershoot. By the end of the 5-min ramp, stabilize the coolant out temperature at

50 ± 0.5°C.

11.2.6.3 *Engine Speed Transitions*

After Stage I, increase the engine speed with minimal overshoot from a nominal 800-r/min to the Stage II engine speed target of 1500-r/min. Do not allow speed to exceed 1600-r/min during the transition. The transitory time is defined as the first 5-min of Stage II, following the end of Stage I. At 30-s into the ramp, the engine speed shall range from 1150-1250-r/min. At 60-s into the ramp, the engine speed shall range from 1400-1500-r/min. By the end of the 5-min ramp, stabilize the engine speed at 1500 ± 20-r/min.

After Stage II, decrease the engine speed with minimal undershoot from a nominal 1500-r/min to the Stage I engine speed target of 800-r/min. Do not allow speed to drop below 750-r/min during the transition. The transitory time is defined as the first 5-min of Stage I, following the end of Stage II. At 30-s into the ramp, the engine speed shall range from 1100 to 1200-r/min. At 60-s into the ramp, the engine speed shall range from 800 to 900-r/min. By the end of the 5-min ramp, stabilize the engine speed at 800 ± 20-r/min.

11.2.6.4 *Torque Steadiness During Transitions*

Do not change the torque target of 25-N·m during the transition from Stage I to Stage II, and from Stage II to Stage I. During the 5-min transitions for speed and temperature changes, control the torque within 23-27-N·m. By the end of the 5-min transition, stabilize the torque at 25 ± 1.5-N·m.

11.3 *Periodic Measurements and Functions*

11.3.1 *Blowby Flow Rate Measurement*

Measure and record the blowby flow rate during the middle of Stage I of cycle 5 and cycle 100. Stabilize and operate the engine at normal Stage I operating conditions. Use a 3.175-mm diameter blowby orifice size for the normal blowby flow range of 5 to 12-L/min. Use the apparatus schematic shown in Annex A3. Use the following procedure for measuring blowby flow rate:

11.3.1.1 Open the flow valve (bleeder valve) completely.

11.3.1.2 Connect the blowby apparatus flow line to the 3-way valve located between the engine PCV and intake vacuum port.

11.3.1.3 Disconnect the hose at the air cleaner that is routed from the rocker cover. Then, connect it to the inlet plumbing of the blowby apparatus orifice meter.

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

11.3.1.5 Connect the blowby apparatus pressure sensor to the dipstick tube.

11.3.1.6 Adjust the flow valve (bleeder valve) to maintain crankcase pressure at 0 –25-kPa.

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

11.3.1.8 After completing the measurement, return the engine to normal operating configuration. First, the dipstick tube pressure port; second, reconnect the hose from the rocker cover to the air cleaner; third, reposition the 3-way valve to ensure porting of the intake vacuum to the engine PCF; fourth, disconnect blowby apparatus hose from the closed port of the 3-way valve.

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

11.3.2 *Ignition Timing Measurement*

Measure and record the ignition timing during Stage I every 5th cycle. The specification is 10 ± 1° at Stage I. Adjust when needed. Check the timing during Stage II, a typical reading of 24 ± 2° indicates proper advance as determined by the engine controller.

11.3.3 *Air-to-Fuel Ratio Measurement*

Monitor the air-to-fuel ratio continuously using the output of a wide-range exhaust gas oxygen sensor.

11.3.4 *Oil Additions and Used Oil Sampling*

During the 100-h test, do not add oil. New oil makeup is not allowed if oil leaks occur. Take a 10-mL oil sample of the new oil, used oil at 25-h, used oil at 50-h, and used oil at 75-h. Remove used oil samples during the transient portion of Stage II (near end of cycle 25, 50, and 75). Remove a 120-mL purge sample from the engine prior to drawing the oil sample. This purge sample is to be returned to the engine via the cover fill cap using a clean filler pipe equipped with an isolation valve to prevent oil *spit back* due to positive crankcase pressure. After the oil consumption has been calculated at the end of 100-h, remove a 100-mL sample of used oil for chemical analyses of the 100-h test oil. Take the 100-mL sample during the final engine oil drain at the end of the test (100-h). No purge sample is required for this final oil sample.

11.3.5 *General Maintenance*

11.3.5.1 *Spark Plug Replacement*

Replace the spark plugs, see Annex A2, before conducting the oil flushing procedure in 9.7.2.

11.3.5.2 *PCV Valve Replacement*

Replace the PCV valve after 8 tests, when replacing the engine or cylinder head. The PCV valve may be obtained from any authorized Nissan dealership.

11.4 *Diagnostic Data Review*

This section outlines significant characteristics of specific engine operating parameters. The parameters may directly influence the test or indicate normalcy of other parameters.

11.4.1 *Intake Manifold Pressure*
Several factors affect intake manifold pressure, including barometric pressure, engine load, air-fuel ratio, ignition timing, and engine wear. Use intake manifold pressure to monitor the engine condition, although not a specifically controlled parameter.

11.4.2 *Fuel Consumption Rate*
The fuel consumption rate during any stage shall remain relatively constant throughout the test. Like intake manifold pressure, use fuel consumption rate as a diagnostics tool. Fuel consumption rate and intake manifold pressure relate to similar operating parameters.

Note 5: High fuel consumption rate can promote excessive cylinder bore, camshaft, and rocker arm wear.

11.4.3 *Spark Knock*
Spark knock does not normally occur during this test. The fuel octane rating, ignition timing, engine speed and load, and operating temperatures do not promote spark knock. Spark knock indicates abnormal combustion, and may cause extensive engine damage. If spark knock occurs, take immediate corrective action. Errors in the measurement and control of engine load, ignition timing, operating temperatures, and air-to-fuel ratio may result in spark knock.

11.4.4 *Crankcase Pressure*
Crankcase pressure is a function of blowby flow rate and PCV valve flow. High blowby flow rate or a significant loss of PCV valve flow causes high crankcase pressure. Incorrect 3-way valve plumbing or port plugging also promotes high crankcase pressure. High crankcase pressure, may cause oil leaks (gasket or seal failure). Low blowby flow rate or a vent air restriction to the PCV valve may cause low or negative crankcase pressure.

11.4.5 *Oil Pressure*
The oil pressure is a function of oil viscosity, operating temperature, and engine bearing clearances. Normally, the oil pressure is higher in Stage II than Stage I. The oil pressure shall remain consistent throughout the test, unless the oil exhibits a significant increase in viscosity.

11.4.5.1 *Abnormal Oil Pressures*
An excessive oil pressure fluctuation may indicate large bearing clearance. An excessive oil pressure differential between the engine gallery and head gallery indicates the presence of a gallery restriction at the head gasket or an increased oil flow rate to the cam bearing pedestals.

11.4.6 *Coolant Temperature Differential*
The coolant temperature differential is a function of the coolant flow rate and is normally stable throughout the test. Coolant flow rate or temperature measurement errors may cause large variations in the differential. Foreign objects in or near the flow-meter may cause coolant flow rate measurement errors.

11.5 *End of Test Procedures*

Shut down the engine at the end of cycle 100.

11.5.1 *Oil Consumption Determination*

Use the following equation to calculate oil consumption:

$$J = \{(B - A) - [(F - E) + (H - D)]\} = C - (G + I) \quad (1)$$

Where: $C = B - A$
$G = F - E$
$I = H - D$

Where:
A = Empty Container Weight, dry @ test start (g)
B = Initial Oil Charge and Container Weight (g)
C = Initial Oil Charge (g)
D = New Oil Filter Weight, dry @ test start (g)
E = Empty Container Weight, dry @ test end (g)
F = Drain Oil and Container Weight *E* (g)
G = Drain Oil @ end of test (g)
H = Used Oil Filter Weight, with absorbed oil, @ end of test (g)
I = Oil Remaining in filter, (g)
J = Oil Consumption per test (g)

11.5.1.1 *Oil Drain*

Drain the engine test oil and remove the used test oil filter. While removing the oil filter, catch any oil that drains out. Add this oil to the drained test oil. Drain the used test oil for 30-min. Maintain a warm condition during the 30-min engine drain. Continue to circulate the coolant and maintain a 50°C coolant temperature. Remove the rocker cover. Using a suction device, remove the used test oil that is trapped in the cavities of the cylinder head under the camshaft. Do not add this oil to the drained test oil. Properly discard this oil.

11.5.1.2 *Measurement of Oil Drained*

After completing the 30-min drain, and adding the oil from the oil filter, weigh the drained test oil and the used test oil filter. Use the equation provided in 11.5.1 to calculate oil consumption.

11.5.1.3 *Used Oil Sample*

After calculating the oil consumption, remove a 237-mL sample of used test oil for chemical analyses of the 100-h test oil. Use a 237-mL plastic container. After calculating oil consumption and obtaining the 237-mL sample for chemical analyses, place the remaining used test oil into a 4-L container and store.

11.5.2 *Test Parts Removal*

Remove the test parts (camshaft, rocker arms, rocker shafts) for wear measurement according to the procedures outlined in 9.7.1.

11.5.3 *Lobe Wear Measurement*

11.5.3.1 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.

11.5.3.2 Use a surface measurement profilometer with real time digital display and graphical output capability. Use a vertical scale graphical resolution capable of 1-µm per graph division. Use a profilometer capable of traversing at least 100-mm, with a straightness accuracy equal to or less than 1-µm per 100-mm of traversed length. Use a right angle pickup without a skid. Use a conical or spherical shaped diamond tip stylus, with a nominal radius of 2-µm – 5-µm. House the profilometer in an environment that meets the profilometer manufacturers recommendations. Maintain a clean area, temperature controlled, and stabilize and free the profilometer worktable from external vibration sources.

11.5.3.3 The Precision Devices Inc. – MicroAnalyzer 2000 system as the computer-driven profilometer is recommended. Equip it with custom V-blocks, see Annex A2, for holding the work-piece (the camshaft on its journals). Use a skid-less diamond stylus, which features a 0.005-mm stylus radius, and a 6.5-mm stylus height. Take a trace across the lobe from front-to-rear of the lobe, at a traversing speed of 0.50 – 0.75-mm/s. Slightly extend (drop) the stylus off the lobe edges to ensure a full trace. View the data from the trace in the profile mode, allowing an analysis of the texture and waviness of the trace. Configure the instrument software for a 2-point line texture leveling at the average value of the unworn edges of the cam lobe. Display the waviness of the profile, using the Gaussian smoothing filter, set at 0.25-mm cutoff length, with the filter set (non-standard setting) to extend to the ends of the texture. Typically, the leveling line coincides with (contracts or is very close to) the highest peak of the waviness profile that exists at each unworn end. To obtain the wear measurement, the waviness evaluation length encompasses the whole lobe width. The *Wt* parameter (waviness total) yields the value of the height from the maximum peak to the lowest valley of the waviness profile. Record the wear measurement as the *Wt* measurement.

11.5.3.4 After test, analyze the graphs of the profilometer traces of the cam lobe noses to determine the *Wt*. Since the cam lobe is wider than the rocker arm pad, there is a narrow non-worn edge at the rear of the cam lobe and another at the front of the cam lobe. If possible, discern these distinct non-worn edges, and draw the reference line on the graph. The nose wear is the maximum excursion (deepest valley) of the worn surface on the cam nose, as graphically measured normal to the reference line. In the absence of one of the discrete non-worn lobe edges, use the pre-test profile to extrapolate the reference line.

11.5.3.5 If two unworn edges are missing, level the trace by the *two-point line* method (electronic leveling).

11.5.3.6 If one of the unworn edges is missing, level the trace by the *no form* method (mechanical).

11.5.3.7 A cam lobe edge shall be at least 0.10-mm width and exhibiting an unworn surface finish pattern to be deemed an unworn edge. If the narrow edge is < 0.10-mm width, it will be treated as a worn edge and the trace shall be leveled by the *no form* method.

11.5.3.8 If one unworn edge is missing, no anomalies exist, and at least 30% of the trace exhibits no wear, the trace shall be leveled by the *two-point line* method using the one large non-worn edge.

11.5.3.9 If an anomaly exists at the cam lobe unworn edge, either a significant rise or decline in slope, the trace area shall be excluded from the wear calculation. The waviness evaluation length lines shall be oriented as close as possible to the end of the trace while excluding the edge anomaly.

11.5.3.10 If a cam lobe defect exists such as surface scratches or an anomaly (pushed metal), the waviness evaluation length lines shall be oriented to exclude the defect or anomaly from the wear calculation.

11.5.3.11 When leveling by the *no form* method, level the camshaft on the base circle for the TDC trace, on the ATC side of the cam lobe for the ATC traces and the BTC side of the cam lobe for the BTC traces. Run the ATC and BTC leveling traces at a point closest to TDC where no wear exists, but no closer than 20°C from TDC.

12. Calculation or Interpretation of Results

The summary of results and calculations are recorded in the appropriate report form.

12.1 *Camshaft Lobe Wear*

Use a surface roughness meter (profilometer) to measure the change in profiles across the worn cam lobe. Each lobe usually has an unworn edge at the front of the lobe, and at the rear of the lobe. Use these unworn edges to define a two-point reference line, and measure a maximum depth of wear. For each lobe, make seven profilometer traces, scribing across the lobe. The seven locations on each lobe are: at the nose, which is zero° cam lobe; ±4°; ±10°; and ±14°. Locate the nose by reading the highest profilometer position (to within 0.5-µm) on the unworn cam lobe surface. Affix a 360° wheel a minimum of 25-cm diameter or optical angle encoder to the front of the camshaft. Resolution of the degree wheel is 1° or better. After locating the lobe nose, determine the degree wheel *zero* reference mark.

When viewed from the engine front, the camshaft normally rotates clockwise. Use this same sign convention for profilometer measurements. When viewing the camshaft front, the *plus* direction is before cam nose top center. The *minus* direction is after the cam nose top center.

The maximum deviation (W_t) of the worn nose profile (phase-correct filtered waviness profile) from a deduced unworn profile (reference line) is the wear value for that cam lobe location. (Report individual wear measurements to a resolution of ½ of 1-µm in the range of 0-30-µm wear, or better; and to a resolution of 1-µm in a wear range greater than 30-µm wear, or better.) For an individual lobe, the lobe wear is a mathematical summation of the W_t values for the seven defined locations on each lobe. These measurements are recorded in the appropriate report form.

Average (equal weighting) the lobe wear values for the twelve lobes of the camshaft to determine the single test result (average cam wear – ACW) (reported to a 1/100 of an µm). The ACW value is severity adjusted as show in ASTM TM 94-200. This severity adjustment is Average Cam Wear Final (ACWFNL) and is recorded on the appropriate report form. ACWFNL is the primary result from this test method.

12.2 *Oil Analysis*

The results from the used oil analysis are recorded in the appropriate report form.

12.2.1 *Oil Sampling*

Take a 10-mL oil sample of the new oil, used oil at 25-h, used oil at 50-h, and used oil at 75-h. Remove used oil samples during the transient portion of Stage II (near end of cycle 25-h; 50-h; 75-h). Take a 100-mL sample of drain oil at the end of test (100-h).

12.2.2 *Wear Metals*

Measure the used oil samples (25-h; 50-h; 75-h; 100-h) for wear metal concentration (ppm), using Test Method D 5185. Report iron and copper concentrations.

12.2.3 *Kinematic Viscosity*

Determine and report the kinematic viscosity (at 40°C) for the new oil sample and the used oil sample at 100-h, using Test Method D 445.

12.2.4 *Fuel Dilution*

Measure the mass percent fuel dilution of the used oil sample at 100-h. Fuel dilution typically ranges from 3.5% to 7.0%. (If the fuel dilution exceeds 7.0%, the valve-train wear test results may not be interpretable.)

Use the following procedure to determine fuel dilution:

12.2.4.1 Fuel Dilution, % mass, by gas chromatography using Test Method D 3525 as modified:

(a) Use C16 (hexadecane) instead of C14 (tetradecane) for the internal standard (1-mL injector volume).

(b) Define all components lighter than C16 as fuel.

(c) The integrator should establish a horizontal baseline under the output curve.

(d) Column details – Stainless steel (SS) 6-ft by 1/8-in., solid support: Dexsil 300 10%, 80-100 mesh.

(e) Temperature details – oven temperature 60 - 320°C, 8°C/min rate of delta T, hold at 320°C for 16-min to elude oil.

13. Test Report

13.1 *Report Format*
The report forms are furnished by the TMC upon request, and they are mandatory for this test method.

13.2 *Photographs*
The final test report does not require photographs.

13.3 *Electronic Data Dictionary*
The electronic data dictionary will be furnished by the TMC upon request, and it is mandatory for this test method. Use this dictionary for electronic transmission of final report data to the end-user, or to the TMC for calibration tests.

14. Precision and Bias

14.1 *Precision*

14.1.1 Test precision is established on the basis of reference oil test results (for operationally – valid tests) monitored by the TMC. The data are reviewed semiannually by the Sequence IVA Surveillance Panel. Contact TMC for the current industry data.

14.1.1.1 Intermediate Precision (formerly called Repeatability) conditions – conditions where test results are obtained in the same laboratory with the same test method using the same test oil, with changing conditions such as operators, measuring equipment, test stands, and time between tests.

14.1.1.2 Intermediate Precision limit (i.p.) – the difference between two results obtained under intermediate precision conditions that would in the long run, in the normal and correct conduct of the test method, exceed the value show in Table 9, in only 1 case in 20.

14.1.1.3 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.

14.1.1.4 Reproducibility (R) – the difference obtained under reproducibility conditions that would in the long run, in the normal and correct conduct of the test method, exceed the value shown in Table 9, in only 1 case in 20.

14.2 *Bias*

14.2.1 Bias is determined by applying an acceptable statistical technique to reference oil test results and when a significant bias is determined, a severity adjustment is permitted for non-reference oil test results. This technique is described in TMC 94-200.[16]

TABLE 9
TEST PRECISION[A]

Test Result	Intermediate Precision[B]		Reproducibility[C]	
	s i.p.[D]	i.p.[E]	s_R[D]	R[E]
Average Wear (μm)	14.30	40.04	16.22	45.22

[A] Based on results obtained from ASTM reference oil 1006.
[B] See 14.1.1.2.
[C] See 14.1.1.4.
[D] s = standard deviation.

[E] On the basis of test error alone, the difference, in absolute value, between two test results will be expected to exceed this value only about 5% of the time.

15. Key Words

lubricants, crankcase oils, cam lobe wear, valve-train wear

This standard is subject to revision at any time by the responsible technical committee and shall be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful considerations at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing, you should make your views known to the ASTM Committee on Standards, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

Footnotes:

[1] This test method is under the jurisdiction of ASTM Committee D02 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.0B on Automotive Lubricants. Current edition approved MMMM DD, YYYY, Published MMMYYYY

[2] The American Society for Testing and Materials takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

[3] 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 Avenue, Pittsburgh, PA 15206-4489, Attention: Administrator.

[4] Annual Book of ASTM Standards, VOL. 05.01

[5] Annual Book of ASTM Standards, VOL. 05.02

[6] Annual Book of ASTM Standards, VOL. 05.03

[7] Annual Book of ASTM Standards, VOL. 05.04

[8] Annual Book of ASTM Standards, VOL. 14.02

[9] Standards may be obtained from ASTM Headquarters

[10] The EOLCS standard may be obtained from the American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005

[11] Standards may be obtained from the Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096-0001

[12] Standards may be obtained from the American National Standards Institute,

[13] Standards may be obtained from the American Society of Mechanical Engineers,

[14] Standards may be obtained from the Japanese Standards Association, 1-24 Akasaka 4 Minato-KU, Tokyo-107 Japan

[15] Standards may be obtained from the Coordinating European Council for the Development of Performance Tests Transportation Fuels, Lubes, and other Fluids, Madou Plaza 25 Floor Place Madoul, B-1210 Brussels, Belgium

[16] Standards may be obtained from ASTM TMC, 6555 Penn Avenue, Pittsburgh, PA 15206-4489, Attention: Administrator

[17] Nissan North American, Inc., P.O. Box 191, Gardena, CA 90248-0191

[18] Lamdra Electronics Corporation, 515 Broad Hollow Road, Melville, NY 11747-3700

[19] Dowell Chemical Company, 1201 South Sheldon Road, Channelview, TX 77530-0429

[20] Micromotion, 7070 Winchester Circle, Boulder, CO 80301

[21] Horiba Instruments, 17671 Armstrong Avenue, Irvine, CA 92714

[22] ETAS, 2155 Jackson Avenue, Ann Arbor, MI 48103
[23] Texaco Lubricants Company, P.O. Box 4427, Houston, TX 77210-4427
[24] Barco, Hyspan Precision Products, 1685-T Brandwine Avenue, Chula Vista, CA 91911
[25] Sierra Instruments, 5 Harris Court, Monterey, CA 93940
[26] Badger Meter, Inc., Precision Products Division, 6116 East 15th Street, Tulsa, OK 74112
[27] Precision Devices, Inc., 606 County Street, P.O. Box 220, Milan, MI 48160-0220
[28] American Chemistry Council, 1300 Wilson Boulevard, Arlington, VA 22209

A1. OPERATIONAL CONDITIONS

A1.1 This annex defines the following operating conditions:

A1.1.1 Engine Break-In Schedule (Fig. A1.1)
A1.1.2 Oil Flush Operating Conditions (Fig. A1.2)
A1.1.3 Steady-state Test Specifications (Fig. A1.3)
A1.1.4 Typical Operational Performance (Fig. A1.4)

SEQUENCE IVA

Step	Duration min	Engine Speed r/min	Engine Torque N·m	Coolant Flow L/min	Coolant Out Temp °C	Cyl. Head Oil Gallery Temp. °C	Intake Air Temp °C	Intake Air Pressure kPa	Exhaust Pressure kPa-abs
1	10	800	10	20	50.0	49.0	32	0.050	103.5
2	10	1600	10	30	50.6	51.4	32	0.050	103.5
3	10	2000	40	40	55.2	62.6	32	0.050	103.5
4	10	2400	40	50	56.4	65.3	32	0.050	103.5
5	10	2400	75	50	62.5	80.0	32	0.050	103.5
6	15	2800	75	60	64.7	85.2	32	0.050	103.5
7	15	3200	75	70	66.9	90.5	32	0.050	105.5
8	15	3200	110	70	75.0	110.0	32	0.050	105.5

Fig. A1.1 Break-In Schedule

SEQUENCE IVA

Parameters	Units	Flush #1	Flush #2
Duration	Min	20	20
Engine Speed	r/min	800	1500
Engine Torque	N·m	10	10
Coolant Flow	L/min	30	30
Coolant Out Temperature	°C	50	55
Cylinder Head Oil Gallery Temp.	°C	49	59
Air to RAC	SLPM[A]	10.0	10.0
Intake Air Temperature	°C	32	32
Intake Air Pressure	kPa	0.050	0.050
Intake Air Humidity	g/kg	11.5	11.5
Exhaust Pressure	kPa-abs	103.5	103.5

Fig. A1.2 Oil Flush Operating Conditions

[A] Standard liters per minute

SEQUENCE IVA

Parameters	Units	Stage I	Stage II
Duration	min	50	10
Engine Speed	r/min	800	1500
Engine Torque	N·m	25	25
Coolant Flow	L/min	30	30
Coolant Out Temperature	°C	50	55
Cylinder Head Oil Gallery Temp.	°C	49	59
Air to RAC	SLPM	10.0	10.0
Intake Air Temperature	°C	32	32
Intake Air Pressure	kPa	0.050	0.050
Intake Air Humidity	g/kg	11.5	11.5
Exhaust Pressure	kPa-abs	103.5	103.5
Ignition Timing	°BTDC	10	N/A

Fig. A1.3 Steady-state Test Specifications

SEQUENCE IVA

Parameters	Units	Stage I Performance	Stage II Performance
Oil Sump Temperature	°C	53.5 ± 3	63.5 ± 3
Oil Gallery Temperature	°C	50 ± 3	60 ± 3
Oil Cylinder Head Temperature	°C	49 ± 3	59 ± 3
Coolant In Temperature	°C	45.5 ± 3	49 ± 3
Coolant Out Temperature	°C	50 ± 3	55 ± 3
Intake Air Temperature	°C	32 ± 3	32 ± 3
Exhaust Gas Temperature	°C	340 ± 50	450 ± 50
Fuel Rail Temperature	°C	22.5 ± 10	22.5 ± 10
Oil Gallery Pressure	kPa	130 ± 40	260 ± 80
Oil Cyl. Head Pressure	kPa	40 ± 20	65 ± 30
Fuel Pressure	kPa	238 ± 10	234 ± 10
Manifold Vacuum	kPa- vac	60 ± 5	65 ± 5
Exhaust Pressure	kPa- abs	103.5 ± 1.0	103.5 ± 1.0
Intake Air Pressure	kPa	0.05 ± 0.025	0.05 ± 0.025
Crankcase Pressure	kPa	-0.3 ± 0.1	-0.3 ± 0.1
Coolant Flow	L/min	30 ± 0.5	30 ± 0.5
Air-to-Fuel Ratio	None	14.4 ± 0.3	14.4 ± 0.3
Fuel Flow	kg/hr	1.3 ± 0.3	2.15 ± 0.3
Engine Speed	r/min	800 ± 20	1500 ± 20
Engine Torque	N·m	25.0 ± 2.5	25.0 ± 2.5
Humidity	g/kg	11.4 ± 0.7	11.4 ± 0.7
Ignition Timing	°BTDC	10 ± 1	24 ± 2

Fig. A1.4 Typical Operational Performance

A2. PARTS LIST

A2.1 This annex illustrates the parts needed for the Sequence IVA test. (Fig. A2.1)

SEQUENCE IVA

Section	Description	Part Number	Contents	Supplier
6.1	Bare Engine Assembly	A0102-76P01	Engine Block / Head / Valvetrain Assembly	Nissan North America, Inc.
6.4.1.3	Test Kit	13000-40F85	Camshaft Assembly (1) Rocker Shaft (2) Rocker Arms (12) Oil Filter Assembly (3) Spark Plug (4)	Nissan North America, Inc.
6.4.1.4	Head Assembly	A1040-40F80	w/ Valves and Springs w/o Camshaft, Rocker Arms	Nissan North America, Inc.
6.2.7	Cooler Assembly – Oil	21305-03E00	Engine Oil Cooler	Nissan North America, Inc.
6.4.1.4	Engine Valve Regrind Kit	A1042-10C2E	Head Gasket and Seals	Nissan North America, Inc.
	Distributor Assembly	22100-40F00RE	Ignition Distributor	Nissan North America, Inc.
6.4.1.2	Test Stand Kit No. 1	A0001-76P25		Nissan North America, Inc.
6.4.1.2	Test Stand Kit No. 2	A1001-40F25		Nissan North America, Inc.
6.4.1.2	Test Stand Kit No. 3	B4010-40F26		Nissan North America, Inc.
6.4.1.2	Test Stand Kit No. 4	14004-F4003		Nissan North America, Inc.
6.3.9	Jacketed Rocker Cover	TEI-NIVAWCR-020	Aluminum Jacketed Rocker Cover	Test Engineering, Inc.
6.2.9	Modified Wiring Harness	OHTKA24-002-1	Modified Harness for ECM	OH Technologies, Inc.
6.3.4.2	Air Filter Assembly	16500-86G50KT	Air Filter Housing and Element	Nissan North America, Inc.
6.5.1	Cam Angle Encoder	NIVACWM010		Test Engineering, Inc.
	Cylinder Head Calibration Apparatus			OH Technologies, Inc.
7.4.2	Silicone Gasket Maker	999MP-A7007	RTV sealant	Nissan dealer
7.2	Test Fuel	KA24E	KA24E (dyed green)	Dow Chemical
7.3.1	Break-In Oil	TMC 926-2	TMC926-2	ASTM Test Monitoring Center

Fig. A2.1 Parts List

A3. FIGURES AND DRAWINGS

A3.1 This annex illustrates the key elements of the Sequence IVA test engine.

A3.2 Figure and Drawing Descriptions:

A3.2.1 Cooling System Schematic (Fig. A3.1)
A3.2.2 Oil Cooling System Schematic (Fig. A3.2)
A3.2.3 Fuel System Schematic (Fig. A3.3)
A3.2.4 Intake Air System Schematic (Fig. A3.4)
A3.2.5 Oil Filter Adapter Modifications (Fig. A3.5)
A3.2.6 Oil Pan Modification (Fig. A3.6)
A3.2.7 Coolant Spool (Fig. A3.7)
A3.2.8 Water Pump Bore Plug (Fig. A3.8)
A3.2.9 Exhaust Modification (Fig. A3.9)
A3.2.10 Head Modification (Fig. A3.10)
A3.2.11 Cylinder Head Holder (Fig. A3.11)
A3.2.12 Engine Back plate (Fig. A3.12)
A3.2.13 Flywheel Modifications (Fig. A3.13)
A3.2.14 Jacketed Rocker Cover (Fig. A3.14)
A3.2.15 Cross Section of Jacketed Rocker Cover (FigA3.15)
A3.2.16 Valve Train Wear Test Harness (Fig. A3.16)
A3.2.17 Blow-by Measurement Equipment Schematic (Fig. A3.17)

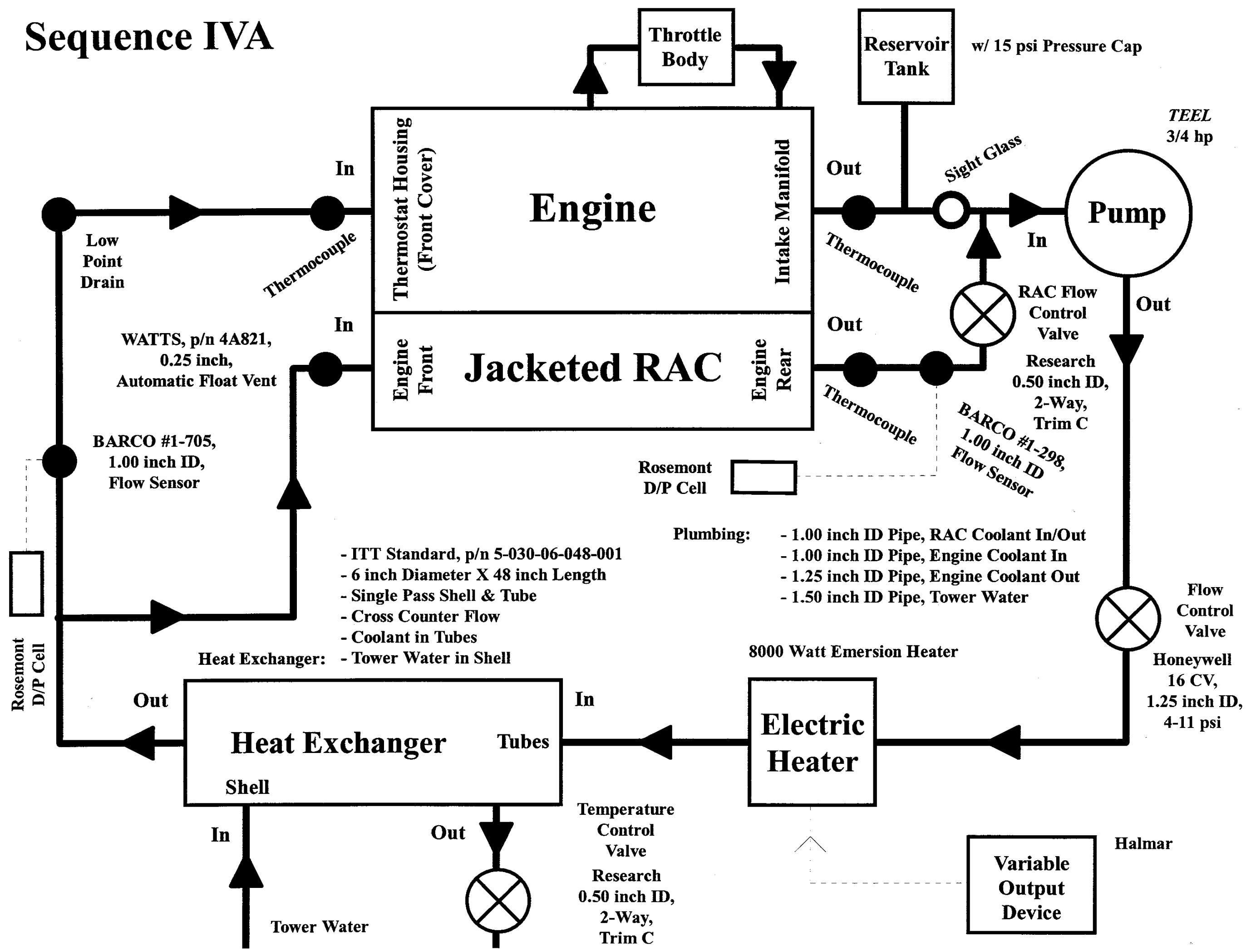


Fig. A3.1 Cooling System Schematic

Sequence IVA

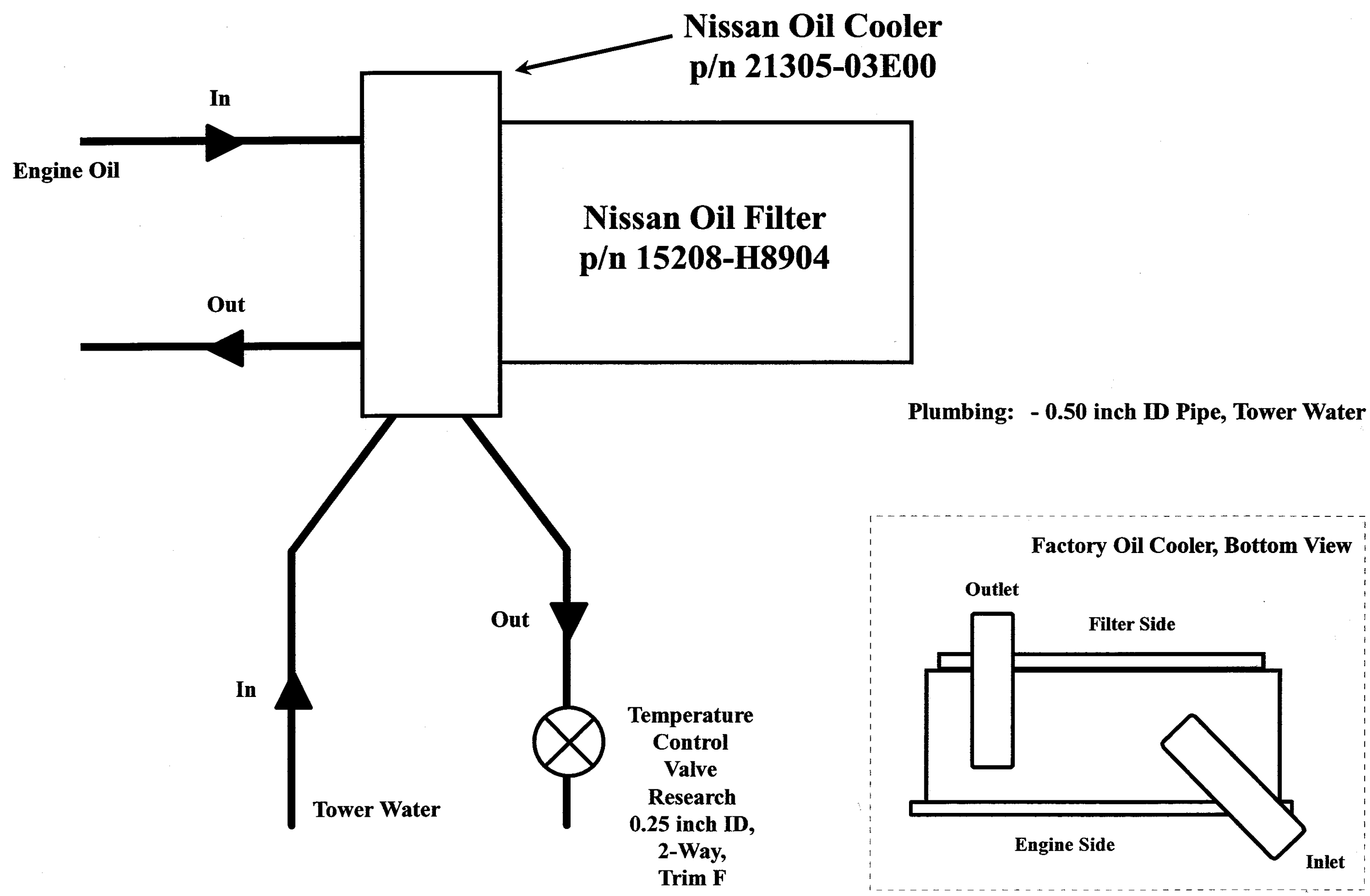


Fig. A3.2 Oil Cooling System Schematic

Sequence IVA

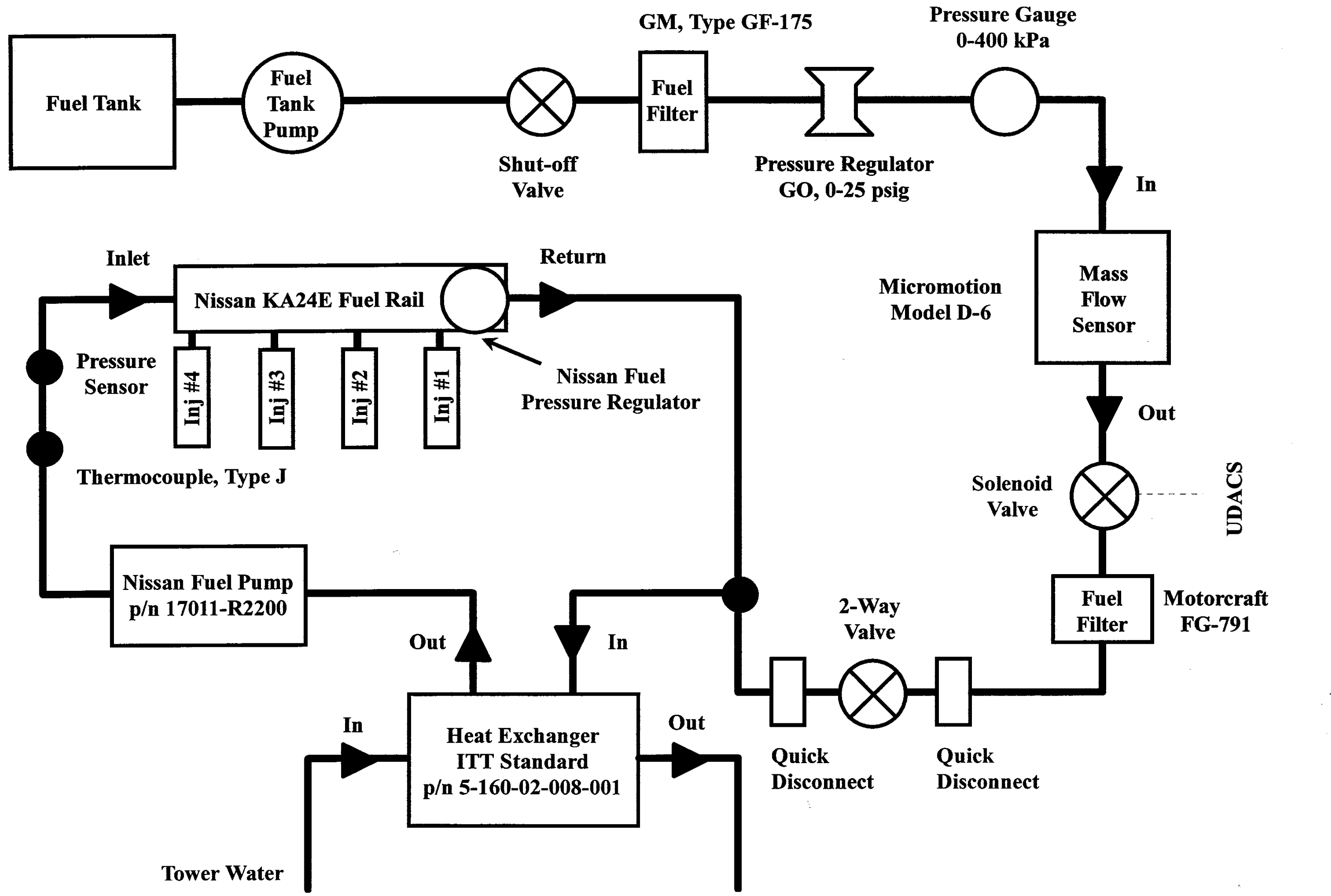


Fig. A3.3 Fuel System Schematic

Sequence IVA

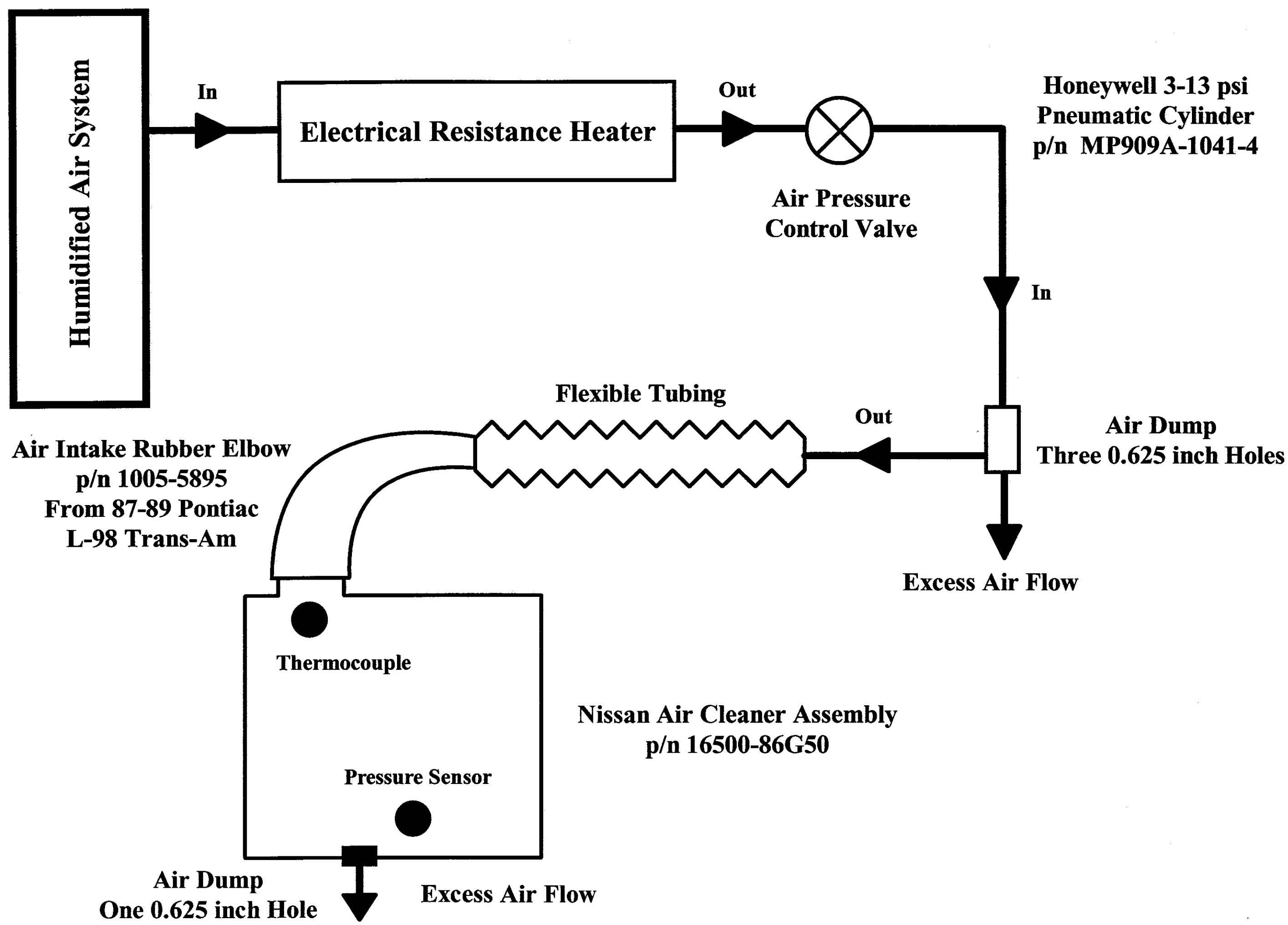
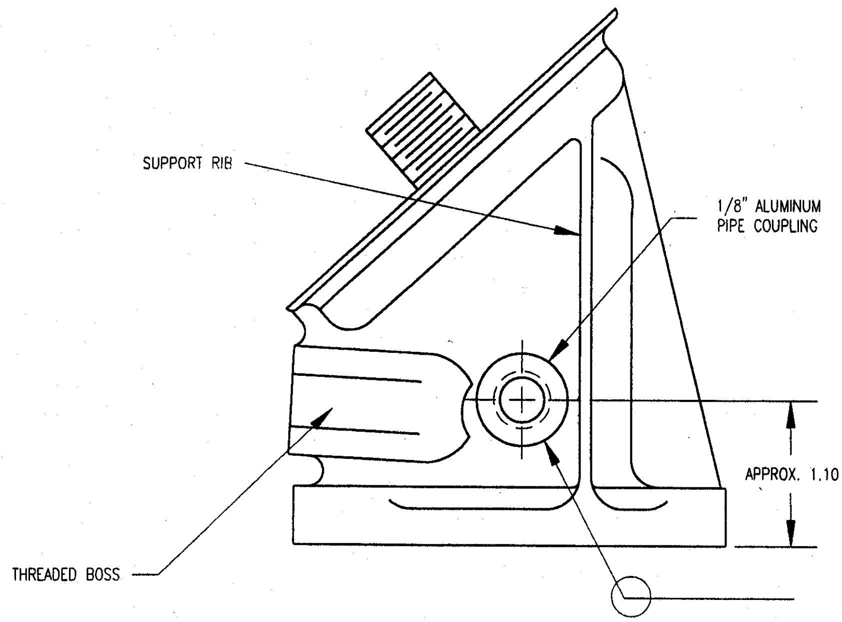


Fig. A3.4 Intake Air System Schematic

REVISIONS			
REV	DESCRIPTION	DATE	APPROVED

1. GRIND ALUMINUM COUPLING TO FIT CONTOURS OF THE FILTER ADAPTER HOUSING.
2. WELD COUPLING BETWEEN THREADED BOSS AND SUPPORT RIB. (WELD MUST BE LIQUID TIGHT).
3. DRILL THRU WITH A "Q" SIZE DRILL.



2.4L NISSAN OIL FILTER ADAPTER

CONTRACT NO.		SOUTHWEST RESEARCH INSTITUTE SAN ANTONIO, TEXAS	
DRAWN T. HABY	13MAR97	2.4L NISSAN OIL FILTER ADAPTER MODIFICATIONS	
CHECKED			
ENGR		SIZE A	CODE IDENT. NO. 26401 · DWG NO. GE-1759 · REV.
NEXT ASSY / USED ON APPLICATION	FILE FLTRADT · DIR GE	SCALE NONE	SHEET 1 OF 1

26401 DWG NO. * SH 1

Fig. A3.5 Oil Filter Adapter Modifications

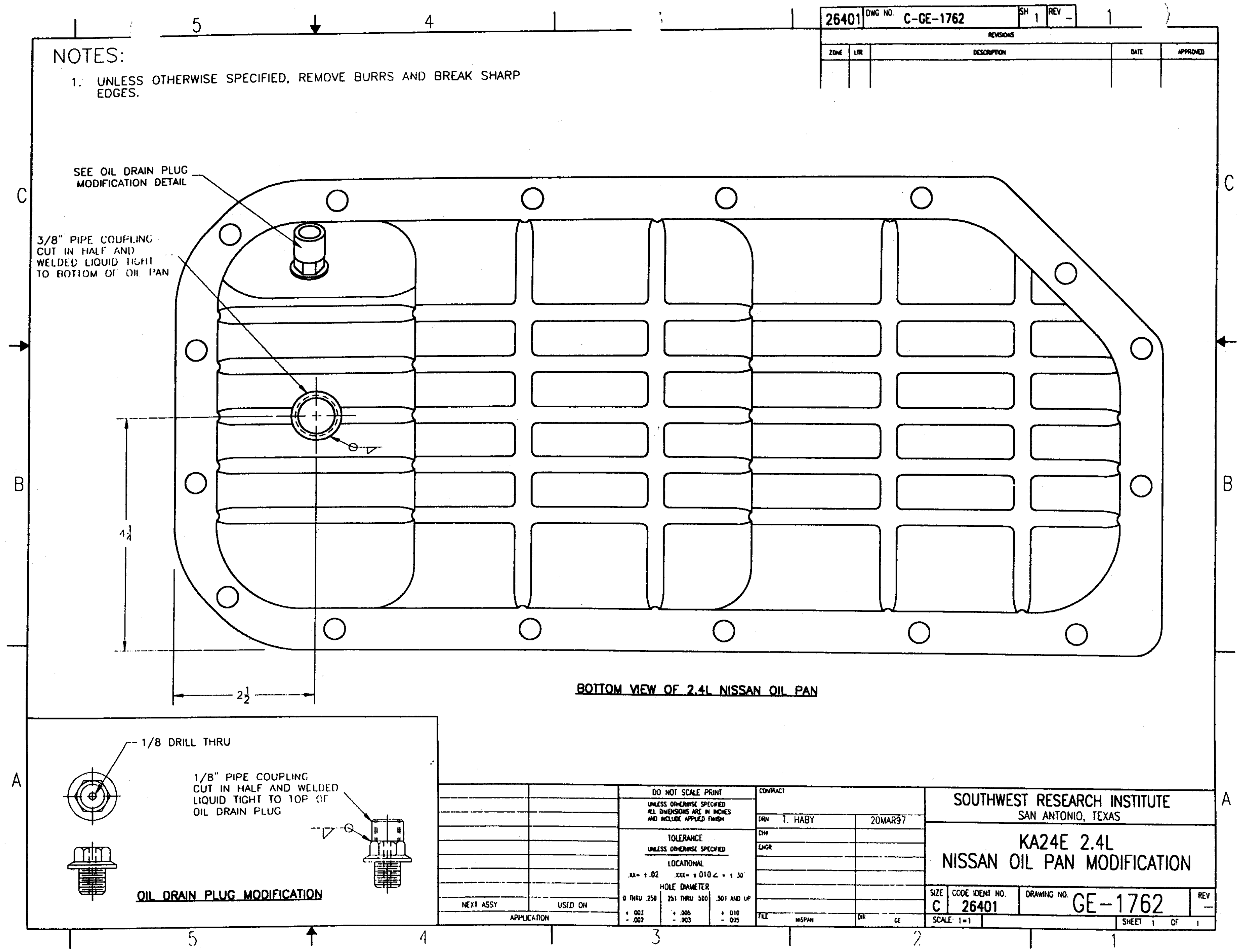


Fig. A3.6 Oil Pan Modification

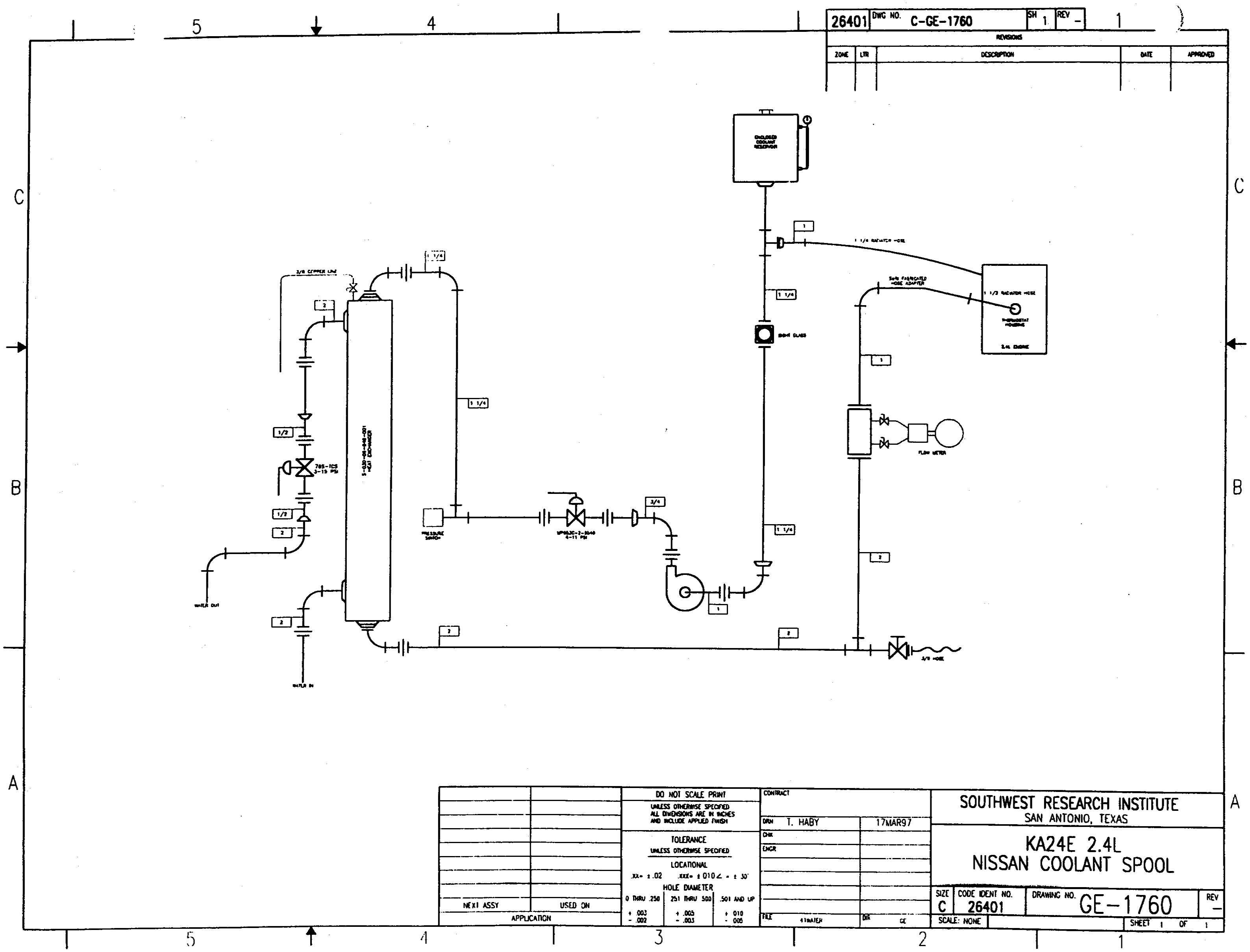
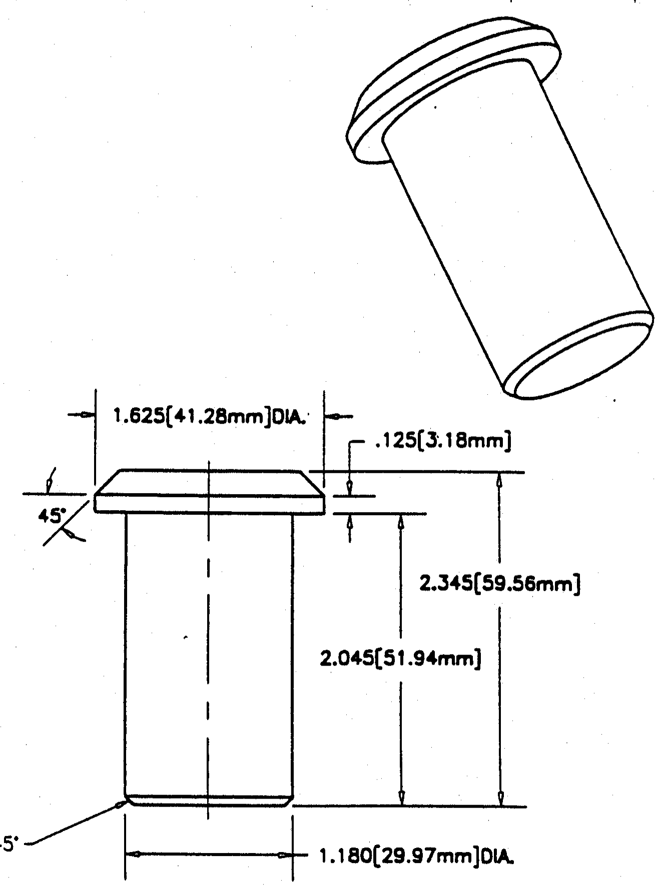


Fig. A3.7 Coolant Spool

26401 DWG NO A-7826-1712 SH

REVISIONS			
REV	DESCRIPTION	DATE	APPROVED



BREAK SHARP CORNERS
DIMENSIONS ARE IN INCHES AND [MILLIMETERS]

CONTRACT NO. 08-7862-301		SOUTHWEST RESEARCH INSTITUTE SAN ANTONIO, TEXAS	
DRAWN T HABY	7JULY96	WATER PUMP BORE PLUG	
CHECKED			
ENGR		SIZE A	CODE IDENT. NO. 26401
		DWG NO. 7826-1712	REV.
FILE PUMPPLUG	DIR DIESEL	SCALE 1=1	SHEET 1 OF 1

TOLERANCE	USED ON
±.005[.127mm]	NISSAN KA24E VTW
APPLICATION	

Fig. A3.8 Water Pump Bore Plug

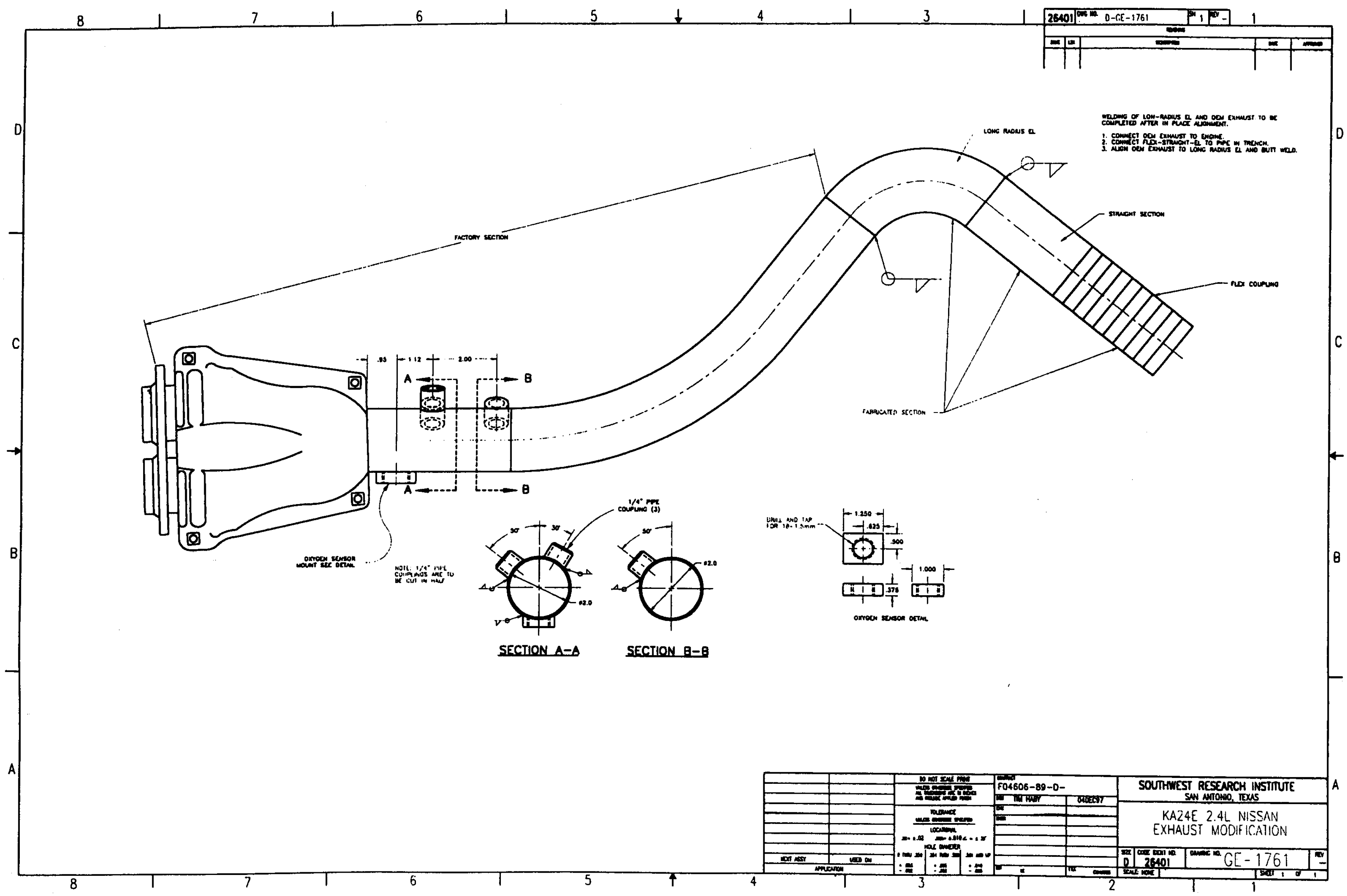


Fig. A3.9 Exhaust Modification

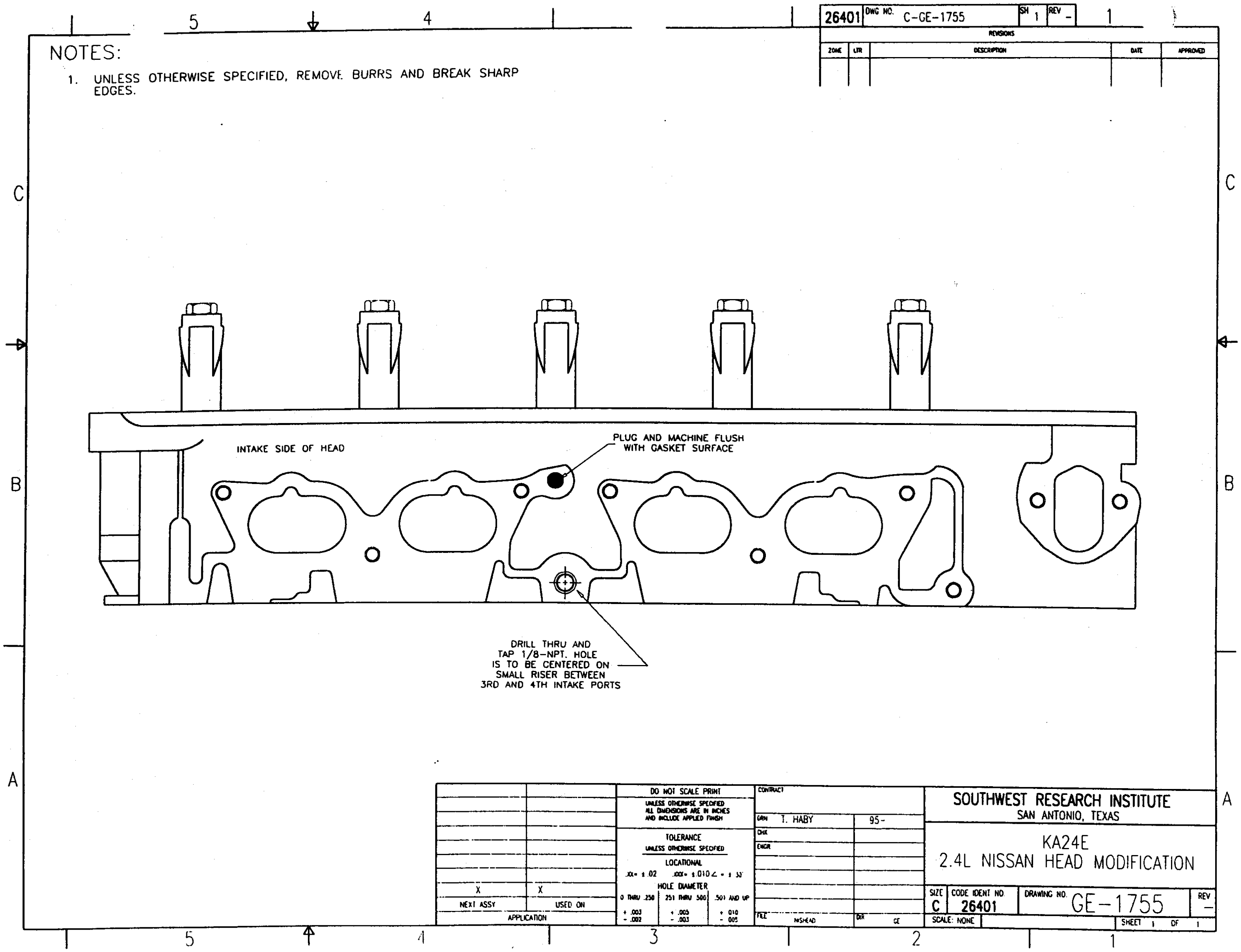


Fig. A3.10 Head Modification

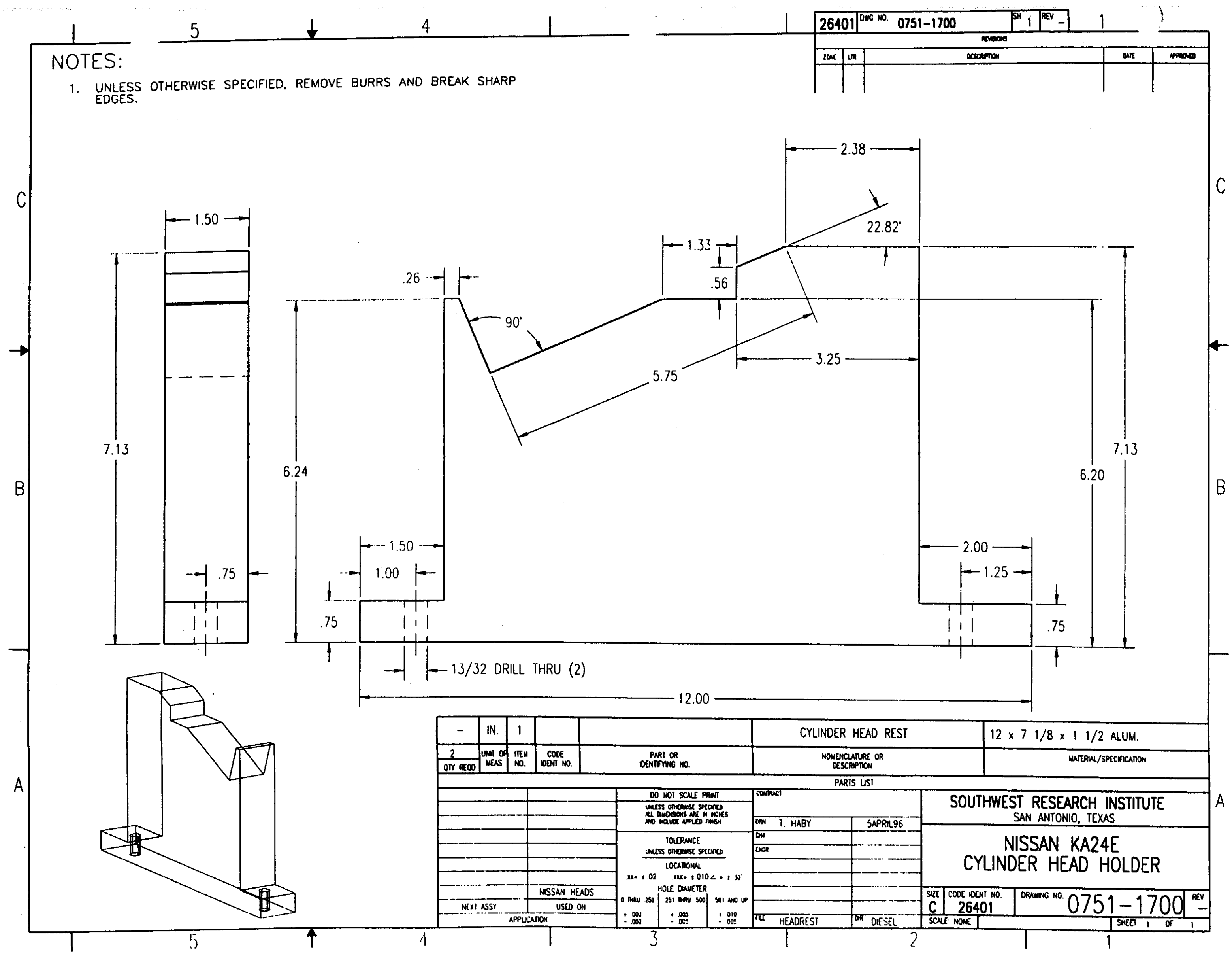


Fig. A3.11 Cylinder Head Holder

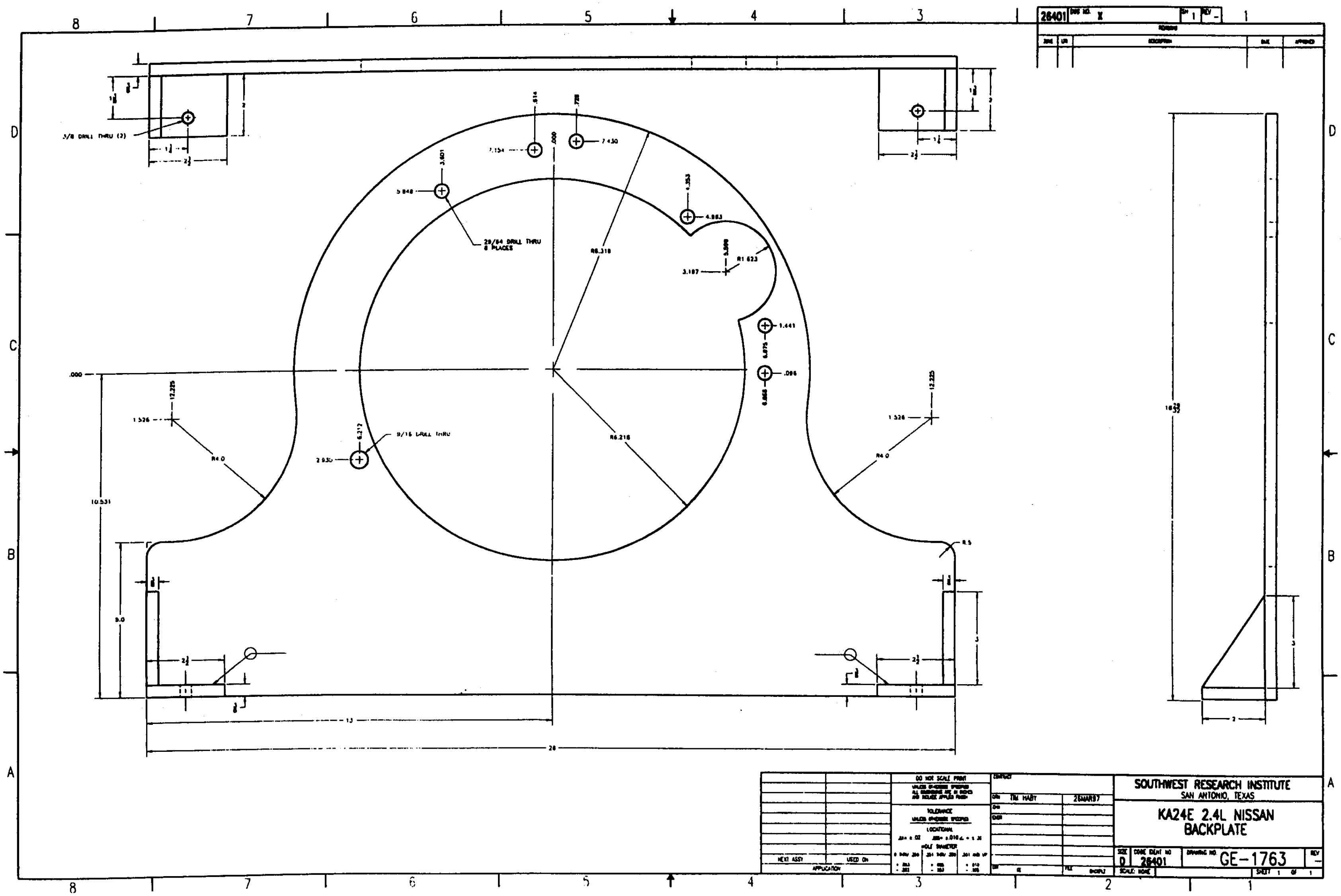


Fig. A3.12 Engine Backplate

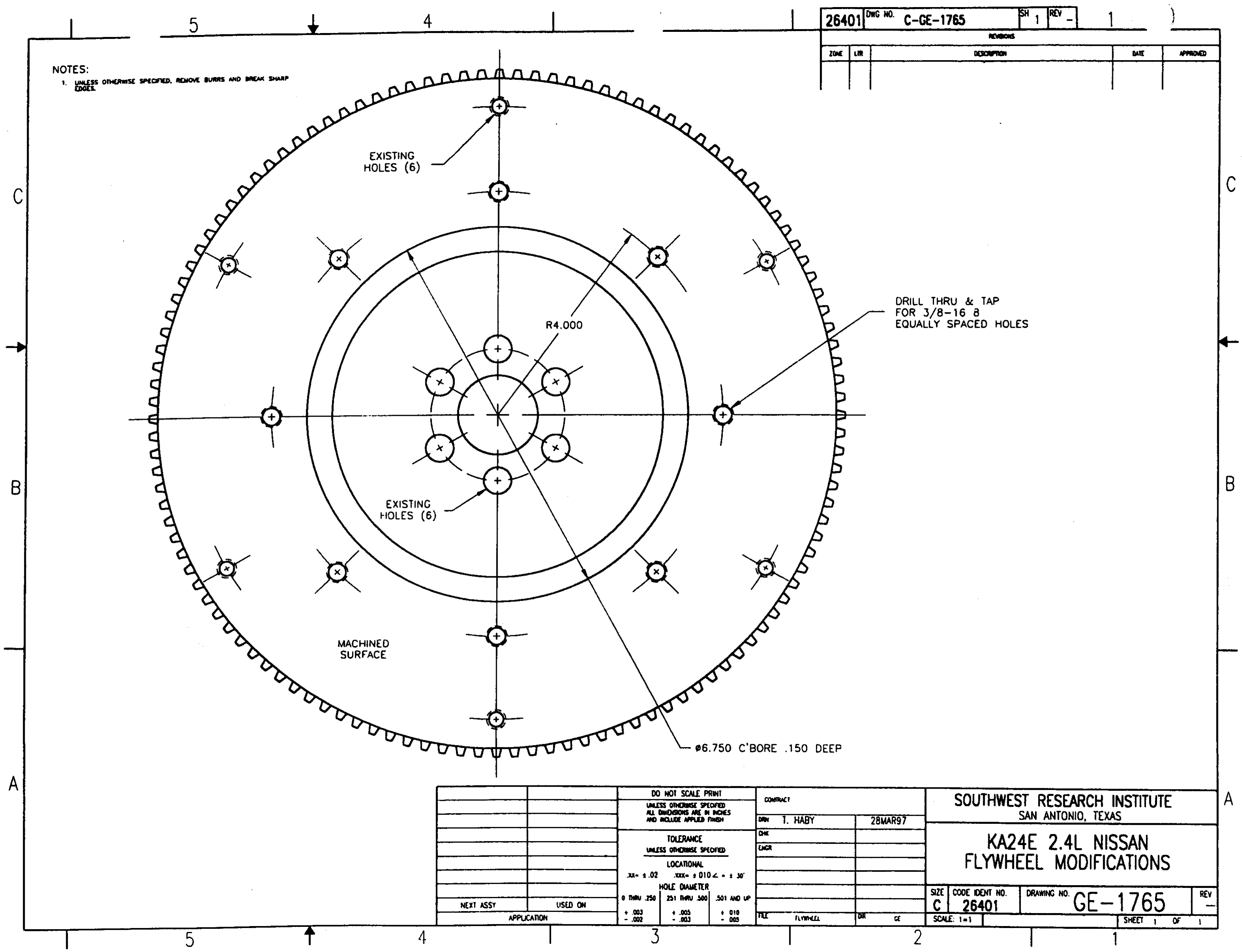


Fig. A3.13 Flywheel Modifications

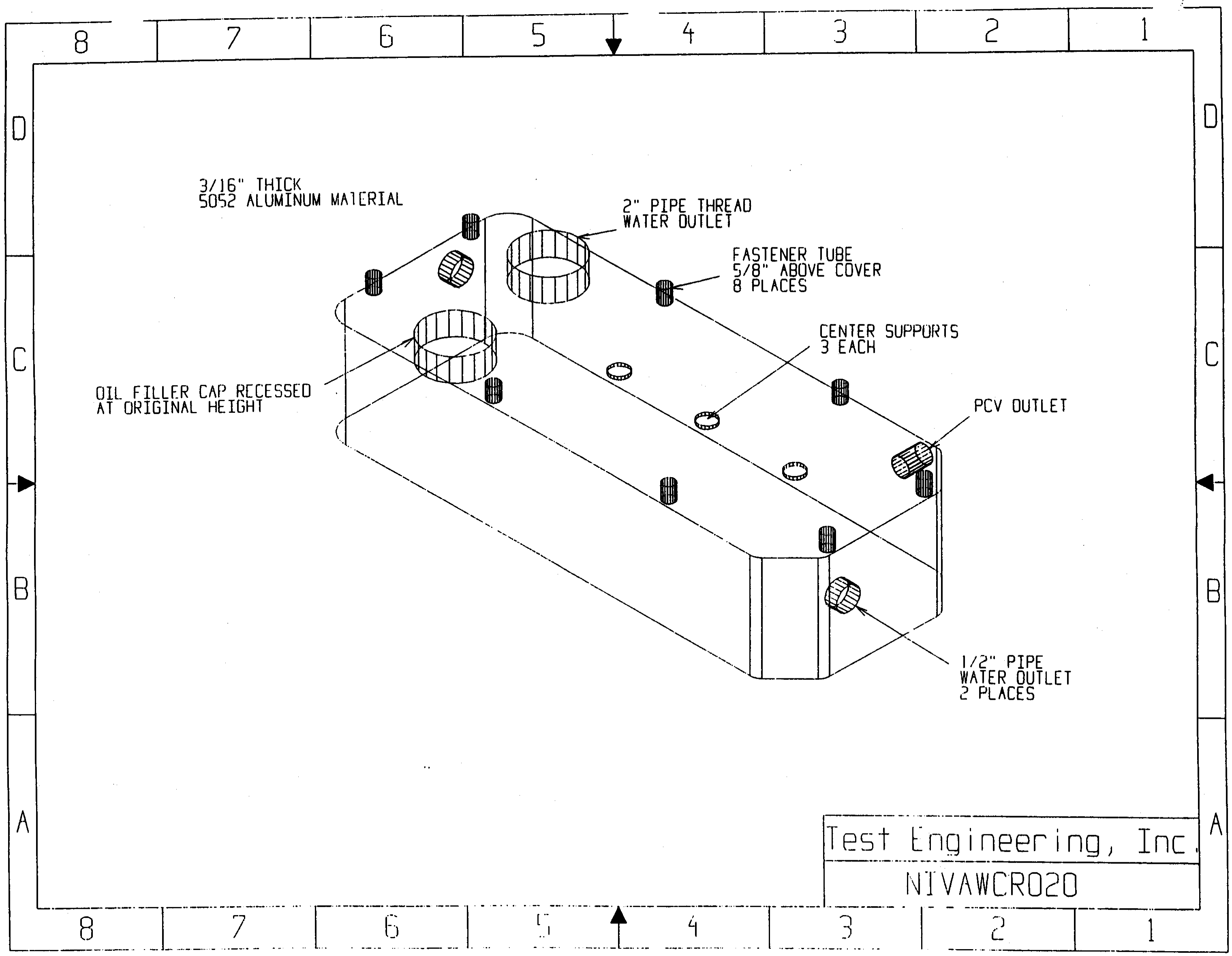


Fig. A3.14 Jacketed Rocker Cover

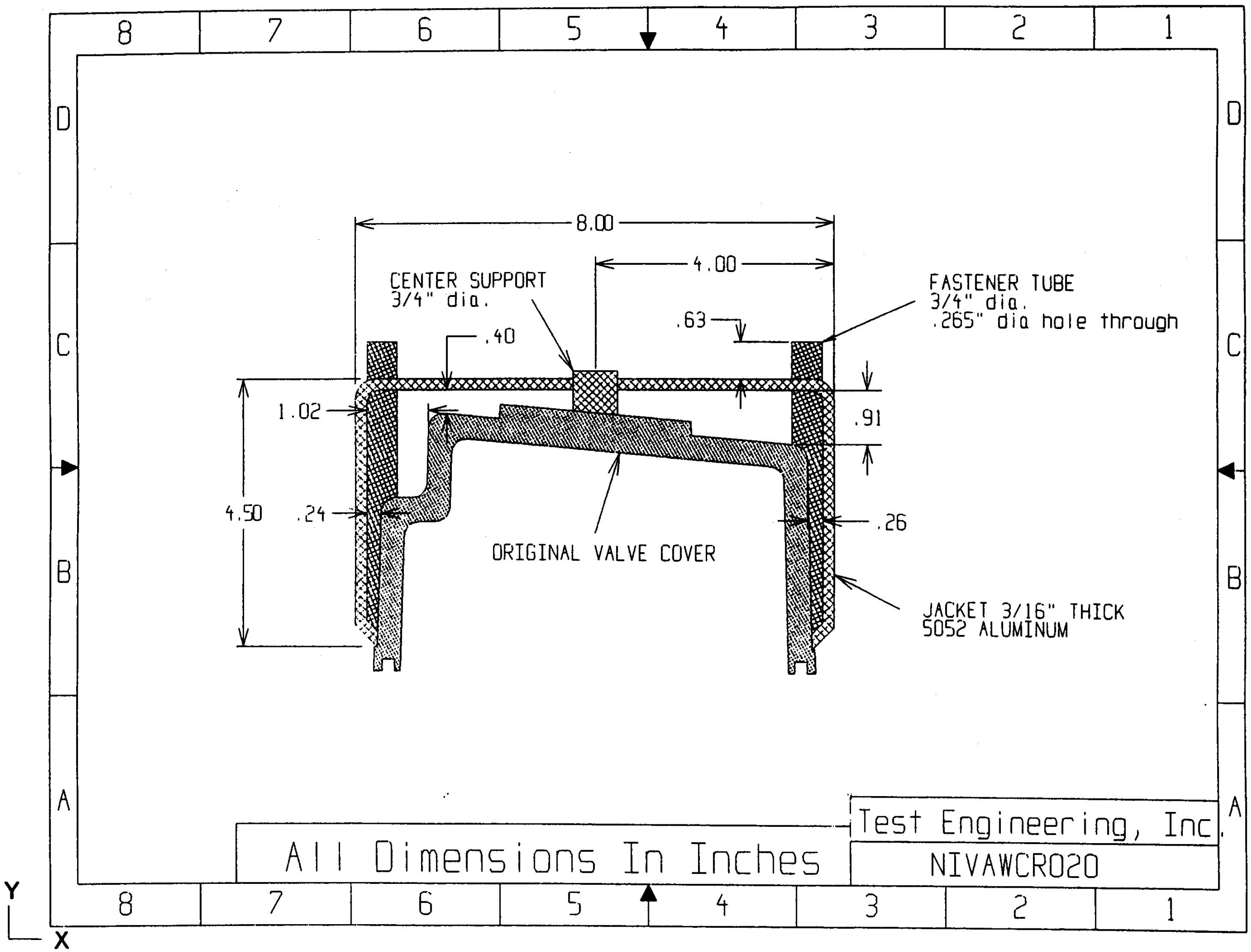


Fig. A3.15 Cross Section of Jacketed Rocker Cover

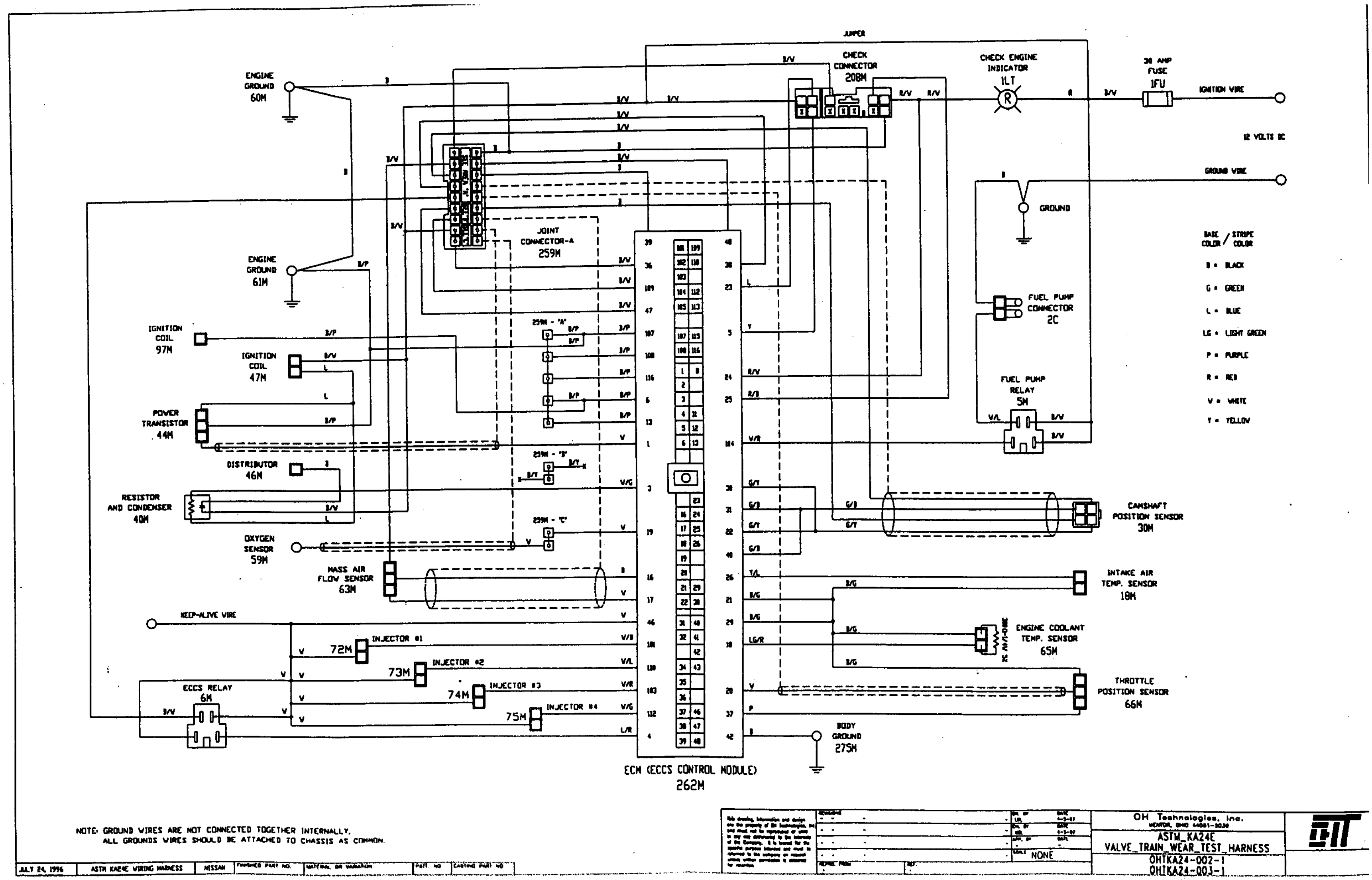


Fig. A3.16 Valve Train Wear Test Harness

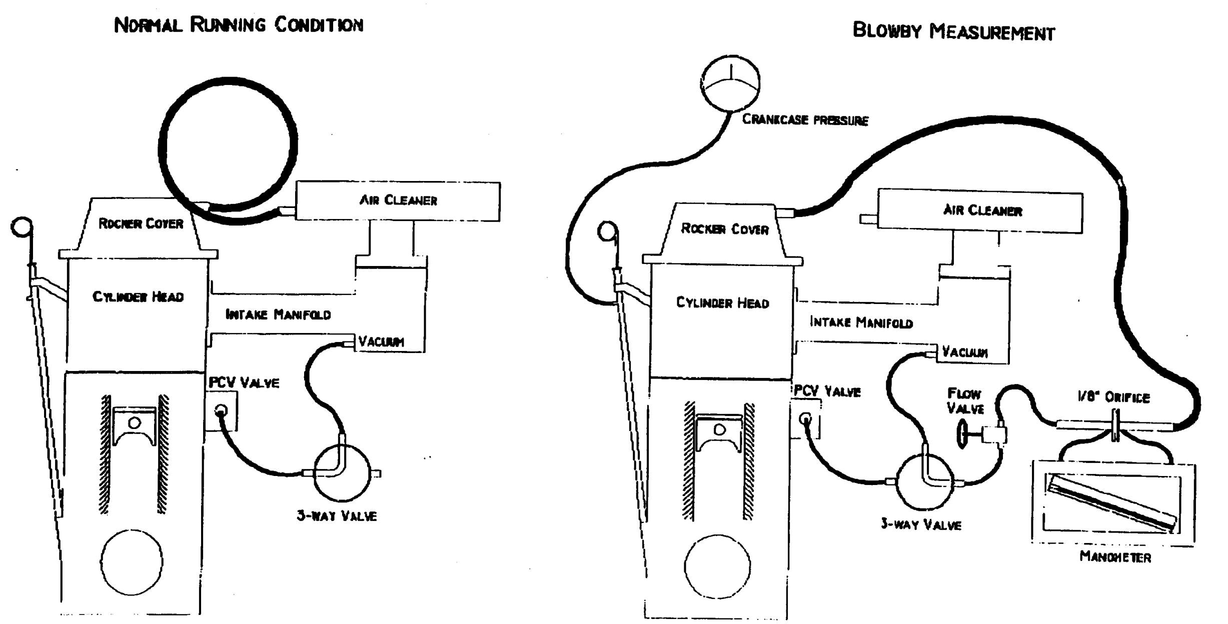


Fig. A3.17 Blow-by Measurement Equipment Schematic

A4. TEST ENGINE SPECIFICATIONS

A4.1 This annex provides the test engine specification requirements for the Sequence IVA test engine. (See Figure A4.1 through A4.xxx)

(IN PROCESS – Awaiting duplicating authorization from Nissan.)

A5. FUELS SPECIFICATION INFORMATION

A5.1 This annex provides information on the test fuel and engine coolant used in the Sequence IVA test procedure.

A5.1.1 KA24E Test Fuel (Fig. A5.1)

PRODUCT INFORMATION

Haltermann PRODUCTS

RESPONSIBLE CARE
ISO 9001 CERTIFIED

T (281) 457-2768 **F** (281) 457-1469

PRODUCT: KA24E TEST FUEL

PRODUCT CODE: HF008

Batch No.:	0109688	0011769
TMO No.:	25830	25736
TMC No.:	0109688-21	0011769-21
Tank No.:	682	682
Analysis Date:	9/27/2001	11/20/2000
Shipment Date:	10/16/2001	10/2/2001

TEST	METHOD	UNITS	SPECIFICATIONS			RESULTS	RESULTS
			MIN	TARGE	MAX		
Distillation - IBP	ASTM D86	°F	75		95	86	87
5%		°F				114	113
10%		°F	120		135	127	127
20%		°F				149	150
30%		°F				177	180
40%		°F				208	212
50%		°F	200		230	224	227
60%		°F				233	234
70%		°F				242	243
80%		°F				260	261
90%		°F	300		325	320	319
95%		°F				344	343
Distillation - EP		°F	385		415	402	387
Recovery		vol %		Report		98.5	97.9
Residue		vol %		Report		1.0	1.0
Loss		vol %		Report		0.5	1.1
Gravity	ASTM D4052	°API	58.7		61.2	59.2	58.9
Density	ASTM D4052	kg/l	0.734		0.744	0.7420	0.7430
Reid Vapor Pressure	ASTM D323	psi	8.8		9.2	9.1	9.1
Carbon	ASTM E191	wt fraction	0.8580		0.8667	0.8633	0.8610
Carbon	ASTM D3343	wt fraction		Report		0.8657	0.8659
Sulfur	ASTM D4294	wt %	0.01		0.04	0.02	0.02
Lead	ASTM D3237	g/gal			0.05	<0.01	<0.01
Oxygen	ASTM D4815	wt %			0.05	<0.05	<0.05
Composition, aromatics	ASTM D1319	vol %			35.0	29.9	29.9
Composition, olefins	ASTM D1319	vol %	5.0		10.0	6.2	5.5
Composition, saturates	ASTM D1319	vol %		Report		63.9	64.6
Oxidation Stability	ASTM D525	minutes	1440			>1440	>1440
Copper Corrosion	ASTM D130				1	1	1
Gum content, washed	ASTM D381	mg/100ml			5	1	1
Research Octane Numb	ASTM D2699		96.0		97.5	97.5	97.0
Motor Octane Number	ASTM D2700			Report		88.2	87.8
R+M/2	D2699/2700			Report		92.9	92.4
Sensitivity	D2699/2700		7.5			9.3	9.2
Net Heat of Combustion	ASTM D240	btu/lb		Report		18364	18388
Color	Visual			Green		Green	Green

This information is offered for your consideration, investigation and verification. It should not be construed as a warranty, guaranty nor as permission or recommendation to practice any patented invention without a license.

Fig. A5.1 KA24E Test Fuel

A6. SAFETY PRECAUTIONS

A6.1 *General Information*

A6.1.1 The operating of engine tests can expose personnel and facilities to a number of safety hazards. It is recommended that only personnel who are thoroughly trained and experienced in engine testing should undertake the design, installation, and operations of engine test stands.

A6.1.2 Each laboratory conducting engine tests should have their test installation inspected and approved by their Safety Department. Personnel working on the engines should be provided with proper tools, be alert to common sense safety practices, and avoid contact with moving, or hot engine parts, or both. Guards should be installed around all external moving or hot parts. When engines are operating at high speeds, heavy-duty guards are required, and personnel should be cautioned against working alongside the engine and coupling shaft. Barrier protection should be provided for personnel. All fuel lines, oil lines, and electrical wiring should be properly routed, guarded, and kept in good order. Scraped knuckles, minor burns, and cuts are common, if proper safety precautions are not taken. Safety masks or glasses should always be worn by personnel working on the engines and no loose or flowing clothing, including long hair or other accessory to dress which could become entangled, should be worn near running engines.

A6.1.3 The external parts of the engines and the floor area around the engines should be kept clean and free of oil and fuel spills. In addition, all working areas should be free of tripping hazards. In case of injury, no matter how slight, first aid attention should be applied at once and the incident reported. Personnel should be alert for leaking fuel or exhaust gas. Leaking fuel represents a fire hazard and exhaust gas fumes are noxious. Containers of oil or fuel cannot be permitted to accumulate in the testing area.

A6.1.4 The test installation should be equipped with a fuel shut-off valve, which is designed to automatically cut off the fuel supply to the engine when the engine is not running. A remote station for cutting off fuel from the test stand is recommended. Suitable interlocks should be provided so that the engine is automatically shutdown when any of the following events occur; engine loses oil pressure; dynamometer loses field current; engine overspeeds; exhaust system fails; room ventilation fails; or the fire protection system is activated.

A6.1.5 Consider an excessive vibration pickup interlock if equipment operates unattended. Fixed fire protection equipment should be provided.

A6.1.6 Normal precautions should be observed whenever using flammable solvents for cleaning purposes. Make sure adequate fire fighting equipment is immediately accessible.