SURFACE VEHICLE RECOMMENDED PRACTICE	J2714™	JAN2023
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(R) Gasoline Direct Injection Pump

RATIONALE

The continued use of direct injection systems in gasoline internal combustion engines, along with the use of direct injection pumps in those systems, requires a document that provides for standardized testing, performance evaluation, and characterization of such pumps. The SAE Recommended Practice is updated to reflect current best practices in test procedures and latest-use conditions in industry.

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1. SCOPE

The scope of this SAE Recommended Practice is limited to gasoline fuel pumps used in automotive direct fuel injection systems. It is primarily restricted to bench tests.

This SAE Recommended Practice also defines the minimum design verification testing that is recommended to verify the suitability of gasoline direct injection (GDI) high-pressure fuel pumps used for pumping gasoline or gasoline-blend fuels to direct injection gasoline injectors. Additional tests not specified in SAE J2714 will be required for non-automotive pump applications or pumps, such as those intended for use on aircraft, motorcycles, or marine equipment. The pump and the gasoline direct injector are complementary components, and the direct injector component is fully described in SAE J2713, which provides a full range of test procedures for the characterization of such injectors.

Except where specifically stated otherwise, test results are recorded for individual parts under recommended test conditions. Where population characteristics are reported, the sample size, selection method, and statistical analysis technique shall be explicitly stated.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise specified, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J310 Automotive Lubricating Greases

SAE J312 Automotive Gasolines

SAE J814 Coolants for Internal Combustion Engines

SAE J1297 Alternative Automotive Fuels

SAE J1537 Gasoline Low-Pressure Electric Fuel Pump Characterization

SAE J1681 Gasoline, Alcohol, and Diesel Fuel Surrogates for Materials Testing

SAE J1747 Recommended Methods of Conducting Corrosion Tests in Hydrocarbon Fuels or Their Surrogates and Their Mixtures with Oxygenated Additives

SAE J2713 Direct Injection Gasoline Fuel Injector Characterization

2.1.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org

ASTM B117 Standard Practice for Operating Salt Spray (Fog) Apparatus

ASTM D56 Standard Test Method for Flash Point by Tag Closed Tester

ASTM D86 Standard Test Method for Distillation of Petroleum Products at Atmospheric Pressure

ASTM D128 Standard Test Method for Analysis of Lubricating Grease

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

ASTM D471 Standard Test Method for Rubber Property-Effect of Liquid

ASTM D893 Standard Test Method for Insolubles in Used Lubricating Oils

ASTM D1298 Standard Practice for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method

ASTM D1744 Standard Test Method for Determination of Water in Liquid Petroleum Products by Karl Fisher Reagent

ASTM D4806 Standard Specification for Denatured Fuel Ethanol for Blending with Gasolines for Use as an Automotive Fuel

ASTM D4814 Standard Specification for Automotive Spark Ignition Engine Fuel

2.1.3 Code of Federal Regulations (CFR) Publications

Available from the United States Government Printing Office, 732 North Capitol Street, NW, Washington, DC 20401, Tel: 202-512-1800, www.gpo.gov.

40 CFR 86.113 Control of Emissions from New and in-use Highway Vehicles and Engines Fuel Specifications

49 CFR 571.116 Federal Motor Vehicle Safety Standards Motor Vehicle Brake Fluids

2.1.4 U.S. Government Publications

Copies of these documents are available online at https://quicksearch.dla.mil.

MIL-STD-2165 Military Standard Testability Program for Electrical Systems and Equipment

MIL-STD-810 Environmental Considerations and Laboratory Tests

3. BASIC DEFINITIONS AND DATA REPORTING REQUIREMENTS

The following are parameters that define the basic functional characteristics of the GDI fuel pump.

3.1 PUMP STATIC FLOW (Q_{STATIC})

The flow through a non-rotating pump assembly with the pumping element(s) positioned to allow fluid to pass directly from the pump inlet through the pump outlet. Any control valve must be held in the full-open position. The pump static flow is created by the supply pump pressure, P_{IN}, and is expressed in cm^3/s.

3.2 PUMP INLET PRESSURE (P_{IN})

The pressure as supplied by the low-pressure, in-tank fuel pump that operates in conjunction with the GDI pump. This is sometimes referred to as the lift pump pressure or supply pressure. It is measured at the GDI pump inlet and is expressed in kPa. A minimum inlet pressure must be maintained so that fluid in the pump remains in the liquid state at high temperatures to avoid cavitation.

3.3 PUMP OUTLET PRESSURE (P_{OUT})

The pressure supplied by the GDI pump measured at the pump outlet and is expressed in MPa.

3.4 MAXIMUM SYSTEM PRESSURE (P_{MAX})

Also referred to as maximum working pressure, is the maximum pressure to which the GDI pump assembly will be commanded during normal operation. The maximum system pressure is typically specified by the pump manufacturer and is expressed in MPa.

3.5 MINIMUM SYSTEM PRESSURE (P_{MIN})

Also referred to as minimum working pressure, is the minimum pressure to which the GDI pump assembly will be commanded during normal operation. The minimum system pressure is typically determined by the application and is expressed in MPa.

3.6 PROOF PRESSURE (P_{PF})

A test pressure applied to the GDI pump to verify structural integrity. No permanent deformation or leakage is permitted at this pressure and the GDI pump must function normally subsequent to this test. The proof pressure is 2.0 times P_{MAX} and is expressed in MPa.

3.7 BURST PRESSURE (P_B)

Test pressure applied to the GDI pump, possibly resulting in permanent deformation or external leakage, but with an expectation that no sudden rupture will occur. The applied burst pressure is 3.0 times P_{MAX} and is expressed in MPa.

3.8 PUMP OUTLET PRESSURE FLUCTUATION (P_{OUTF})

The maximum fluctuation of pressure at the pump outlet measured while operating the pump at a specified condition. It is normally expressed in units of MPa. P_{OUTF} is the difference between the maximum and minimum instantaneous pressure values observed over a minimum of ten full pump cycles.

3.9 PUMP INLET PRESSURE FLUCTUATION (P_{INF})

The maximum fluctuation of pressure at the pump inlet measured while operating the pump at a given condition. It is expressed in units of kPa. P_{INF} is the difference of the maximum and minimum instantaneous pressure values observed over a minimum of ten full pump cycles.

3.10 NORMAL OPERATING PRESSURE (P_{NORM})

Normal operating pressure is the average pressure to which the particular GDI pump will be commanded during normal operation and is used to establish the dynamic characteristics. The Normal operating pressure is typically specified by the application and is expressed in MPa.

3.11 PUMP DISPLACEMENT (V_D)

The displacement of the pump is the theoretical volume displaced per pump drive shaft revolution. The displacement is dependent only upon the physical dimensions of the pumping elements. It is a volume expressed in cm^3 per cam revolution (cm^3/cam rev). A variable displacement pump should be rated at its maximum displacement. For example, for a piston type pump the equation would be:

$$V_D = \text{Number of pumping pistons x Number of lobes on cam x Pison displacement} \quad \text{(Eq. 1)}$$

3.12 PUMP SPEED (N_P)

The speed of a pump is the number of revolutions per minute (rpm) of the drive shaft of the pump.

3.13 RATED SPEED (N_{RATED})

Rated speed is the speed of the pump corresponding to the engine speed operating at maximum power. The rated speed is application specific and is expressed in units of rpm.

3.14 MAXIMUM SPEED (N_{MAX})

Maximum speed is the highest speed of the pump attainable without sustaining permanent damage. It is expressed in units of rpm.

3.15 ENGINE CRANK SPEED (N_{CRANK})

Engine crank speed is the speed representing a typical pump shaft speed during an engine starting operation. The engine crank speed for this recommended practice is 100 rpm.

3.16 DIFFERENTIAL PRESSURE (P_{DIF})

Differential pressure is the difference between the pressure of the fluid at the outlet port (P_{OUT}) and the pressure at the inlet port (P_{IN}). Differential pressure is expressed in MPa. The equation for P_{DIF} is:

$$P_{DIF} = P_{OUT} - P_{IN} \quad \text{(Eq. 2)}$$

3.17 PUMP VOLUMETRIC CAPACITY (Q_P)

The capacity of a pump is the volume of fluid actually delivered per pump shaft revolution, including both liquid and any dissolved or entrained gases, under stated operating conditions. Pump volumetric capacity is expressed in cm^3/cam rev.

3.18 PUMP VOLUMETRIC EFFICIENCY (E_V)

The volumetric efficiency is the ratio of the pump volumetric capacity (actual output) to the pump displacement (theoretical output) at a given operating condition. The formula for computing pump volumetric efficiency (%) is:

$$E_V = Q_P/V_D \times 100\% \quad \text{(Eq. 3)}$$

3.19 DRIVE TORQUE (TO_{DRIVE})

The measured time-integrated mean torque required to rotate the pump drive shaft at a given operating condition. It is measured in units of N-m. Torque fluctuates instantaneously so TO_{DRIVE} must be determined over a minimum of ten full pump cycles.

3.20 TORQUE PULSATION (TO_P)

The maximum fluctuation of torque measured while rotating the pump drive shaft at a given operating condition. It is expressed in units of N-m. Torque pulsation is the difference of the maximum and minimum instantaneous torque values observed over a minimum of ten full pump cycles.

3.21 INPUT POWER (BP, brake power)

The input pump power is the power delivered to the pump drive shaft, under stated operating conditions of the pump. The equation for input power is:

$$\text{Input power [kW]} = TO_{DRIVE}\ \text{[N-m]} \times N_P\ \text{[rpm]} \times 1.047 \times 10^{-4} \quad \text{(Eq. 4)}$$

3.22 OUTPUT POWER (WP)

The output pump power (hydraulic power) is the power imparted by the pump to the fluid discharged from the pump, under stated operating conditions of the pump. It is less than the Input power by the amount of power loss in the pump. The equation for output power is:

$$\text{Output power [kW]} = Q_P\ [cm^3/rev] \times N_P\ \text{[rpm]} \times P_{OUT}\ \text{[MPa]} \times 1.6667^5 \quad \text{(Eq. 5)}$$

3.23 PUMP MECHANICAL EFFICIENCY (E_M)

Pump mechanical efficiency is the ratio of the pump output power (determined from flow and pressure measurements) to the pump input power (determined from pump torque and speed measurements). The equation for pump mechanical efficiency (%) is:

$$E_M = WP/BP \times 100\% \quad \text{(Eq. 6)}$$

3.24 PUMP CONTROL VALVE DELIVERY ANGLE (CV_{DA})

CV_{DA} is the angular value of the pump shaft revolution at which the control valve is commanded to deliver fuel. It is expressed in units of degrees relative to top dead center or bottom dead center of the cam lobe depending on control valve driver conventions.

3.25 CRANK PRESSURE RISE TIME (P_{CRT})

The time, measured in seconds, for a pump to achieve P_{NORM} with P_{IN} at 400 kPa while rotating at N_{CRANK}.

3.26 INLET TEMPERATURE (T_{IN})

The inlet temperature is the fuel temperature measured at the inlet of the GDI pump. T_{IN} is expressed in degrees Celsius.

3.27 OUTLET TEMPERATURE (T_{OUT})

The outlet temperature is the fuel temperature measured at the outlet of the GDI pump. T_{OUT} is expressed in degrees Celsius.

3.28 PUMP HOUSING LEAKAGE RATE ($Q_{LEAK\text{-}HOUSING}$)

The pump housing leakage rate is the rate at which liquid fuel leaks past the pump structural assembly (non-moving components) into the surrounding external environment. This is an indirect measurement using helium as a surrogate medium and is expressed in units of mbar*L/s.

3.29 PUMP INTERNAL (FUEL TO OIL) LEAKAGE RATE ($Q_{LEAK\text{-}INTERNAL}$)

The pump internal leakage rate is the rate at which liquid fuel leaks past the pump piston seal into the engine lubrication system. $Q_{LEAK\text{-}INTERNAL}$ is expressed in units of mm^3/min.

3.30 RELIEF PRESSURE (P_R)

The pump relief pressure is the actuation pressure value at which the safety relief valve opens and allows high-pressure fuel to exit to the low-pressure side of the pump.

3.31 DATA REPORTING REQUIREMENTS AND RECOMMENDATIONS

The test conditions and required observed values for any of the tests described in this document shall be recorded on the designated data reporting sheet for the associated test. This will provide a detailed record of the test. Any testing conditions or procedures that differ from those required or recommended shall be noted in the Comments or Test Deviations lines of the data reporting sheet that is designated for the particular test. The data recording sheets for each specific test will have reporting spaces for the test conditions, as well as for the parameters that are measured in the test. Except where stated, test results are to be recorded for individual test pumps. Whenever the population characteristics of a test set are to be reported, the sample size, sample selection method and the analysis technique that is utilized shall be noted on the data reporting sheet. At a minimum, the following test hardware descriptions, test environment, test conditions and fluid description are to be recorded:

a. Pump type, serial number, and manufacturer.

b. Test date, test stand designation, and operator name.

c. Test fluid type, ambient and fluid temperature (unless tested dry).

d. For non-standard test fluids: name, specific gravity, Reid vapor pressure.

e. The rated operating performance of the pump.

f. For electrically driven GDI pumps: voltage and resistance.

g. Any deviations from the standard test conditions or methods that are specified in a test procedure.

4. STANDARD TEST CONDITIONS AND PARAMETER FLUCTUATION LIMITS

4.1 Recommended Standard Test Conditions

4.1.1 Test Fluid

Normal heptane (n-Heptane) is recommended for the measurement of pump performance characteristics, unless otherwise specified for a particular test.

4.1.2 Fluid Temperature

The test fluid temperature shall be measured at the pump inlet, and is to be stabilized at 21 °C ± 2 °C, unless otherwise specified.

4.1.3 Pump Inlet Pressure

The average gauge pressure measured at the inlet to the pump. Pump inlet pressure shall be held to ±2% of set value throughout the test, unless otherwise specified. The pump inlet pressure fluctuation (P_{INF}) shall not exceed 100 kPa.

4.1.4 Pump Outlet Pressure

The average gauge pressure measured at the pump outlet. Pump outlet pressure shall be held to ±2% of set value throughout the test, unless otherwise specified.

4.1.5 Pump Speed

Pump shaft speed shall be held to within ±5 rpm of the set value throughout the test, unless otherwise specified.

5. TEST EQUIPMENT

5.1 Leakage Test Equipment

A commercially available helium leak-detection device is recommended for measuring the pump housing leakage. A commercially available flame ionization detector (FID) analyzer is recommended for measuring pump internal leakage. Leakage rate measurement test equipment must be accurate to within ±1% of its full scale reading.

5.2 Performance Test Bench

To assure that the performance test stand is versatile enough to evaluate the various pump design characteristics, the hydraulic system should be capable of operating with n-Heptane. A representative piping diagram is shown in Figure 1 for a typical hydraulic system.

The test fluid supply pump must be capable of delivering sufficient flow and pressure (P_{IN}) as required for the high-pressure pump on test. The test fluid filtering system must be 5 µm or better. The test fluid temperature control system must be capable of maintaining the test fluid temperature within ±2 °C. The test fluid pressure regulation system must be capable of maintaining the inlet test fluid pressure to the pump within ±30 kPa. The inlet pressure shall be measured within 75 mm of the pump inlet. The test fluid pressure regulation system must be capable of maintaining the outlet test fluid pressure from the pump within ±100 kPa. The outlet pressure shall be measured within 75 mm of the pump outlet. The test fluid flow rate measurement device must be accurate to ±2%. The speed control system must be capable of maintaining the pump shaft speed to within ±5 rpm. The stand must have a device capable of measuring torque at the pump driveshaft that is accurate to ±2%.

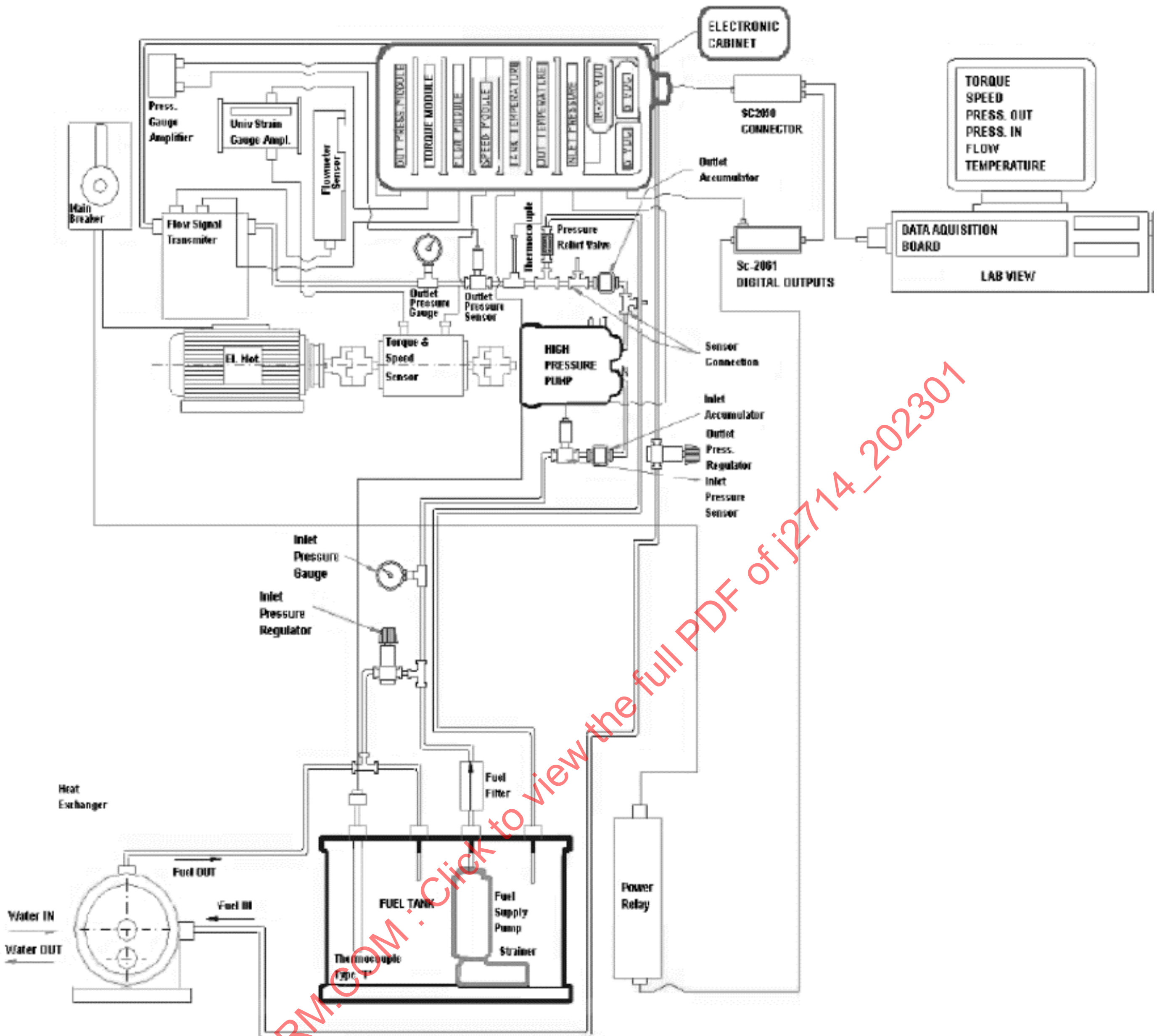

Figure 1 - Schematic of a representative GDI pump performance test stand

5.3 Noise Test Bench

The pump noise measurement technique defined in this section will require a quiet room with a free-field sound environment such as that of an anechoic or hemi-anechoic chamber. A typical test setup with the pump and the drive unit is shown in Figure 2 . The electric motor drive unit can be integrated with the pump but shall be maintained inside an acoustic enclosure as shown. Alternatively, the electric motor can also be mounted outside the hemi-anechoic chamber in order to maintain the desired ambient noise level. Ambient noise inside the chamber without the pump operation shall be below 40 dB(A).

Typical Sound Measurement Setup in an Hemi-Anechoic Chamber

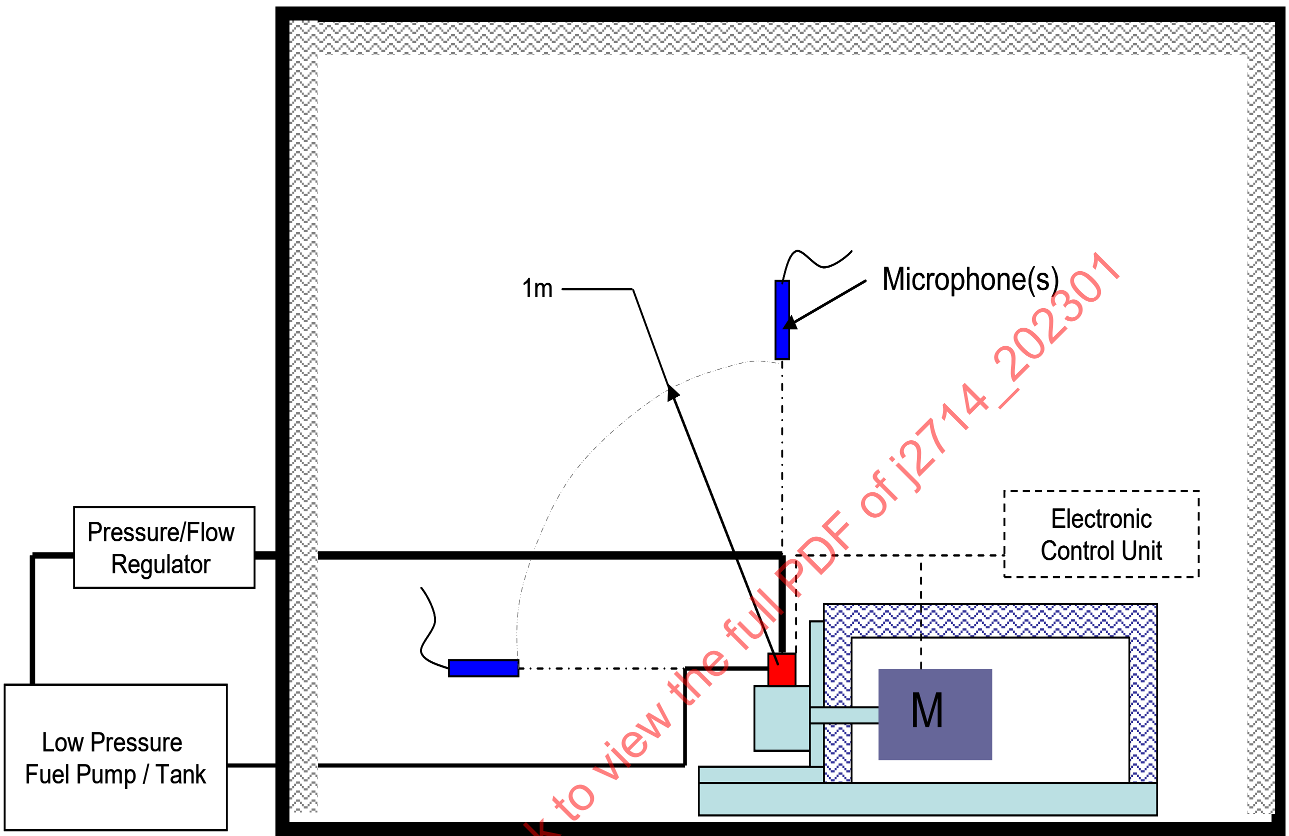

Figure 2 - Schematic of sound measurement setup with integrated motor in a hemi-anechoic chamber

A typical hydraulic circuit for the pump test unit is shown in Figure 3. A fixed volume chamber that simulates a typical fuel rail volume shall be used downstream of the pump test fixture with rigid fuel lines. The downstream side of this fuel volume shall be connected through a flexible line with a metering device to control the flow and operating pressure. The fixture to which the pump is mounted shall be designed sufficiently rigid as to not influence the test results as described below. The flanges or face plate used to support the drive shaft shall be designed sufficiently rigid so that it does not radiate significant additional noise. The typical guideline to satisfy this requirement is to maintain the first fundamental resonant frequency to above 14 kHz. If the flange or face plate is a contributor of significant additional radiated noise, an acoustic enclosure shall be used.

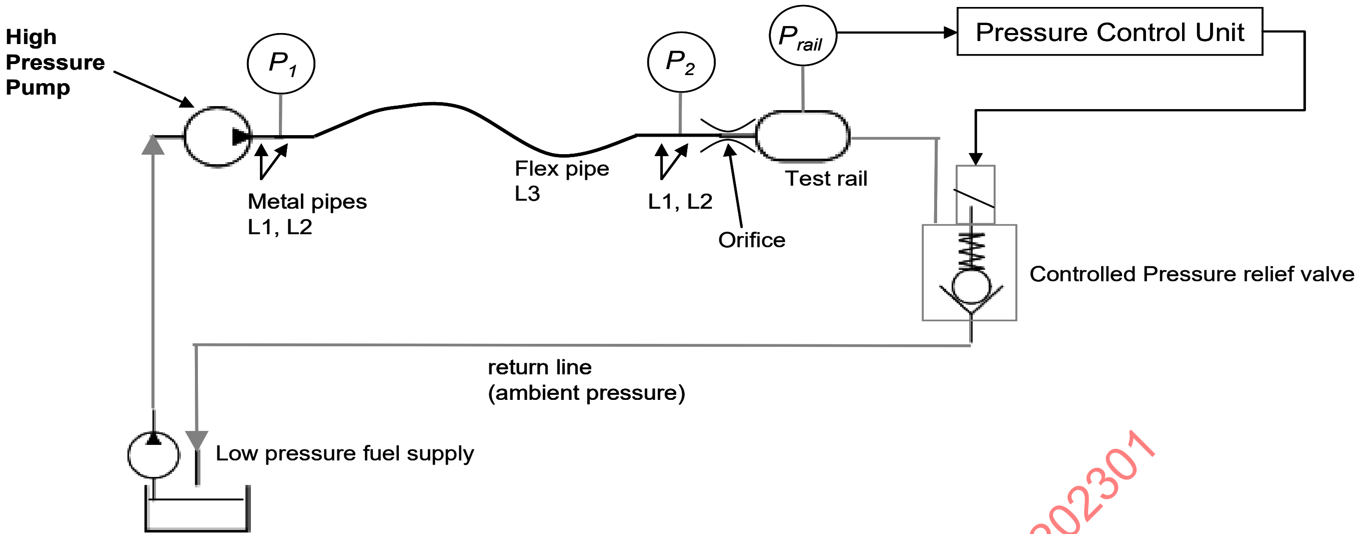

Figure 3 - Hydraulic circuit for the pump noise characterization test fixture

where:

L1 = 50 mm

L2 = 25 mm

L3 = >2000 mm (flexible pipe line)

Inner diameter = 15 mm

Orifice diameter = 1.5 mm

Test rail volume = 140 to 150 cm^3

The flexible pipe line shall be high-pressure capable. The noise directly radiated by the pump shall be measured using condenser-type, free-field microphones. The microphones shall be located at a distance of 1 m from the pump center. One microphone shall be placed directly above the pump and another at a hemispherical position where the maximum sound pressure level can be measured, as shown in Figure 2.

The mechanical forces exerted by the pump to its mounting structure (typically the cylinder head) shall be measured using accelerometers (vibration sensors) on the mounting structure. The accelerometers should be attached near the edge of the fixture using standard adhesive. They should be positioned near, but not on, the heads of the mounting bolts. The size of the mounting bolts used shall be same as those used to mount the pump in the respective application. The source of mechanical excitation in pumps with single pistons is most often the opening and closing of the electronic control valve. In which case, the vibration at the end of the flow control valve needle stop can also be measured with an extreme miniature, single-axis accelerometer. This may not be possible in some pumps where the control valve ends are encapsulated within the housing.

The hydraulic forces (hydraulic hammer) generated by the pump during pumping are another source of noise generated by the pump depending upon the control method employed by the flow control valve. This hydraulic excitation also manifests itself in the form of mechanical excitation which will be captured by the structure-borne and radiated (airborne) noise measurements. If characterization of this hydraulic excitation alone is necessary, then a dynamic fluid pressure sensor can be used to measure the rate of rise of fuel pressure at the outlet of the pump.

5.4 Environmental Test Chambers

Use commercially available standard environmental test equipment, following the manufacturer's recommended guidelines.

5.5 Vibration Test

Test to be performed using commercially available vibration table and associated measurement test equipment. Test equipment setup and operation shall be made following the recommended guidelines for the equipment.

5.6 Durability Test Stand

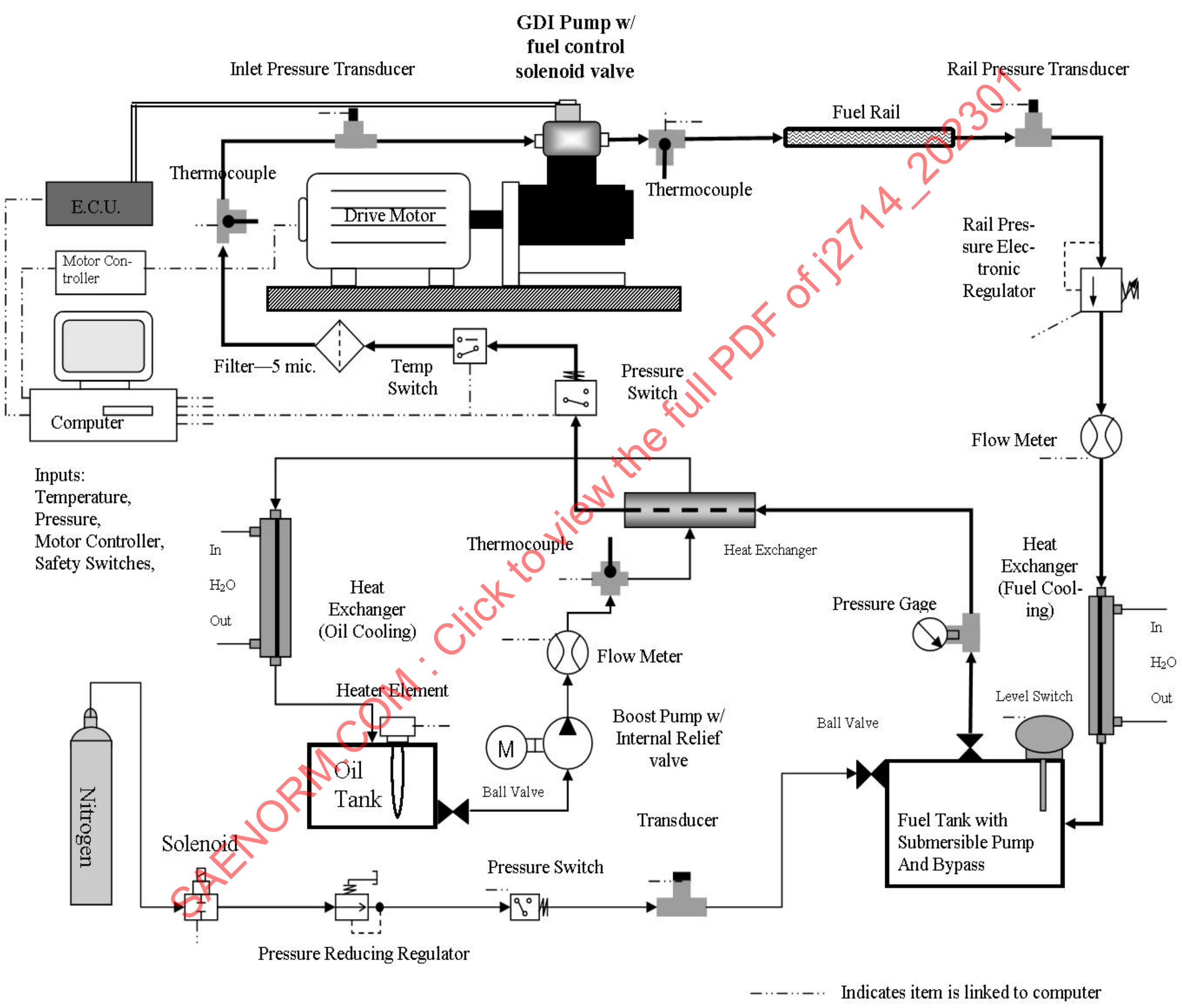

Figure 4 - Schematic of a GDI durability test stand

5.6.1 Filtration: Inlet Filter

The fluid supply pump shall be fitted with a 30 µm inlet filter that meets the particle pass and pressure drop specification of the pump manufacturer. A commercially available automotive in-tank pump that provides sufficient pressure for the application may be used.

5.6.2 Outlet Filter

Each fluid supply pump outlet shall be fed into a 5 μm automotive in-line filter used in gasoline fuel injection applications.

5.6.3 Tank Size

The tank of the test stand, where the pumps are to be tested, must be of sufficient size to accommodate the fluid flow and temperature test requirements.

5.6.4 Fluid Change Interval

The fluid in the tank must be changed every 168 hours ± 24 hours.

5.7 Cyclic Corrosion Chamber

The cyclic corrosion test consists of an ambient temperature, salt mist, high humidity, and high drying rate temperature cycle. The test chamber shall be capable (at a minimum) of providing the high humidity (up to 100% RH) and high dry-off temperature (60 °C ± 2 °C at <30% RH) required to run the cyclic corrosion test in a 24 h/day automated cycle. The chamber may be an approved commercial unit or may be constructed by the user to satisfy these test requirements. While the salt mist application can be applied manually, it is preferred that the corrosion chamber be capable of automatically applying a sufficient salt mist spray at the proper Phase 1 time and duration (see 8.4.4) to thoroughly wet the parts and rinse away any previous salt accumulation in a single continuous application.

5.8 Thermal Shock Test

The thermal shock test requires two insulated containers that have containment volumes capable of holding multiple pumps. One is essentially a freezer and the other is essentially an oven. One must be capable of generating and maintaining an internal temperature of -50 °C and the other +140 °C. The two storage volumes should ideally be in close proximy to facilitate a rapid transfer of pumps from one to the other.

6. PUMP FUNCTIONAL TESTING

6.1 Pump Leakage Testing

The purpose of the leakage testing is to demonstrate the ability of the pump to contain fluid under various operating conditions. The pump housing leakage test is conducted by measuring the concentration of helium in a test chamber, whereas the pump internal leakage test utilizes a FID to measure the concentration of hydrocarbons in a carrier gas. The number of individual GDI pumps to be leak tested may be selected by the user, with the number being clearly indicatd on the associated data reporting sheet. A typical number of pumps is in the range from three to eight.

6.1.1 Pump Housing Leakage Rate Testing ($Q_{LEAK-HOUSING}$)

The preferred method of testing for pump housing leakage is by utilizing a commercial helium leak detector. The units of the measured leakage are to be mbar*L/s.

6.1.1.1 Drying Procedure for Pump Leakage (Helium and FID Methods)

Dry the pump by applying nitrogen or air at P_{IN} (typically 300 to 500 kPa) to the inlet side of the pump with the discharge port pointing downward and continue the nitrogen or air purge for a minimum of 30 seconds to remove residual fluids from the pump. Any controlling valve must be opened during the drying process in order to purge the entire flow path up to the discharge port. Repeat the process until all trapped fluid is purged. Clean any external pump surface that will be exposed to the sample volume of any oils, fuels or other contaminants may lead to an inaccurate leakage measurement.

6.1.1.2 Helium Leakage Test Procedure

Calibrate the vacuum leak test fixture, which is a commercial helium mass spectrometer, per the specified procedure of the equipment manufacturer. With the pump at an ambient temperature of 21 °C ± 2 °C, close and seal all pump ports except the discharge port. Any controlling valve must be opened during the measurement process in order to pressurize the entire flow path up to the discharge port. Place the pump into the vacuum chamber. Evacuate the vacuum chamber until pressure reaches the manufacturer specified operating conditions for the mass spectrometer. The test shall be performed with pressurized helium applied to the pump inlet at P_{IN}. Test time should be a minimum of 30 seconds. The measured external leakage rate is to be reported in mbar*L/s on the data reporting sheet in Appendix B.

6.1.2 Pump Internal (Fuel to Oil) Leakage Rate Testing ($Q_{LEAK\text{-}INTERNAL}$)

The preferred method of pump internal leak testing is with the use of a commercially available flame ionization detector (FID).

6.1.2.1 Overview of Fuel to Oil Leakage Test Using FID

The pump internal leakage path (fuel to oil) is typically the sealing joint between the pumping piston and the pump housing. Leakage past this sealing joint results in increased oil dilution and subsequent engine-related problems.

The test fixture used for driving the pump during this test must also isolate the pump from the driving mechanism. Without this isolation, contaminants from the driving mechanism may lead to inaccurate pump internal leakage measurement. A cross section of a representative test fixture for internal leakage measurement is illustrated in Figure 5. The FID sample lines shall be heated to prevent condensation of hydrocarbons within the system during the test.

6.1.2.2 Pump Drying for FID Leakage Measurement

Dry the pump according to the process described in 6.1.1.1. Ensure that any external pump surface that will be exposed to the sample volume is cleaned of any oils, fuels or other contaminants that could influence the FID measurement.

6.1.2.3 FID Leakage Test Procedure

Calibrate the FID analyzer prior to the test with a calibration gas (propane) spanning the appropriate measurement range, per the equipment manufacturer's procedure. Install the pump onto the test fixture. Pressurize the fuel inlet side of the pump with n-Heptane at P_{IN} = 500 kPa. The test is to be run at room temperature of 21 °C ± 2 °C.

Flow the nitrogen carrier gas through the sample chamber at a rate of 10 L/min ± 0.1 L/min.

Run the pump at the four specified speeds and pressures listed below for a minimum of 3 minutes, until the FID measurement stabilizes. Once the stabilization period has ended, record the average value of the hydrocarbon leakage over the next 10 seconds, sampled at 1 Hz. Convert the recorded average value to the units of mm^3/min using Equation 7. Record the data in mm^3/min on the data reporting sheet in Appendix C.

$$Q_{LEAK-INTERNAL} = Q_{CARRIER} \times \frac{1000mL}{1L} \times \frac{1mol}{22400mL} \times \frac{c}{10^6} Carbon \times \frac{3carbon}{1propane} \times \frac{1nhept}{7Carbon} \times \frac{100.204g}{1mol} \times \frac{1mL}{.68376g} \times \frac{1000\mu L}{1mL} \quad \text{(Eq. 7)}$$

where:

$Q_{CARRIER}$ = carrier gas flow rate in L/min

c = concentration of carbon in ppm

$Q_{LEAK\text{-}INTERNAL}$ = the leak rate in mm^3/min

Test points:

N_P = 500 rpm, 4.0 MPa

N_P = 500 rpm, P_{NORM}

N_P = N_{MAX} rpm, P_{NORM}

N_P = N_{MAX} rpm, P_{MAX}

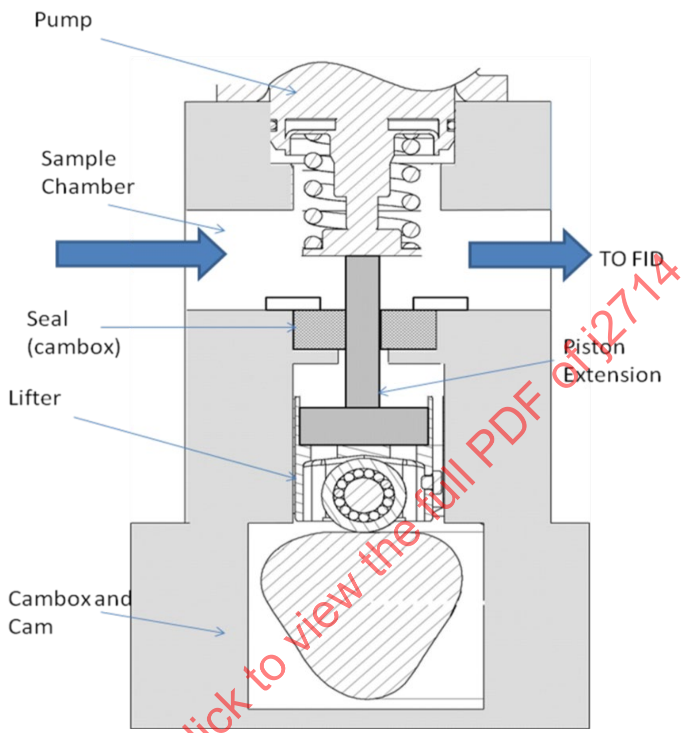

Figure 5 - Representative test fixture for GDI internal leakage measurement

6.2 Pump Basic Performance Testing

6.2.1 Background

This section defines a procedure for conducting and reporting tests to accurately determine performance characteristics. It provides conditions for evaluating quantitative measures of capacity, pressure, speed, and power. This procedure shall also be used to establish pump performance prior to, and after, other types of tests.

6.2.2 Test Equipment for Basic Performance Testing

The test equipment details are described in 5.2.

6.2.3 Pump Basic Performance Test Procedure

a. Install the pump into the performance test stand.

b. Measure and record pump control valve resistance in ohms at 21 °C ± 2 °C.

c. Operate the pump for sufficient time to ensure that the temperature stabilizes and that no air remains in the system.

d. Run the pump at desired CV_{DA} to achieve the maximum Q_P, and P_{NORM} at 100 rpm and at speeds from 250 rpm to N_{RATED} in increments of 250 rpm.

6.2.4 Data Reduction and Analysis

At each pump speed record the following data: Q_P, P_{IN}, P_{INF}, P_{OUT}, P_{OUTF}, TO_{DRIVE}, T_{IN}, and T_{OUT}. Calculate E_V using Equation 3 and E_M per Equation 6.

6.2.5 Data Reporting

Record Q_P, P_{IN}, P_{INF}, P_{OUT}, P_{OUTF}, TO_{DRIVE}, T_{IN}, T_{OUT}, and E_V on the data reporting sheet in Appendix D. Also record the values of E_V and E_M.

6.3 Additional Characterization Tests

6.3.1 Background

The following are optional available tests that may be performed to establish pump operating characteristics at extreme operating conditions:

6.3.2 Static Flow Test, Q_{STATIC} (0 rpm versus P_{IN})

This test is performed to determine the flow through the high-pressure pump when it is not actuated. It includes the pressure drop across the pump.

6.3.2.1 Procedure for Static Flow Test

The pump is not operated during this test. With the control valve held in the fully open position, apply fluid pressure at the nominal pressure P_{IN} to the pump inlet. Measure P_{OUT} and Q_P at the discharge port of the pump.

6.3.2.2 Data Reporting

Record P_{OUT} and Q_P on the appropriate data reporting sheet in Appendix E.

6.3.3 Varying Inlet Pressure P_{IN}

The purpose of this test is to define pump performance over the expected design range of the pump inlet pressures, P_{IN}.

6.3.3.1 Procedure for Varying Inlet Pressure Test

Conduct the basic performance test at both the minimum and maximum P_{IN} limits. For each limit, measure P_{OUT} and Q_P at the discharge port of the pump.

6.3.3.2 Data Reporting

For each limit, record P_{OUT} and Q_P on the appropriate data reporting sheet in Appendix E. Additional copies of the basic performance data reporting sheet in Appendix D may be used to record the results.

6.3.4 Varying Outlet Pressure P_{OUT}

The purpose of this test is to determine the pump performance over the expected design range of the pump outlet pressures, P_{OUT}.

6.3.4.1 Procedure for the Varying Outlet Pressure Test

Run the basic performance test and repeat it varying the outlet pressure: P_{MIN}, P_{MAX}, P_{NORM}, and an evenly split pressure value between P_{NORM} and P_{MIN}, as well as an evenly split pressure value between P_{NORM} and P_{MAX}, for a total of five pressure levels.. For each pressure level, measure P_{OUT} and Q_P at the discharge port of the pump.

6.3.4.2 Data Reporting

For each pressure level, record P_{OUT} and Q_P on the appropriate data reporting sheet in Appendix E. Additional copies of the basic performance data reporting sheet in Appendix D may be used to record results.

6.3.5 Varying Control Valve Delivery Angle CV_{DA}

The purpose of this test is to define pump performance over the operating range of the control valve.

6.3.5.1 Procedure for the Varying Control Valve Delivery Angle Test

Run the basic performance test and repeat it varying either opening or closing timing, by changing the pump control valve delivery angle (CV_{DA}) in 10 degree increments. For each pump control valve delivery angle, measure P_{OUT} and Q_P at the discharge port of the pump.

6.3.5.2 Data Reporting

For each pump control valve delivery angle, record P_{OUT} and Q_P on the appropriate data reporting sheet in Appendix E. Additional copies of the basic performance data reporting sheet in Appendix D may be used to record results.

6.3.6 Pressure-Rise Test

The purpose of this test is to determine the crank speed pressure rise time of the pump pressure to the desired first-injection pressure, or desired P_{NORM}.

6.3.6.1 Procedure for the Pressure-Rise Test

With the pump being driven at N_{CRANK}, command the pressure control valve to provide maximum pump flow and measure the rise time to desired P_{NORM} (or desired first-injection pressure) in seconds, measuring from initiation of the first pumping event until P_{NORM} is achieved.

NOTE: The command to the pressure control valve must be synchronized with the cam to ensure that the first pumping event is a complete event, or the data will not accurately reflect the capability of the pump. Rise times may also be recorded for additional values of P_{NORM}.

6.3.6.2 Data Reporting

Record the pressure-rise-time values on the data reporting sheet in Appendix E. Prepare a pressure-versus-time plot and attach it to the data reporting sheet in Appendix E.

6.3.7 Bleed-Down Test

The purpose of this test is to determine the average pump bleed/leak down rate. This parameter is the indicator of overall system pressure retention.

6.3.7.1 Procedure for the Bleed-Down Test

For a given rail or simulated fuel rail volume, regulated to P_{OUT} = 5.0 MPa, run the pump until the pressure is stable. Then, simultaneously shut down the pump control (control valve and driving system), sealing off the regulated end of the volume (to the fuel rail) and also the P_{IN}. Measure the value of P_{OUT} at 1800 seconds. Bleed-down times may optionally be obtained for additional values of P_{OUT}. Measure P_{OUT} at the beginning and end of test, as well as the duration of test.

6.3.7.2 Data Reporting

Obtain the Bleed-Down rate by dividing (P_{OUT} at the beginning - P_{OUT} at the end) by the duration of the test, in kPa/s. Record data on data reporting sheet in Appendix E.

6.4 Noise Measurement

6.4.1 Background for the Noise Measurement

The goal of this test is to provide basic data with which to characterize the overall noise generation potential of the GDI high-pressure fuel pump. The high-pressure fuel pump(s) in GDI engines are responsible for developing the fuel pressure required to spray the fuel directly in to the combustion cylinder. The opening and closing of the flow control valves and/or the change in the pumping chamber volume which generate the structure-borne and fluid-borne vibrations (fluid hammer) are responsible for the noise caused by the pump. The structure-borne vibrations radiate directly from the pump and also travel through the mating components such as fuel rail and cylinder head (both directly and through the drive shaft). The fluid-borne vibrations excite the mechanical structure of the pump and transfer mechanically to the fuel rail and the cylinder head. In addition, the fluid-borne vibrations excite the hydraulic and structural modes of the fuel rail/line structures and radiate as air-borne noise synchronous with the fuel pump noise. Since this noise can be misdiagnosed as pump noise, the pump noise measurement technique should be free from the influences of such external elements, but sufficient to characterize the potential for the hydraulic excitation of the fuel system.

Due to the complex set of noise sources and transfer paths in the high-pressure pump, this standard establishes a simple means to characterize the overall acoustic noise generation potential of the pump in a GDI engine by measuring the directly radiated noise, and the structure-borne and fluid-borne excitations at the mating components by using a standardized test fixture.

6.4.2 Test Equipment

The noise test equipment is described in detail in 5.3.

6.4.3 Pump Set-Up and Conditions for Noise Test

The recommended test fluid is n-Heptane. If an alternative fluid such as Viscor 381 or Stoddard solvent is used, then record the deviation on the data reporting sheet in Appendix F.

The following test parameters are to be controlled, recorded, and presented with the test data. The values shown below are typical, and are to be run as a standard SAE test point. Each OEM may request additional values as applicable to their systems. The use of the standard test point will promote ease of comparison of similar types of pumps for similar applications.

a. Drive shaft speed, N_P = 300 rpm.

b. Idle fluid flow rate, Q_P = 0.5 g/s (30 g/min).

c. Fluid input pressure, P_{IN} = 400 kPa.

d. Fluid output pressure, P_{OUT} = 3.0 MPa.

The control strategy for actuation of the flow control valve during all noise measurement shall be basic, offered by the pump supplier, and should require no adjustments from the engine control unit.

Other operating conditions may be evaluated according to the customer-specific applications, and normal idle or cold start conditions may also be requested. In such cases, the parameters that characterize the cold start conditions, such as temperature and duration for soak shall be specified.

Background ambient noise levels should be measured and recorded before and after noise testing of the pump.

6.4.4 Noise Measurement Test Procedure

a. Flush the pump and the entire fuel line system to ensure that all air is purged from system. Operate the pump for 20 seconds without operating the flow control valve and record the mechanical and hydraulic system baseline noise.

b. Operate the pump at a driveshaft speed and system output pressure corresponding to normal engine idle and survey with a single microphone at a hemispherical surface area 1 m away from the center of the pump. Identify the location on this hemispherical (imaginary) surface. Locate the direction where the maximum sound pressure level is recorded and fix the microphone at this location. If this location cannot be easily determined or if it is the same as the position of the microphone at the top, then place the microphone at 45 degrees from the vertical plane along the cam shaft axis.

c. Operate and measure the following for 5 seconds at a driveshaft speed and system output pressure corresponding to normal engine idle. Perform all sound and pressure measurements at a minimum sample rate of 40 kHz. Measure the sound pressure level at the two microphone positions described in 6.4.4.2. Also measure the vibration (acceleration) and the hydraulic pressures at the locations defined in 5.3.

d. Repeat the above measurements with any enhanced control strategy if one is supplied from the pump manufacturer for a quieter actuation of the electronic flow control valve.

6.4.5 Data Reporting

Record the test conditions and the test fluid used on the data reporting sheet in Appendix F. Also record the following measurement data and plots:

a. A-weighted sound pressure level shall be reported with A-weighting on 1/3 octave band values at center frequencies, ranging from 500 to 16000 Hz (FFT average using Hanning window, with a spectrum size of 4096). Tabular data and plots should be provided for each microphone position individually. Attach the plots to the data reporting sheet.

b. Linear average of acceleration at all locations presented in 1/3 octave band (data processing as in 6.4.5.1) without any weighting.

c. Control strategy profile used for the electronic flow control valve: basic/standard and enhanced version, if any. Attach the labeled plot of the control strategy profile to the data reporting sheet.

d. Time signal of the pressure rise profile at the P_{OUT}, location P_1 (see Figure 3) shall be plotted along with the electronic control valve signal for three consecutive pumping events. Attach the labeled plot of the pressure rise profile to the data reporting sheet.

e. Number of cam lobes on the drive shaft for single piston pumps, along with the individual lobe profile from the pump manufacturer.

7. DURABILITY TESTING

7.1 Background

The durability life test procedure defines a standardized test for evaluating the variation in performance of a specified pump design that is subjected to an increasing number of operating cycles. Variations on this standardized test, such as an optional pre-durability thermal shock procedure, an optional dry-run procedure and an optional use of alternative testing fluids may also be employed. The standard durability test interval is one billion pump cycles, which may be alternatively defined as a number of equivalent miles/kilometers, years, or hours.

7.2 Test Equipment and Test Fluid Maintenance

The test equipment details for durability testing are provided in 5.6. The test fluid in the test stand tank shall be changed weekly, or approximatly every 168 hours ± 24 hours.

7.3 Durability Test Procedure

a. Specify the number of new production pumps in the durability test set. The number is optional, and the serial number of each pump in the set shall be noted.

b. Test each pump in the test set for basic performance, leakage, and bleed-down values as per 6.2, 6.1, and 6.3.7. Designate these parameter values as the pre-durability values and associate them with the serial number of the pump.

c. Purge all fluids from the pumps in the test set.

d. A thermal shock test may optionally be performed as listed in 8.5.4 for the pumps intended for the durability test. Following the thermal shock application, determine the post-thermal-shock values for basic performance, leakage, and bleed-down as per 6.2, 6.1, and 6.3.7 for each pump. For each pump compute the change from pre-duration to post-thermal-shock and compare each change to an agreed-upon, acceptable limit of change for each measured parameter.

e. Those pumps having changes that exceed the limit values due to thermal shock may optionally be excluded from the subsequent duration test. If a pump is eliminated, another pump should replace it and be subjected to thermal shock and parameter measurement until all pumps going forward for durability testing have thermal shock parameter changes that are within the specified limits. If this option is invoked and a pump (or pumps) are accepted for durability testing, the measured values for post-thermal-shock performance, leakage, and bleed-down become the pre-durability values for the durability test. Further, if this option is invoked, it shall be so indicated by checking the thermal shock box on the data reporting sheet in Appendix G.

f. A brief dry-run procedure may optionally be performed prior to any durability testing if required by the entity requesting the durability test. It is performed on each pump in the test set, and no parameter measurements are associated with it. This procedure simulates a start-up condition.

g. A start-up condition may occur immediately after an engine build and a pump install, and can result in a brief dry-running condition. In this procedure the pump is run in a dry environment prior to the initiation of testing on the durability test stand. The dry-run environment is defined as a pump that contains residual fluid (from the manufacturing process or from previous characterization) but is not yet receiving incoming fuel flow from a lift pump. The dry-run is conducted without an incoming fuel supply or an electrical signal to the flow control valve. The dry-run is performed by cycling the pump drivetrain at a speed of 500 pump rpm for 3 minutes, and conducting this run three times with a 10 minute dwell between runs, without exceeding 18000 pump strokes. If the dry-run procedure is optionally invoked it shall be so indicated by checking the dry-run box on the data reporting sheet in Appendix G.

h. Mount a pump from the test set on the durability test stand. Multiple pumps from the set may be optionally mounted if that capability exists. The pump (or pumps) are to be mounted in the same orientation that is used in the application. Attach the required electrical connectors and fuel lines.

i. Using the standard test fluid, initiate the speed cycling on the durability test stand. Note that an alternate test fluid may be optionally used as noted in 7.6. Operate at the pump speeds and loads in Table 1 to simulate normal operating conditions. Accumulate 1 x 10^9 pump cycles using the listed parameter profiles.

Table 1 - Speed cycling test procedure parameters

Step	Pump Speed, N_P (rpm)	Pressure, P_{OUT} (MPa)	Cycles
1	10% N_{RATED}	30% P_{MAX}	10000000
2	100% N_{RATED}	100% P_{MAX}	40000000
3a	50% N_{RATED}	70% P_{MAX}	1000000
3b	75% N_{RATED}	70% P_{MAX}	2600000
Repeat steps 3a + 3b 250 times			
4	20% N_{RATED}	60% P_{MAX}	15000000
5	90% N_{RATED}	100% P_{MAX}	35000000

j. For each test pump determine the basic performance values per 6.2 at the following designated intervals: Leakage and bleed-down are not required to be measured.

25×10^6 cycles

50×10^6 cycles

100×10^6 cycles

And at every 100×10^6 cycles until end of test.

k. At the completion of 1×10^9 cycles, perform performance, leakage, and bleed-down tests. These values are to be designated as the post-durability values.

7.4 Procedure for Speed Cycling using Alternate Test Fluids

The speed cycling test may be optionally conducted using an alternate test fluid. Examples of these test fluids include, but are not limited to, those listed in 8.3 for the internal fluid compatibility test. Durability testing using an alternative to the standard test fluid is to be considered as a test deviation, and shall be so indicated on the data reporting sheet. The test profile to be used is the same as that shown in Table 1. The data to be acquired and reported are also the same as required when using the standard test fluid. If this test option is invoked it shall be so indicated by checking the alternate fluid box on the data reporting sheet in Appendix G.

7.5 Data Reduction and Analysis for Durability

At each interval listed in step (j) compute the change in each measured performance parameter from the pre-duration value to the value at the current interval. At the end-of-test interval compute the change in each of the parameters of performance, leakage and bleed-down from the pre-durabilty to the end-of-test.

7.6 Data Reporting for Durability

Report basic performance test results for each interval that is listed in Table 1. For the end of test measurements also report the leakage and bleed-down values. Also report the cumulative change in the measured parameters from the start of the test. Report the results on the data reporting sheets in Appendices B, C, D, and E, respectively. In addition, report the flow rates and the end-of-audit-interval flow rate shift in percent for N_P speeds of 500 rpm, 2000 rpm, and 3500 rpm on the data reporting sheet in Appendix G . The flow shift is to be calculated by using Equation 8.

$$\text{Flow shift (5)} = ([\text{End of test } Q_P - \text{Start of test } Q_P] / [\text{Start of test } Q_P]) \times 100 \quad \text{(Eq. 8)}$$

Where Q_P is the maximum flow rate at P_{NORM}.

8. PUMP INTEGRITY TESTING

8.1 Proof Pressure

8.1.1 Introduction

The proof pressure test is the application of an assigned pressure level that represents a pressure to which the direct injection gasoline pump may be subjected if a system malfunction occurs. The pump is not expected to function normally while at the elevated pressure, but shall function normally after returning to the design pressure range following a specified exposure of the proof pressure. The proof pressure test is a bench test that has the objective of evaluating any visible damage, external leakage or degradation of the basic performance of the pump that results from the application of a specific elevated pressure. The high-pressure circuit of the GDI pump housing shall be capable of withstanding the specified proof pressure at an internal fluid temperature of 21 °C for a minimum of 5 minutes without permanent distortion or visual external leakage. Further, the pump shall operate within normal performance limits following the relaxation of the proof pressure. The specified proof pressure level is nominally defined as twice the specified maximum operating pressure of the pump, P_{max}. A non-combustible test fluid is required, which may be selected from a group of available solvents or mineral spirits that are commonly utilized as a safe substitute for actual combustible fuels.

8.1.2 Procedure for the Proof Pressure Test

a. A minimum of three new pumps from serial production are to be tested. More pumps may be optionally tested as required.

b. For every pump in the test set conduct the pre-test basic performance, internal leakage, external leakage and bleed-down measurements per 6.1 and 6.2 using the standard test fluid.

c. Following the pre-test performance tests for each pump in the test set, the pump to be tested is purged of the standard test fluid and then filled with the non-combustible test fluid. The pump inlet is to be sealed. The pump outlet is to be fitted with an adapter allowing a pressure tap and an inlet pressurization tube of adequate strength to withstand the level of the applied proof pressure.

d. The relief valve of the pump may need to be deadheaded. In applications where the relief valve design makes it impossible to achieve the desired pressure, the relief valve will need to be deadheaded. The electrical connector is not to be installed during the test. It may only be installed temporarily prior to the application of the proof pressure if required to activate the closure of an internal relief valve port.

e. Install the test pump in a suitable shielded containment chamber. This shall be a transparent chamber that provides operator protection in case of a bursting event.

f. With the pump control valve held in the position that isolates the high-pressure circuit from the low-pressure circuit, pressurize the pump at the outlet port using a suitable pressurization method such as a hydraulic accumulator or a hand-operated hydraulic pump.

g. Increase the pressure level over a 15-second period until the proof pressure level of twice the maximum operating pressure, P_{max}, is attained, then maintain that level for a duration of 5 minutes. View the pump surfaces during this period and note any deformations or visible external leakage.

h. Reduce the level of the applied gauge pressure back to zero and remove the pump for a more detailed inspection for any signs of damage or external leakage. Note the observations for later reporting. Drain all of the non-combustible test fluid from the pump and set it aside for subsequent post-test performance and leakage testing.

i. If there are additional pumps remaining in the test set, repeat the testing steps (c) through (h) for the next pump.

j. When all pumps in the test set have been subjected to the application of the proof pressure, conduct the post-test performance, bleed-down, and internal and external leakage measurements on each pump per 6.2, 6.1, and 6.3.7.

8.1.3 Data Reduction for the Proof Pressure Test

For each pump in the test set compute the change in each basic performance, leakage, and bleed-down parameter from pre-test to post-test. Convert the computed changes to a percentage for those parameters that are to be reported as a percentage change on the data reporting sheets.

8.1.4 Data Reporting for the Proof Pressure Test

For each pump in the test set record the pre-test and post-test performance, leakage and bleed-down measurements on the data reporting sheets in Appendices B, C, D, and K. Also record the visual observations of any case distortion, damage or external leakage for each pump along with the associated serial number of the pump. If no case distortion, damage, or external leakage was observed, clearly indicate that on the data reporting sheet.

8.2 Burst Pressure

8.2.1 Introduction

The Burst Pressure Test is the application of an assigned high level of internal pressure that represents a pressure to which the direct injection gasoline pump may be subjected if a system control valve failure or pressure relief valve failure occurs. The pump is not expected to function normally either while at this pressure nor after the pressure is fully removed and normal operating pressure is restored. The burst pressure test is a bench test that has the objective of evaluating any visible damage, external leakage or degradation of the basic performance of the pump that results from the application of a specified extreme pressure. The objective of the test is to verify that the integrity of the high-pressure circuit can be maintained without bursting or experiencing external fluid leakage. The high-pressure circuit of the pump housing shall be capable of withstanding the specified burst pressure at an internal fluid temperature of 21 °C for a minimum of 5 minutes without structural failure or external leakage. It is a destructive test for which the pump is ultimately discarded after testing. The specified burst pressure level is nominally defined as three times the specified maximum operating pressure of the pump, P_{max}. A non-combustible test fluid is required, which may be selected from a group of available solvents or mineral spirits that are commonly utilized as a safe substitute for actual combustible fuels.

8.2.2 Procedure for the Burst Pressure Test

a. A minimum of three new pumps from serial production are to be tested. More pumps may be optionally tested as required. No pre-test or post-test measurements are required for this test. Pre-test measurements of external leakage may be optionally conducted if required, and post-test measurements of external leakage may be optionally conducted if required on those pumps that are not damaged in the test.

b. If optionally desired, conduct the pre-test external leakage test per 6.1 for each pump in the test set using the standard test fluid.

c. Dope the non-combustible test fluid with a suitable dye-tracer that exhibits fluorescence when illuminated with ultraviolet light, whether the test fluid is liquid or dried.

d. Fill the pump with the doped test fluid and seal the pump inlet. The pump inlet is to be sealed. The pump outlet is to be fitted with an adapter allowing a pressure tap and an inlet pressurization tube of adequate strength to withstand the level of the applied burst pressure.

e. The relief valve of the pump may need to be deadheaded. In applications where the relief valve design makes it impossible to achieve the desired pressure, the relief valve will need to be deadheaded. The electrical connector is not to be installed during the test. It may only be installed temporarily prior to the application of the burst pressure if required to activate the closure of an internal relief valve port.

f. Install the test pump in a suitable shielded containment chamber. This shall be a chamber that provides operator protection in case of a bursting event and also permits full observation of the pump by means of both white and ultraviolet light.

g. With the pump control valve held in the position that isolates the high-pressure circuit from the low-pressure circuit, pressurize the pump at the outlet port using a suitable pressurization method such as a hydraulic accumulator or a hand-operated hydraulic pump.

h. Increase the pressure level over a 15-second period until the burst pressure level of three times the maximum operating pressure, P_{max}, is attained, then maintain that level for a duration of 5 minutes. View the pump surfaces during that period with both white light and ultraviolet light and note any deformations or visible external leakage. If any cracking, significant external leakage or external deformation is observed, note the damage details and flag the pump as one for which no post-testing for external leakage will be conducted.

i. Reduce the level of the applied gauge pressure back to zero and continue to conduct a detailed inspection using sources of both white and ultraviolet light. Allocate enough time for an inspection in the chamber, and then remove the pump for a more detailed inspection for any signs of damage or external leakage. Note the observations for later reporting. Drain all of the non-combustible test fluid from the pump and set it aside for an optional post-test measurement of the external leakage for a non-flagged pump or for an optional disassembly of a flagged pump for inspection of internal damage.

j. If there are additional pumps remaining in the test set, repeat the testing steps (d) through (i) for the next pump.

k When all pumps in the test set have been subjected to the application of burst pressure, conduct the optional post-test measurement of the external leakage per 6.1 if desired for each pump that was not flagged.

8.2.3 Data Reduction for the Burst Pressure Test

For each pump that was not flagged for damage, and for which an optional post-test measurement of external leakage was made, calculate the change in external leakage from the pre-test to the post-test condition. Convert these net differences into percentage changes in external leakage.

8.2.4 Data Reporting for the Burst Pressure Test

Report the serial numbers and the observed inspection data for each tested pump, both flagged and non-flagged on the data reporting sheets in Appendices B and K. Also, if optionally measured, report the measured pre-test values of external leakage for all pumps, as well as the measured values of post-test external leakage and the percentage pre-test to post-test change for each non-flagged pump.

8.3 Pressure Relief Valve

8.3.1 Introduction

The presence of a relief valve system in a direct injection gasoline pump is a safety feature that protects the pump and the fuel delivery system from damage that may result from a pump pressure that exceeds design limits the opening of the pressure relief valve is intended to return high-pressure fuel to the low-pressure side of the pump. The pressure relief valve test is a bench test that has the goal of verifying that the pressure relief valve safely opens at the designed relief pressure, and that it indeed does prevent excessive pressure levels in the high-pressure chamber. For this bench test a non-combustible test fluid is recommended, which may be selected from a group of available solvents or mineral spirits that are commonly utilized as a safe substitute for actual combustible fuels. The designed relief pressure for a particular GDI pump is dependent upon the maximum operating pressure, P_{MAX}, of the fuel system, as well as the particular application. For informational purposes a range of pump maximum operating pressures and the associated typical relief pressure values are shown in Table 2.

Table 2 - Typical relief pressure settings for GDI pumps

Pump Operating Pressure (MPa)	Typical Pressure Relief Setting (MPa)
20	22
24	26
34	38
40	46
70	78

8.3.2 Procedure for the Pressure Relief Valve Test

a. A minimum of three new pumps from serial production are to be tested. More pumps may be optionally tested as required. No pre-test and post-test measurements are required for this test.

b. Fill the pump with the non-combustible test fluid and make a connection to the pump inlet and relief valve fitting if so equipped in order that flow from the relief valve can be observed. The electrical connector is not to be installed during the test. The pump outlet is to be fitted with an adapter allowing a pressure tap and an inlet pressurization tube of adequate strength to withstand the level of the applied relief pressure. Install the test pump in a suitable shielded containment chamber (preferably transparent). This shall be a chamber that provides operator protection in case of a bursting event and, if transparent, would also permit a full observation of the pump during the test.

c. Pressurize the pump at the pump outlet using a suitable pressurization method such as a hydraulic accumulator or a hand-operated hydraulic pump. Rapidly raise the pressure level to that of the maximum operating pressure, P_{MAX}, then slowly continue to increase the pressure level while monitoring its displayed value.

d. Continue to elevate the pressure level until a sudden drop in pressure indicates that the relief valve has opened. Note the pressure level at which that occurred.

e. Reduce the applied pressure to well below P_{MAX} and repeat steps (d) and (e) five times, each time noting the value at which the relief valve opened.

f. Drain all of the non-combustible test fluid from the pump and set it aside.

g. If there are additional pumps remaining in the test set, repeat the testing steps (b) through (g) for the next pump.

8.3.3 Data Reduction for the Pressure Relief Valve Test

Calculate the average value of the six measured pressure relief valve openings for each pump that was tested.

8.3.4 Data Reporting for the Pressure Relief Valve Test

For each pump tested, record the six measured values of relief valve opening along with the average value of those six tests. Also record the pump serial number associated with each set of measured values.

8.4 Fluid Compatibility - Internal

The Internal fluid compatibility test is used to determine the compatibility of internal fuel pump components with fluids similar to those that may be found in the vehicle's fuel system. Pumps are to be filled with a test fuel, sealed and maintained at fixed, controlled conditions for a specified time period. sealed and maintained tested in the eleven solutions listed in 8.3.2 as follows (fluid quantity to be adequate for the size of the pump tested). A new pump must be used for each test fluid.

8.4.1 Test Fluids

8.4.1.1 ASTM Reference Fuel C (50% Iso-Octane 2-2-4 Tri-Methyl Pentane, 50% Toluene)

Per ASTM D4814.

8.4.1.2 Water/Reference C Solution (Corrosive Fuel)

Preparation: Mix by volume, 98% ASTM Reference Fuel C and 2% corrosive water. Corrosive water is a solution formed by dissolving 165 mg of sodium chloride in 1 L of distilled water, per SAE J1681. The water may be heated to 40 °C to aid the mixing.

8.4.1.3 ASTM Reference Fuel C and 15% Methanol

Shall be 15% by volume reagent-grade methanol added to ASTM Reference Fuel C.

8.4.1.4 ASTM Reference Fuel C and 10% Ethanol

Shall be 10% by volume reagent-grade ethanol added to ASTM Reference Fuel C. Ethanol must meet the requirements of ASTM D4806.

8.4.1.5 ASTM Reference Fuel C and 22% Ethanol

Shall be 22% by volume reagent-grade ethanol added to ASTM Reference Fuel C. Ethanol must meet the requirements of ASTM D4806.

8.4.1.6 ASTM Reference Fuel C and 85% Ethanol (E85)

Shall be 85% by volume reagent-grade ethanol added to ASTM Reference Fuel C. Ethanol must meet the requirements of ASTM D4806.

8.4.1.7 Oxidized Gasoline (Sour Gas)

Stock fuel ASTM Reference Fuel B shall be mixed with a copper ion stock solution as the initial step in preparimg the oxidized gasoline test fuel blend. The two components shall be mixed according to the following procedure to achieve a peroxide number of 180 millimole/L: The stock fuel ASTM Reference Fuel B is (70% iso-octane 2-2-4 tri-methyl pentane, 30% toluene) per ASTM D4814. The copper ion stock solution must be prepared sequentially in the following three steps:

CAUTION: Due to the hazardous nature of these chemicals, failure to follow proper procedures can result in fire. Refer to OSHA Material Safety Data Sheets for additional information.

a. First, add 10 mL of 12% copper ion concentrate solution to 990 mL of stock fuel.

b. Second, add 100 mL of the solution from (a) to 1040 mL of stock fuel.

c. Third, dilute 10 mL of the solution from (b) with 990 mL of stock fuel.

8.4.1.8 Peroxide Stock Solution

Prepare the peroxide stock solution by diluting 335 mL of 90% by weight t-butyl hydroperoxide with 665 mL of n-Heptane. Prepare the oxidized gasoline test fuel blend by diluting 60 mL of peroxide stock solution with 10 mL of copper ion stock solution and 93 mL of stock fuel.

8.4.2 Internal Fluid Compatibility Test Procedure

a. First, select a desired list of the reference fuel blends to be tested. Note that a new test pump is required for each individual test fuel blend that is selected. It is not practical to evaluate all possible variations of test fuel blends that could come into contact with the interior surfaces of the pump. Therefore, a specified list of such fuel blends are normally employed in this test. The most commonly employed fuel blends for this test are listed in 8.2.1; however, additional or alternate fluids may be specified and utilized as long as they are clearly described on the data reporting sheet.

b. Next, conduct pre-test basic performance, leakage, and bleed-down measurements per 6.2, 6.1, and 6.3.7 on the number of new pumps that are required for this test. Each test fuel blend requires one new pump. Note the resultant values of the measured parameters for each of the pumps and associate them with the pump serial number.

c. Following the pre-test measurements for all required pumps, a fuel blend from the desired test list is placed into one of the new pumps. The test pump is to be run a few seconds to ensure that it is filled with the fuel blend that is one of the 11 specified in 8.2.1 The pump is then to be sealed and maintained for 720 hours at 20 °C ± 10 °C.

d. At the end of the 720-hour test period, unseal and drain the pump, then flush with the standard test fuel. Then set the pump aside until all of the test fuel blends scheduled for testing have been similarly tested, each in a new pump.

e. Using another new test pump, repeat 8.2.2.3 and 8.2.2.4 for the next fuel blend in the desired test set. When the last fuel blend in the desired test set has been maintained for 720 hours, transfer all of the individual pumps to where they can each undergo post-test functional performance measurements.

f. Next, inspect the pump inlet and outlet for any signs of damage, corrosion or cracking. Note any occurrences. Then test each pump in the test set for post-test basic performance, leakage, and bleed-down. This is to be performed using the standard test fuel, according to 6.2, 6.1, and 6.3.7.

8.4.3 Data Reduction for Internal Fluid Compatibility Test

Compute the change in the measurements from pre-test to post-test. Compute the percentage change for those parameters for which the units on the data reporting sheet are percent.

8.4.4 Data Reporting for Internal Fluid Compatibility Test

Record the observations from the visual inspection on the data reporting sheet in Appendix I. Also record the pre-test and post-test measurements, along with the computed changes in the measurements from pre-test to post-test on the data reporting sheets in Appendices B, C, D, and E. Use three copies of Part 5 of Appendix D to record the pre-test, post-test, and the changes from pre-test to post-test.

8.5 External Cyclic Corrosion

8.5.1 Introduction

The External Cyclic Corrosion Test is to be applied to direct injection gasoline pumps to ensure that they can withstand the effects of external salt corrosion, which is likely to be encountered on seaside, marine applications and salty road conditions. The cyclic corrosion test consists of an ambient environment salt spray mist combined with a high humidity and high temperature drying. One 24-hour period is considered a single cycle. The test duration is a total of 70 cycles, of which the cosmetic evaluation of corrosion first takes place after ten cycles. The test is monitored through the use of small, metallic corrosion coupons and their subsequent mass loss as the cycles progress. The mass loss of the coupons is assumed to be linear throughout the test.

8.5.2 Test Equipment

The test equipment (corrosion chamber) is described in 5.7. Examples of salt spray chamber and spray nozzle design are described in ASTM B117-11. However, any chamber and nozzle design that achieves the proper corrosion rate is permissible. The corrosion coupons shall consist of steel (AISI 1006-1010) coupons 25.4 x 50.8 mm in size, either 1.59 mm or 3.18 mm thick (mass loss based on thickness outlined below). Fourteen coupons are required for the 70 cycle corrosion test.

8.5.3 Test Setup

Each pump to be tested shall have its inlet and outlet suitably sealed. The pump is to have its electrical connector fitted. However, it is not to be energized. The pump is to be tested dry, with no internal fluids, not even oil. The test pump, henceforth referred to as the “sample,” shall be mounted with the axis between 15 degrees and 30 degrees from the vertical with the top of the pump facing up, as opposed to down. Samples shall be at least 30 mm from each other and at least 35 mm from any chamber wall. Each sample shall be so placed as to permit free settling of spray mist on all samples, but avoid salt solution from one sample dripping onto another. The salt spray mist solution shall consist of the following: 0.9% sodium chloride, 0.1% calcium chloride, and 0.25% sodium bicarbonate, with a pH between 6 and 8. It is important to note that either the calcium chloride or the sodium bicarbonate must be dissolved separately in de-ionized water and then added to the solution separately to avoid any solid precipitate that could clog the spray nozzles in the corrosion chamber.

The initial mass of each coupon shall be recorded on the data sheet prior to the start of the test. Coupons shall be mounted on a bracket and isolated from the bracket via plastic studs and nuts. The coupons shall be mounted at a 15 degree angle from vertical and not contact or shadow each other. The coupons shall be placed a minimum of 5 mm apart, and shall be placed adjacent to the parts being tested so that they encounter the same corrosive environment as the test samples.

8.5.4 Test Procedure

Conduct pre-test basic performance, leakage, and bleed-down measurements per 6.1, 6.2, and 6.3.7 prior to starting the cyclic corrosion test. These measurement values are to be designated as the pre-test values. The test cycle consists of three phases, each 8 hours in duration. The three phases of the test in the order of being performed are;

a. First phase: ambient temperature (25 °C ± 3 °C, 40 to 50% RH) with salt spray mist.

b. Second phase: high humidity (49 °C ± 3 °C, 95 to 100% RH).

c. Third phase: high temperature drying (60 °C ± 3 °C, <30% RH).

During phase 1 (Salt spray mist) the parts are to be sprayed at 2 hour intervals for a total of four spray events. When sprayed, the spray nozzles must be capable of applying sufficient quantity to rinse away any residual salt from previous sprays, and spray sufficient amount of solution onto the parts to maintain wetness for 15 minutes. The ramp times between phases are:

a. Ramp time between phases 1 and 2 is 1 hour.

b. Ramp time between phases 2 and 3 is 3 hours.

c. Ramp time between phases 3 and 1 is 2 hours.

8.5.5 Test Monitoring

Two coupons are to be removed at the end of the tenth cycle. Sandblast the corrosion by-products off of the coupon until the surface is again bare. After cleaning (with alcohol or acetone), weigh the coupon and compare to the original mass of the coupon, assuming a linear mass loss. To calculate the linear slope of the mass loss, the total mass loss (for 70 complete cycles) is 5825 to 6755 mg for 1.59 mm thick coupons and 6402 to 7322 mg for a 3.19 mm thick coupon. Therefore, the mass loss at ten cycles should be 1/7 of the total mass loss listed. A cosmetic evaluation of each of the parts should be completed after the tenth cycle and documented with photographs and notes. The test should be monitored again in this manner at each ten-cycle interval. If the mass loss is greater or less than the projected linear amount then the monitoring interval should be compensated to ensure that 70 mass-loss equivalent cycles will be completed.

8.5.6 Data Reduction and Analysis

At the initiation of the test, record the pH of the salt solution. Also measure and record the mass of each coupon. Photograph each of the test samples at the beginning of the test and at the tenth cycle. At each monitoring interval record the mass loss (in mg) and the cycle number of the mass loss of each coupon.

8.5.7 End-of-Test Evaluation and Reporting

At the conclusion of the 70th cycle, photograph each of the test samples. Remove the samples, wash gently in water not warmer than 38 °C, and dry by blotting with absorbent paper. Record observations of the appearance of the test samples at the end of test on the data reporting sheet in Appendix H. Special attention should be paid to welded joints, crevices, and other areas that may be particularly susceptible to corrosion. The parts shall be tested at the end of test for basic performance, leakage, and bleed-down per 6.1, 6.2, and 6.3.7.

The change in each parameter from pre-test to post-test should be computed, and should be converted to a percentage change for those parameters for which the reporting units on the data reporting sheet are percent. Record the acquired data on the data reporting sheets in Appendices B, C, and D. Use three copies of Part 5 of Appendix D to record the pre-test, post-test, and the changes from pre-test to post-test. Photographs of the samples shall be attached to the data reporting sheets.

8.6 Environmental Tests

8.6.1 External Fluid Compatibility Test

This test is to ascertain whether a particular GDI pump design can withstand the contact of a range of common automotive reference fluids on its exterior surfaces. For each reference fluid tested a determination is made of the changes in numerous pump performance parameters that result. A reference fluid is defined as a material representative of its particular group, which is sufficiently well defined in all respects so that supplies from different sources are essentially identical in action for which the test is intended (refer to ASTM D471).

8.6.1.1 Procedure for the External Fluid Compatibility Test

a. Select a desired list of the reference fluids to be tested. Note that a new test pump is required for each individual test fluid. It is not practical to evaluate all possible variations of test fluids that can contact the exterior surface of the pump. Therefore, specified reference fluids are normally employed in this test. The most commonly used fluids for this test are listed in Table 3; however, additional or alternate fluids may be specified and utilized as long as they are clearly described on the data reporting sheet.

b. Prior to applying any test fluid to any of the pumps, conduct pre-exposure basic performance and external leakage tests on each pump in the test set per 6.2 and 6.1.

c. The first test fluid in the desired test set of fluids is to be applied to the entire external surface of a new test pump by either brushing or spraying at low pressure. This application should exclude any external O-rings.

d. The test pump shall then be installed in a holding fixture representing its intended application, with fuel lines and electrical connections in place. The test pump must be at 21 °C ± 3 °C when fluid is applied. Place the holding fixture containing the pump in an environmental chamber at 80 °C ± 3 °C and soak for 24 hours.

e. Following the hot soak, remove the pump from the holding fixture, then clean the external surfaces and perform a visual inspection. Note any apparent degradation or damage. Specific issues to look for include, but are not limited to, external leakage, penetration of the test fluid, and areas of corrosion, cracking or deformation. Upon completion of the inspection, set the pump aside for later post-test measurements of the performance parameters.

f. If there are additional fluids in the desired test set to be tested, repeat the procedure described for the first test fluid. If all test fluids have been applied and hot-soaked, proceed to test all of the pumps to determine the post-test parameter values for basic performance and external leakage.

Table 3 - Test fluids for external compatibility testing

Fluid	Description
Automatic transmission fluid	Dexron III, or equivalent
Engine oil	Commercially available SAE grades
Battery electrolyte	Reagent grade sulfuric acid diluted with water to a specific gravity of 1.25 to 1.28
Anti-freeze	Ethylene glycol/water mixture in equal portions
Brake fluid	Polyglycols and cellosolves per SAE J1703, 49 CFR 571.116
E22	A blend of ASTM Reference Fuel C and 22% ethanol
Engine cleaner	Commercially available engine cleaning solvent
Windshield washer fluid	Commercially available washer fluid containing methanol or equivalent

8.6.1.2 Data Reduction for External Fluid Compatibility

For each test pump, compute the change in each measured performance parameter from pre-test to post-test. For those parameters for which the unit of change on the data reporting sheet is percent, convert the measured change to a percentage.

8.6.1.3 Data Reporting for External Fluid Compatibility

Record on the associated data reporting sheets in Appendices B and D the measured pre-test and post-test values of the performance parameters and external leakage for each pump. Also record the computed changes from pre-test to post-test. Use three copies of Part 5 of Appendix D to record the pre-test, post-test, and the changes from pre-test to post-test. In addition, record any observed damage or degradation for each pump on the associated data reporting sheet in Appendix I.

8.6.2 Jet Spray

In this test the pump is exposed to a water jet from a high-pressure spray nozzle that is typical of that present in commercial hand operated car wash facilities. This nozzle should deliver a water jet of an approximate pressure of 10 MPa at a distance of 150 mm towards the pump.

8.6.2.1 Test Procedure for Jet Spray

Prior to the water jet exposure, conduct the pre-exposure basic performance tests on each test pump per 6.1 and 6.2. Suitably seal the inlet and outlet of the pump and mount it on a block simulating the engine mounting condition. The pump is to have the electrical connector fitted; however, it is not to be energized. The water jet application shall consist of a 30-second exposure that is repeated for a total of four exposures.

Following exposure to the jet spray, perform a visual inspection of the pump samples and note any findings. Specific issues to look for include, but are not limited to, external visible damage and penetration of water into the electrical connector. If there are no significant issues from the inspection, conduct the post-exposure basic performance tests per 6.1 and 6.2.

8.6.2.2 Data Reduction for Jet Spray

Compute the measured changes in the performance parameters from pre-exposure to post-exposure. Express the changes as a percentage for those variables that are to be reported as a percentage.

8.6.2.3 Data Reporting for Jet Spray

Record the data from the pre-exposure and post-exposure performance tests, as well as any external damage or water penetration observations on the data reporting sheets in Appendices B and D. Also compute and record the changes in the measured performance parameters from pre-exposure to post-exposure. Convert the changes to a percentage for those parameters with reporting units of percentage. Use three copies of Part 5 of Appendix D to record the pre-test, post-test, and the changes from pre-exposure to post-exposure. Record the results of the visual inspection on the data recording sheet in Appendix I.

8.6.3 Thermal Cycling

The thermal cycling test shall be conducted on a test bench that is capable of operating pumps inside a thermal chamber at elevated and reduced temperatures. The test bench must be capable of providing a series of specified pump operating points that are listed in Table 4. The test fuel is to be ASTM Reference Fuel C with 10% by volume reagent-grade ethanol, with a fresh supply of test fuel used at the start of every test.

8.6.3.1 Test Procedure for Thermal Cycling

Prior to the thermal cycling test, conduct pre-cycling tests for basic performance, external and internal leakage and bleed-down on each test pump per 6.1, 6.2, and 6.3.7. The GDI pump assembly with all components and connectors normally mounted shall be subjected to 24 temperature cycles from -40 to 125 °C and back to -40 °C at 3 hours per cycle. The pump goes through three operating cycles while the temperature goes through one cycle.

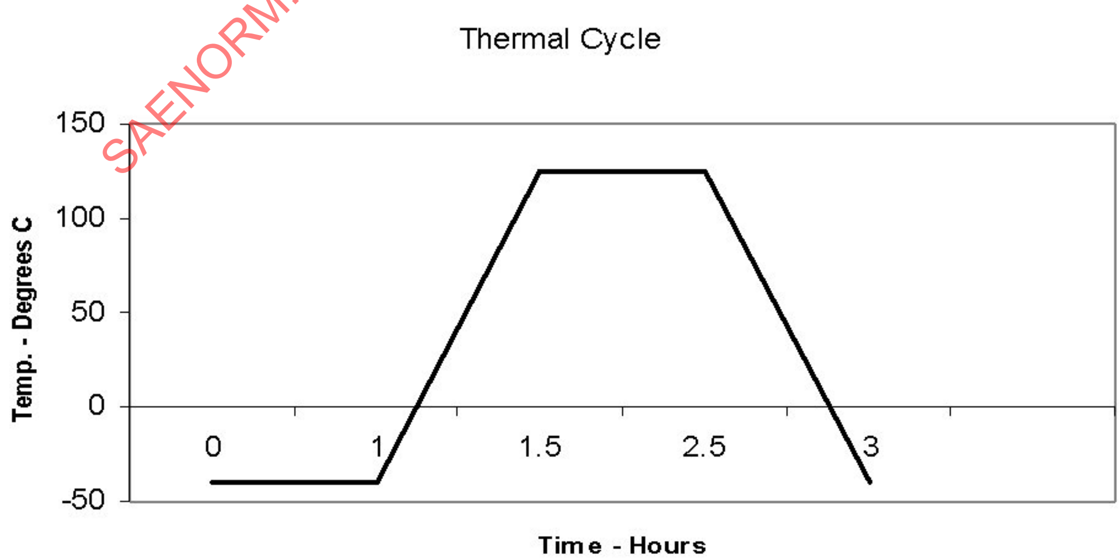

Figure 6 - Thermal cycling temperature profile

During the temperature cycle, the pump speed/pressure profile listed in Table 4 must be continuously repeated.

Table 4 - Listing of test parameters for thermal cycling

Step	Pump Speed, N_P (rpm)	Pressure, P_{OUT} (MPa)	Time (seconds)
1	10% N_{RATED}	30% P_{MAX}	36
2	100% N_{RATED}	100% P_{MAX}	144
3	50% N_{RATED}	70% P_{MAX}	900
4	75% N_{RATED}	70% P_{MAX}	2340
5	20% N_{RATED}	60% P_{MAX}	54
6	90% N_{RATED}	100% P_{MAX}	126

Following the thermal cycle, perform a visual inspection of the samples and note any findings. Specific issues to look for include, but are not limited to, external leakage and distortion. Following the visual inspection, conduct post-cycling measurements for basic performance, leakage, and bleed-down per 6.1, 6.2, and 6.3.7.

8.6.3.2 Data Reduction for Thermal Cycling

Compute the change in each of the measured parameters from pre-cycling to post-cycling. For those parameters with reporting units of percentage, convert the changes to a percentage.

8.6.3.3 Data Reporting for Thermal Cycling

Record the data from the pre-cycling and post-cycling performance tests on the data reporting sheets in Appendices B, C, D, and E. Also record the computed changes in the measured performance parameters from pre-cycling to post-cycling. Use three copies of Part 5 of Appendix D to record the pre-cycling, post-cycling performance parameters and the changes from pre-cycling to post-cycling. Record on the data recording sheet in Appendix I any observable points of external leakage, damage or case distortion resulting from the visual inspection.

8.6.4 Thermal Shock Test

The thermal shock test determines the susceptibility of pump designs to experience performance degradation when subjected to repeated cycles of environmental temperature extremes. One hundred cycles of cold to hot transitions from a -40 °C environment to a 130 °C environment are applied to the pump, and the resultant changes to the performance parameters are measured.

8.6.4.1 Procedure for Thermal Shock Test

a. Specify the number of new pumps in the test set that are to be thermally shocked. Any number of pumps may be specified. Note the serial number of each pump. For each test pump, measure the performance, external leakage and internal leakage per 6.1 and 6.2, designating the data as the pre-thermal shock values. Additional parameters such as the pump bleed-down may also be measured per 6.3.7 as desired, but are not required.

b. Prepare an insulated storage volume that is suitable for containing multiple pumps simultaneously. Pre-cool the ambient air in the storage space to a stabilized temperature -40 °C ± 2 °C. Also pre-heat the ambient air in a similar storage space to 130 °C ± 2 °C . The two storage spaces should be in relative proximity.

c. Purge all fluids from the pump (or multiple pumps) to be shocked and stabilize the pump temperature in an ambient environment at 21 °C ± 2 °C.

d. Insert the pump (or pumps) into the stabilized environment that is at a temperature of -40 °C ± 2 °C for a timed interval of 0.5 hour. After that interval, and as rapidly as the test apparatus will allow, transfer the pump (or pumps) to the stabilized environment that is at 130 °C ± 2 °C for a timed interval of 0.5 hour. Repeat this cycle a total of 100 times by transferring the pump (or pumps) back and forth from the cold to the hot environment every 0.5 hour. One cycle is defined as placing a pump in the cold environment for 0.5 hour, then rapidly placing it in the hot environment for 0.5 hour. The pump is not operated during this test and does not have an inlet pipe or an electrical connector installed.

e. At the completion of 100 thermal shock cycles, allow the hot pump to cool to room temperature, then conduct a visual inspection. Specific issues to look for include, but are not limited to, external leakage, distortion, and cracking. Next, remeasure the performance and leakage parameters that were measured in step (a), designating the resultant data as the post-thermal shock values.

8.6.4.2 Data Reduction and Analysis for Thermal Shock

Compute the change in the performance and leakage measurements from pre-thermal shock to post-thermal shock. Compute the percentage change for those parameters for which the units on the data reporting sheet are percent.

8.6.4.3 Data Reporting for Thermal Shock

Record the pre-thermal shock and post-thermal shock measurements of the performance parameters, along with the computed changes in the measurements from pre-thermal shock to post-thermal shock on the data reporting sheets in Appendices B, C, and D. Use three copies of Part 5 of the data reporting sheet in Appendix D. Record the observations from the visual inspection on the data reporting sheet in Appendix I.

9. MECHANICAL LOADING TESTS

9.1 Vibration Test

9.1.1 Introduction

The goal of the vibration test is to evaluate changes in the GDI pump leakage and structural integrity that result from pump vibration. In this test the pump is subjected to an extensive application of vibration profiles. These applications cover a significant time period and include three pump orientations, as well as ranges of vibration frequencies.

The test is a bench-test procedure with the pump filled with a non-combustible solvent and sealed. The pump fluid is pressurized to the application inlet pressure and is not operated during the test. The methodology and the time durations employed in this test comply with the ISO 16750-3 standard in that standard's Test 1, which is for engine-mounted components. This vibration test follows the sine spectrum profile in Table 3 of the Test 1 section in the ISO document, and also the random spectrum profile listed in Table 4 of Test 1 in the ISO document. For those cases where an application-specific vibration profile is available, that profile may be substituted for the ISO 16750-3 sine-on-random profiles. If this is done it shall be clearly noted as a test deviation on the data reporting sheet in Appendix J.

9.1.2 Vibration Test Procedure

a. Specify the number of new pumps in the test set. A minimum of three pumps are to be tested. Additional test pumps may be specified if required. The serial number of each test pump is to be noted. As per 6.1, 6.2, and 6.3.7, test each pump in the test set for basic performance, leakage, and bleed-down parameters. These parameter values are to be designated as the pre-vibration test data and each shall be assigned to the associated pump serial number.

b. Mount a pump from the test set in a vibration test fixture that is driven by the vibration table. The fixture is to have the same mounting points as the intended application and is to have the capability of providing three mutually perpendicular mounting orientations. The mounting fixture design must allow the pump being tested to be filled with fluid. Multiple pumps may be mounted simultaneously on the vibration table if that capability exists. The control valve and piston shall be positioned according to the requirements of the application. The positions shall be noted on the data sheet.

c. Mount the pump (or pumps) in the pump axis orientation #1. The three axes for the vibration test are defined by: pump test axis #1 is along the pump spill valve axis; pump test axis #2 is along the pump piston axis and pump test axis #3 is mutually perpendicular to axes #1 and #2. The motion of the vibration table should be along the axis described for the axis being tested.

d. Connect the pump electrical wiring harness. Ascertain the equivalent mass representing any unsupported fuel lines and attach that mass securely to the pump inlet and outlet points.

e. Fill the test pump with a fluid that is a non-explosive solvent that is commonly used as a substitute for gasoline. Ensure that all trapped gases are removed from the pump and that the solvent fills all void spaces. Pressurize the liquid in the pump to P_{in}.

f. Vibrate the pump in the pump axis orientation #1 per the sine spectrum profile listed in ISO 16750-3 (Table 1) for 11 hours, followed by the random spectrum profile (Table 4) for an additional 11 hours, for a total vibration time in orientation #1 of 22 hours.

g. Following the completion of a total of 22 hours of vibration testing for pump axis orientation #1, change the pump axis position to orientation #2 and repeat the two 11-hour vibration intervals indicated in step (f).

h. Following the conclusion of 22 hours of vibration testing for pump axis orientation #2, change the pump axis position to orientation #3 and repeat the two 11-hour vibration intervals indicated in step (f).

i. At the conclusion of 66 total hours of vibration testing for all three pump axes, remove the pump and set it aside for later performance testing.

j. For the next new pump in the test set, repeat steps (b) through (i) for that pump.

k. When the vibration testing has been completed for the last pump in the test set, visually inspect all pumps and note any external damage or distortion.

l. Perform basic performance, leakage, and bleed-down tests according to 6.2, 6.1, and 6.3.7 for all pumps in the test set. These parameter values are to be designated as the post-vibration test data, and each shall be assigned to the associated pump serial number.

9.1.3 Data Reduction and Analysis

Any notations from the visual inspection are to be associated with the serial number for that pump. For each pump in the test set, compute the change in each basic performance, leakage, and bleed-down parameter from the pre-test to the post-test condition. For those parameters that are to be reported as a percentage change, compute that percentage.

9.1.4 Data Reporting

For each pump in the test set, record the measured values of basic performance, leakage, and bleed-down for both pre-test and post-test conditions on the data reporting sheets in Appendices B, C, D, and E. Also record the computed changes from pre-test to post-test, converting the change to a percentage for those parameters having percentage change listed on the datasheet. Also record the notes from the visual observations of each test pump, associating each observation with the pump serial number.

9.2 Mechanical Shock

9.2.1 Mechanical Shock Test Procedure

A minimum of five new pumps are to be tested. More pumps may optionally be tested as required. For each pump, conduct the pre-test basic performance, leakage, and bleed-down measurements per 6.2, 6.1, and 6.3.7. Fill the pump with the standard test fluid and cap the pump inlet and outlet. The pump electrical wiring harness shall be connected during testing. Mount the fuel pump onto a shock test fixture that duplicates the application mounting. Perform impacts at 50 G input load and 1/2 sine waveform. The duration of these impacts is to be within 11 to 14 ms and the impacts are performed for one pulse in the positive direction and one pulse in the negative direction in each of the three perpendicular axes. The range in duration is to account for variation in test equipment and capability. After the required number of shock impacts have been applied, remove the pump from the fixture and perform a visual inspection. Note any damage or degradation for later reporting. Following the testing of all pumps in the set, conduct post-shock test measurements for basic performance, leakage, and bleed-down on all tested pumps per 6.1, 6.2, and 6.3.7.

9.2.2 Analysis and Reporting for Mechanical Shock

For each tested pump compute the change in each performance parameter from the pre-shock test to the post-shock test. For those parameters for which the changes are to be reported as a percentage, convert the change to a percentage. Record the pre-shock and post-shock test performance data and the computed changes on the data reporting sheets in Appendix J.

10. NOTES

10.1 Revision Indicator

A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

PREPARED BY SAE GASOLINE FUEL INJECTION STANDARDS COMMITTEE

APPENDIX A - BLOCK DIAGRAM

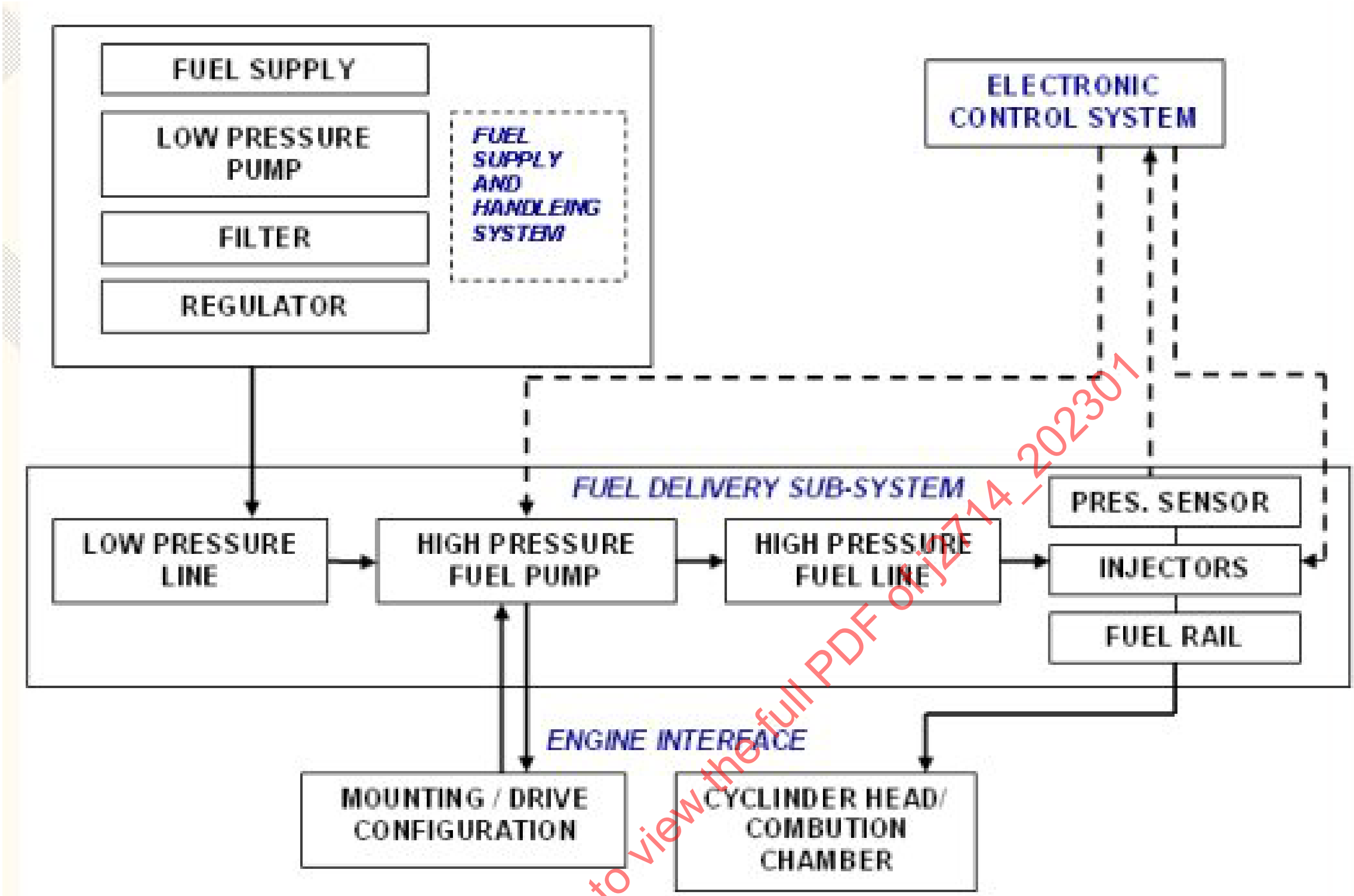

Figure A1 - Direction injection gasoline high-pressure pump, system interface block diagram

APPENDIX B - EXTERNAL LEAKAGE DATA SHEET

SAE J2714 Data Reporting Sheet for GDI Pump External Leakage Measurements			
Part 1: General Test Logistics			
Test name or log		Date of test	
Name of operator		Time of test	
File name of data archive		Location of test	
Additional information			
Part 2: Information on Pump			
Pump manufacturer			
Pump description			
Pump part number			
Pump serial number			
Additional information			
Part 3: Test Conditions			
Test Parameter	**Test Conditions (if Non-Std)**	**Standard Test Conditions**	
Test fluid		Helium	
Ambient temperature (°C)		21 ± 2	
Ambient pressure (kPa)		100 ± 5	
Fluid temperature (°C)		21 ± 2	
Fluid pressure (kPa)		Specified by application (PIN) to within ±1%	
Initial pump temperature (°C)		21 ± 2	
Pump test duration (seconds)		>30	
Additional information or test condition deviations			
Part 4: Specific Instrument Information and Test Deviations			
Additional information or test condition deviations			
Part 5: Test Results for External Leakage			
External leakage rate (pre-test)*	(mbar*L/s)		
External leakage rate (post-test)	(mbar*L/s)		
External leakage rate (change)	(%)		
* This is the SAE J2714 pump external leakage rate if there are no test deviations.			

APPENDIX C - INTERNAL LEAKAGE DATA SHEET

SAE J2714 Data Reporting Sheet for GDI Pump Internal Leakage Measurements

Part 1: General Test Logistics

Test name or log		Date of test	
Name of operator		Time of test	
File name of data archive		Location of test	
Additional information			

Part 2: Information on Pump

Pump manufacturer	
Pump description	
Pump part number	
Pump serial number	
Pump displacement V_D (cm^3/cam rev)	
Additional information	

Part 3: Test Conditions

Test Parameter	Test Conditions (if Non-Std)	Standard Test Conditions
Test fluid		n-Heptane
Ambient temperature (°C)		21 ± 2
Ambient pressure (kPa)		100 ± 5
Fluid temperature (°C)		21 ± 2
Initial pump temperature (°C)		21 ± 2
Pump inlet pressure (kPa)		PIN = 500 kPa

Part 4: Specific Instrument Information and Test Deviations

Additional information or test condition deviations	

Part 5: Test Results for Internal Leakage

		Pump Internal Leakage (mm^3/min)		
Pump rpm	**Pressure (MPa)**	**Pre-Test Leakage**	**Post-Test Leakage**	**Change (Pre-Test to Post)**
500	0.40			(%)
500	PNORM			(%)
NMAX	PNORM			(%)
NMAX	PMAX	**		(%)

** This is the SAE J2714 pump internal leakage rate if there are no test deviations.

APPENDIX D - BASIC PERFORMANCE DATA SHEET

SAE J2714 Data Reporting Sheet for GDI Pump Basic Performance Measurements			
Part 1: General Test Logistics			
Test name or log		Date of test	
Name of operator		Time of test	
File name of data archive		Location of test	
Additional information			
Part 2: Information on Pump			
Pump manufacturer			
Pump description			
Pump part number			
Pump serial number			
Pump displacement V_D (cm^3/cam rev)			
Additional information			

Part 3: Test Conditions		
Test Parameter	**Test Conditions (if Non-Std)**	**Standard Test Conditions**
Test fluid		n-Heptane
Ambient temperature (°C)		21 ± 2
Ambient pressure (kPa)		100 ± 5
Fluid temperature (°C)		21 ± 2
Initial pump temperature (°C)		21 ± 2
Pump outlet pressure (MPa)		P_{NORM}
Additional information or test condition deviations		

Part 4: Specific Instrument Information and Test Deviations	
Additional information or test condition deviations	

Part 5: Test Results for Pump Performance Parameters											
		Pump control valve resistance:									(Ohms)
Check appropriate box. This data is for:		□ Pre-test			□ Post-test		□ Change		□ Pre-to-post		
Pump Speed (rpm)	**CV_{DA}**	**Q_P**	**P_{IN}**	**P_{OUT}**	**TO_{DRIVE}**	**T_{IN}**	**T_{OUT}**	**P_{OUTF}**	**P_{INF}**	**E_V**	**E_M**
Units	**(°)**	**cm^3/ cam rev**	**(kPa)**	**(MPa)**	**(Nm)**	**(°C)**	**(°C)**	**(MPa)**	**(kPa)**	**(%)**	**(%)**
100											
250											
500											
750											
1000											
1250											
1500											
1750											
2000											
2250											
2500											
2750											
3000											
3250											
3500											
3750											
4000											
In 250 rpm increments up to the pump rated speed (N_{RATED})											
At the pump rated speed (N_{RATED}), the pre-test data set are the SAE J2714 basic pump performance parameters (if there are no test deviations).											

APPENDIX E - ADDITIONAL CHARACTERIZATION DATA SHEET

SAE J2714 Data Reporting Sheet for GDI Pump Additional Characterization Measurements

Part 1: General Test Logistics

Test name or log		Date of test	
Name of operator		Time of test	
File name of data archive		Location of test	
Additional information			

Part 2: Information on Pump

Pump manufacturer	
Pump description	
Pump part number	
Pump serial number	
Additional information	

Part 3: Test Conditions

Test Parameter	Test Conditions (if Non-Std)	Standard Test Conditions
Test fluid		n-Heptane
Ambient temperature (°C)		21 ± 2
Ambient pressure (kPa)		100 ± 5
Fluid temperature (°C)		21 ± 2
Pump control value pulse width		Per application
Initial pump temperature (°C)		21 ± 2
Pump outlet pressure (MPa)		P_{NORM}
Pump test duration (minutes)		10
Additional information or test condition deviations		

Part 4: Specific Instrument Information and Test Deviations

Instrument information or test condition deviations	

Part 5: Test Results for Additional Characterizations

Part 5A: Test Results for Static Flow

Parameter	* Q_P	P_{IN}	P_{OUT}	TO_{DRIVE}	T_{IN}	T_{OUT}	P_{OUTF}	P_{INF}	E_V	E_M
Value				0	0	0	N/A	N/A	0	0

Part 5B: Test Results for Pressure Rise

P_{NORM}	N_{CRANK}	P_{CRT}*

Part 5C: Test Results for Pressure Bleed Down Rate

P_{OUT} (Start) (MPa)	P_{OUT} (End) (MPa)	ΔP_{OUT} (kPa)	Duration (min)	Bleed-Down Rate* (kPa/s)

* These are the SAE J2714 static flow, pressure rise, and pressure bleed-down if there are no test deviations.