



SURFACE VEHICLE RECOMMENDED PRACTICE

J2714™

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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 ($\text{cm}^3/\text{cam rev}$). A variable displacement pump should be rated at its maximum displacement. For example, for a piston type pump the equation would be:

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

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 $\text{cm}^3/\text{cam rev}$.

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:

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

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 ($Q_{LEAK-HOUSING}$)

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 ($Q_{LEAK-INTERNAL}$)

The pump internal leakage rate is the rate at which liquid fuel leaks past the pump piston seal into the engine lubrication system. $Q_{LEAK-INTERNAL}$ is expressed in units of mm³/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 $21\text{ }^{\circ}\text{C} \pm 2\text{ }^{\circ}\text{C}$, 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 $\pm 2\%$ 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 $\pm 2\%$ 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 $\pm 1\%$ 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 $5\text{ }\mu\text{m}$ or better. The test fluid temperature control system must be capable of maintaining the test fluid temperature within $\pm 2\text{ }^{\circ}\text{C}$. The test fluid pressure regulation system must be capable of maintaining the inlet test fluid pressure to the pump within $\pm 30\text{ kPa}$. 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 $\pm 100\text{ kPa}$. The outlet pressure shall be measured within 75 mm of the pump outlet. The test fluid flow rate measurement device must be accurate to $\pm 2\%$. 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 drive shaft that is accurate to $\pm 2\%$.

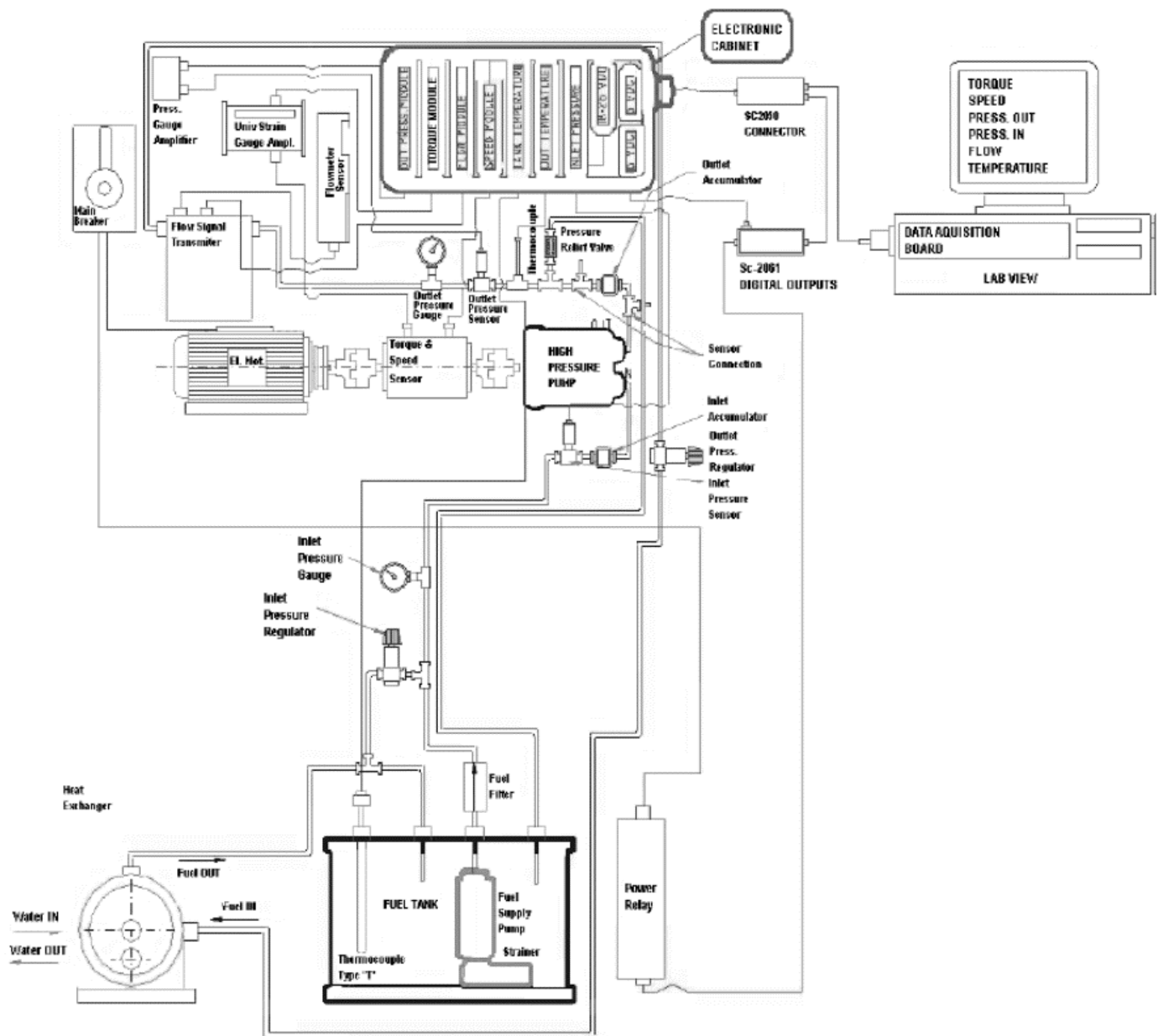


Figure 1 - Schematic of a representative GDI pump performance test stand

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

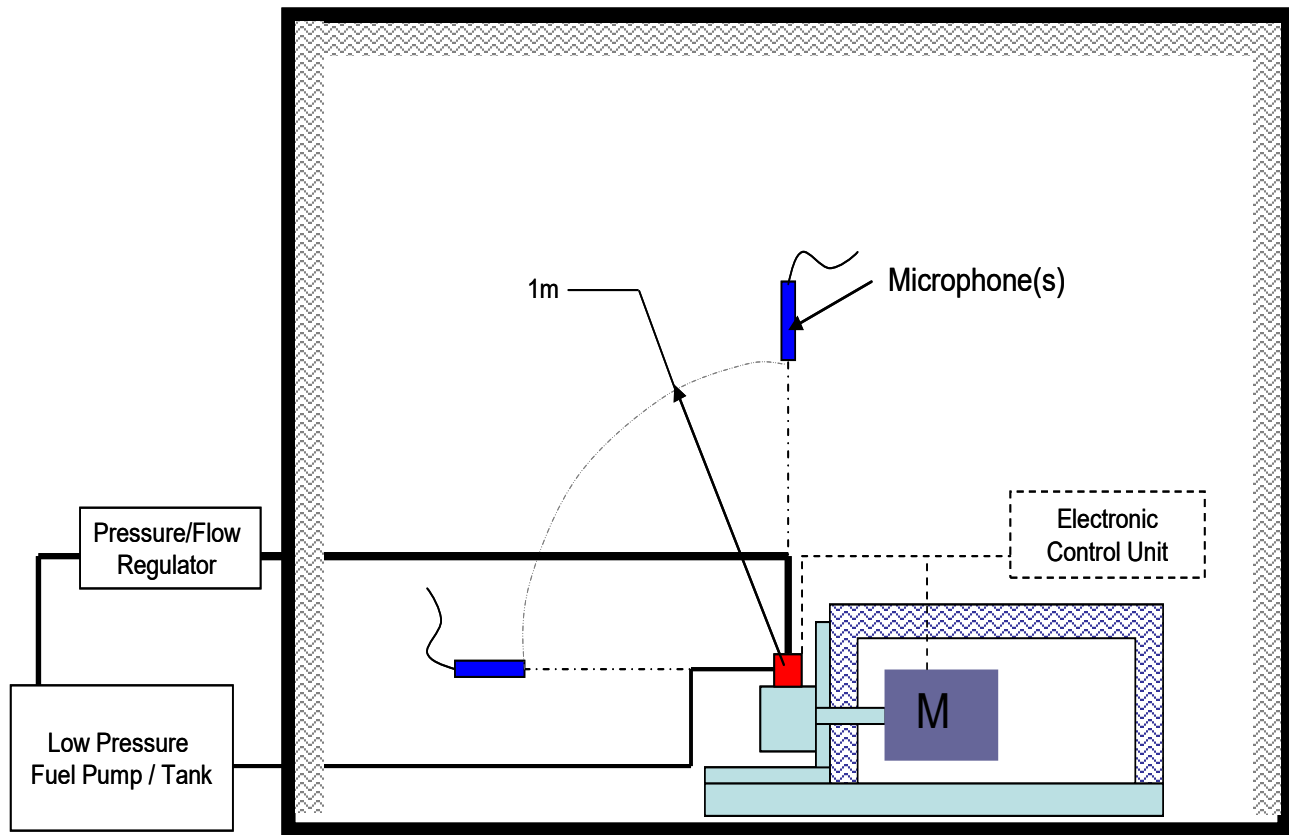


Figure 2 - Schematic of sound measurement setup with integrated motor in a hemi-anechoic chamber

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.

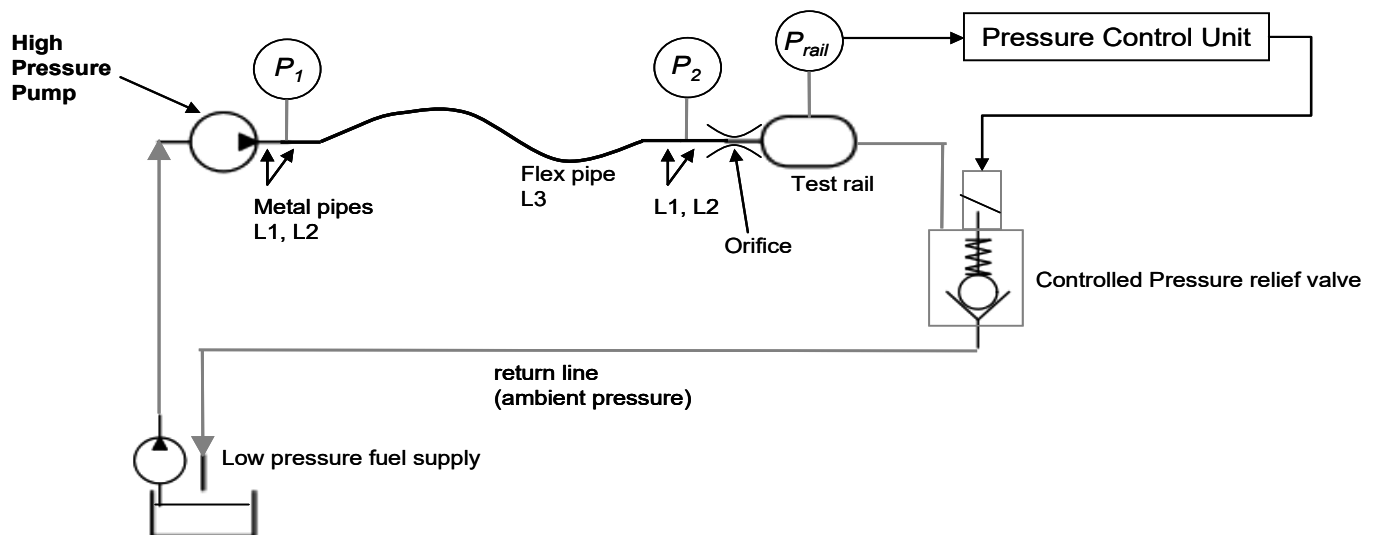


Figure 3 - Hydraulic circuit for the pump noise characterization test fixture

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 cm³

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

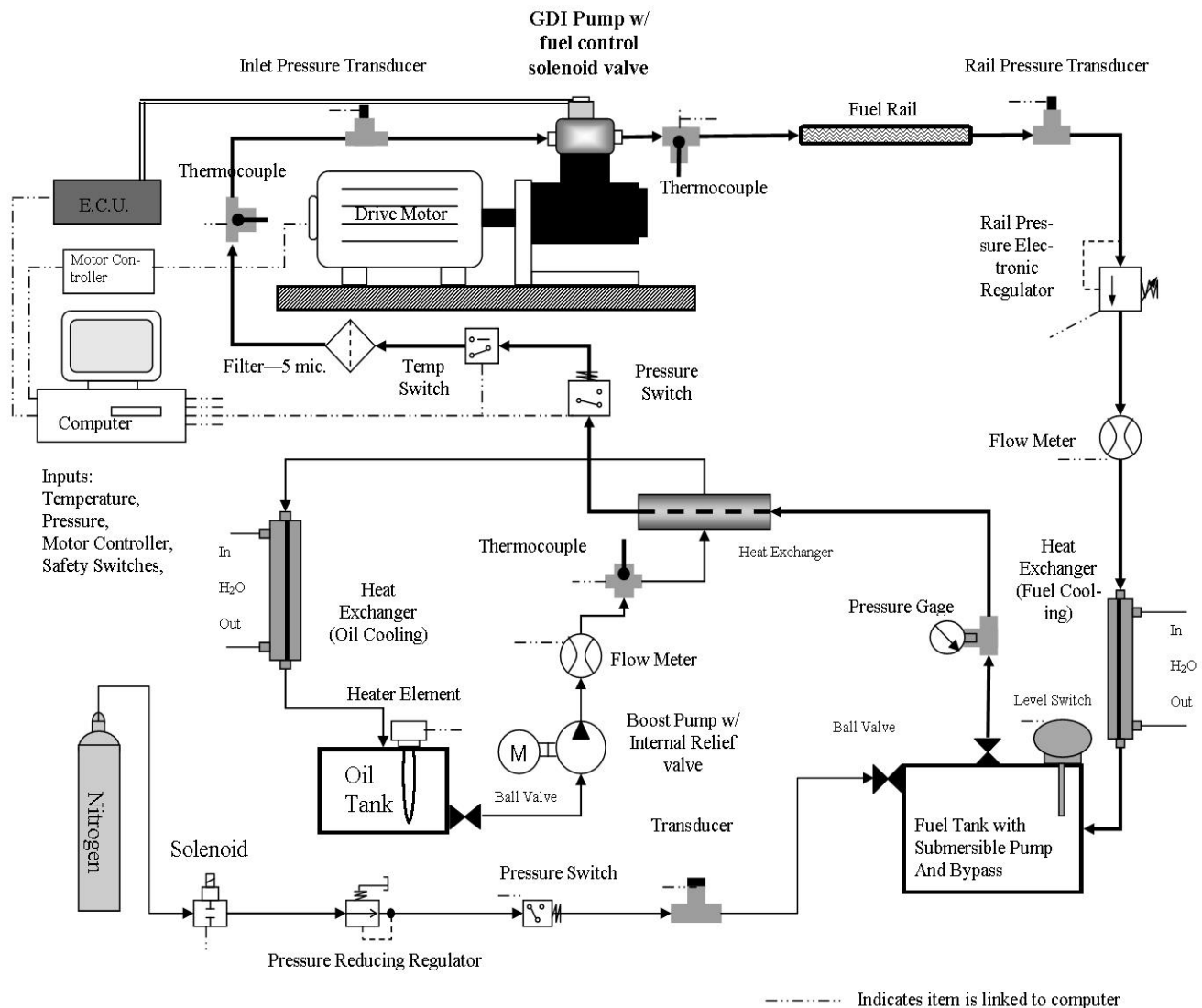


Figure 4 - Schematic of a GDI durability test stand

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 $\pm$ 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 ($60\text{ }^{\circ}\text{C} \pm 2\text{ }^{\circ}\text{C}$ 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 $-50\text{ }^{\circ}\text{C}$ and the other $+140\text{ }^{\circ}\text{C}$. The two storage volumes should ideally be in close proximity 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 indicated 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 ($Q_{\text{LEAK-HOUSING}}$)

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 $\text{mbar}\cdot\text{L/s}$.

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 $21\text{ }^{\circ}\text{C} \pm 2\text{ }^{\circ}\text{C}$, 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 $\text{mbar}\cdot\text{L/s}$ on the data reporting sheet in Appendix B.

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

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 $P_{\text{IN}} = 500\text{ kPa}$. The test is to be run at room temperature of $21\text{ }^{\circ}\text{C} \pm 2\text{ }^{\circ}\text{C}$.

Flow the nitrogen carrier gas through the sample chamber at a rate of $10\text{ L/min} \pm 0.1\text{ L/min}$.

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.

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

where:

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

c = concentration of carbon in ppm

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

Test points:

$N_P = 500 \text{ rpm}$, 4.0 MPa

$N_P = 500 \text{ rpm}$, P_{NORM}

$N_P = N_{MAX} \text{ rpm}$, P_{NORM}

$N_P = N_{MAX} \text{ rpm}$, P_{MAX}

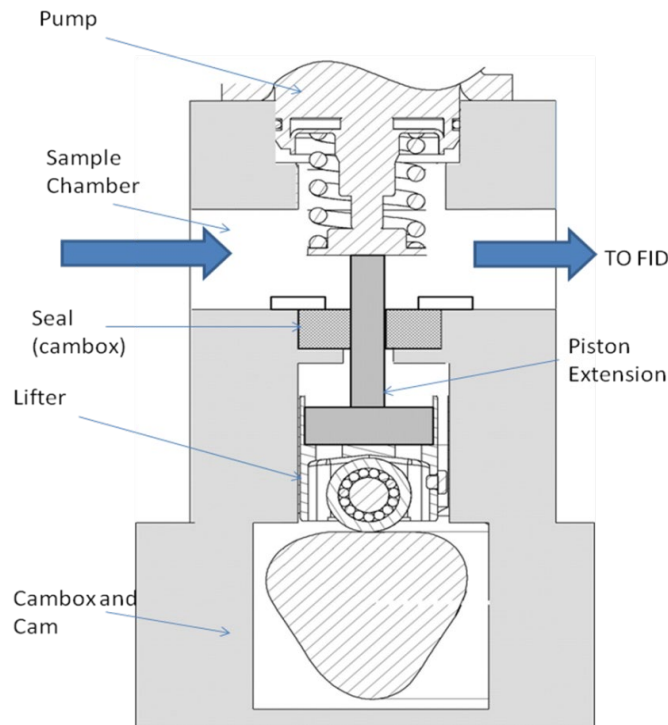


Figure 5 - Representative test fixture for GDI internal leakage measurement

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

- Install the pump into the performance test stand.
- Measure and record pump control valve resistance in ohms at $21 \text{ }^{\circ}\text{C} \pm 2 \text{ }^{\circ}\text{C}$.
- Operate the pump for sufficient time to ensure that the temperature stabilizes and that no air remains in the system.
- 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.