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Fuel Injection System Fuel Pressure Regulator and Pressure Damper

RATIONALE

This document deals with a non-evolving technology, and contains testing procedures that are deemed to be unchanging in the automotive industry.

STABILIZED NOTICE

This document has been declared "Stabilized" by the SAE Gasoline Fuel Injection Standards Committee and will no longer be subjected to periodic reviews for currency. Users are responsible for verifying references and continued suitability of technical requirements. Newer technology may exist.

Foreword—A fuel pressure regulator in an electronic fuel injection system, maintains a controlled differential pressure at the injectors for all engine operating conditions. Fuel delivered to the engine is metered by the length of time the injector is open and the controlled differential pressure. Typical fuel injection systems are shown in Figures 1A, 1B, and 2.

The most commonly used pressure regulator is a hydromechanical bypass pressure relief device that is capable of sealing the fuel from returning to the fuel tank when closed. Typical fuel pressure regulators are shown in Figures 3 and 4. The regulator consists of two chambers separated by a diaphragm. The fuel chamber contains a fuel inlet, a fuel outlet, and a valve. The air chamber contains a spring and is usually referenced to the pressure condition of the discharge side of the injector(s) in a return fuel system, and to the ambient in a returnless (demand) fuel system. When the fuel pressure exceeds the set point pressure, the diaphragm raises the valve off the seat of the outlet passage and the excess pressure is relieved by permitting fuel to flow back to the fuel tank. The actual fuel system pressure can deviate from the desired value due to an accumulation of the following effects: slope, repeatability, hysteresis, dynamic response, and production variability from regulator to regulator. Figure 5A illustrates the relationship of the fuel pressure to a reference pressure, and Figure 5B represents the fuel pressure for a non-referenced pressure regulator case.

Several other types of regulators have been developed based on the principles described previously. These include flow-through regulators for use in returnless systems, and multiple regulators for dual-pressure systems. Also, bleed-down types are used in some CFI applications to allow pressure and vapor relief during soak periods.

A fuel pressure damper in an electronic fuel injection system is used to attenuate the pressure pulsations generated by the fuel pump and the opening and closing of the fuel injectors. The hydraulic pulsations in the fuel injection system can cause an objectionable audible noise, which is transmitted to the vehicle passenger compartment. The fuel pulsations can create standing pressure waves in the fuel supply system, which will affect the pressure at the fuel injectors and cause an uneven fuel delivery. Also, the high frequency pressure pulsations can adversely affect the pressure regulator performance and durability. A fuel pressure damper may be used to reduce the above problems. The control of fuel system hydraulic pulsation has been accomplished by various means, with remote mounted surge chambers and pulse dampers as the most common. A fuel rail assembly with internal damping features has also proven to be effective in attenuating injector induced pulsations.

The pressure damper commonly used in electronic fuel injection systems consists of two chambers, a fuel and an air chamber, separated by a loaded diaphragm. Some pressure dampers use a mechanical spring, shown on Figure 6, and some use a pneumatic chamber, shown on Figure 7. During engine operation, the fuel passes through the pressure damper, which reduces the pressure pulsations.

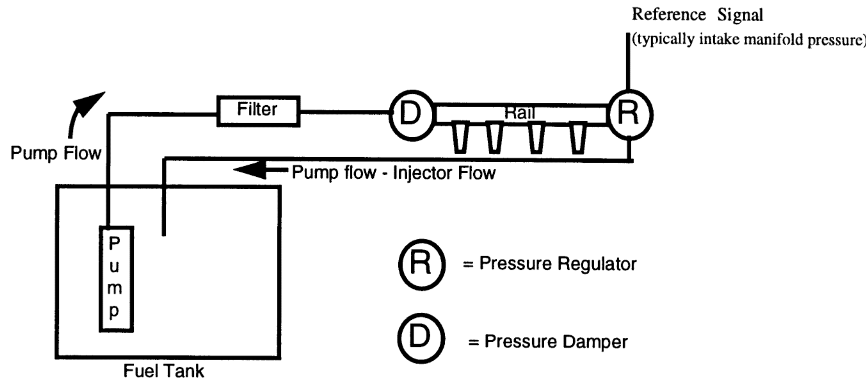

FIGURE 1A—RETURN FUEL SYSTEM

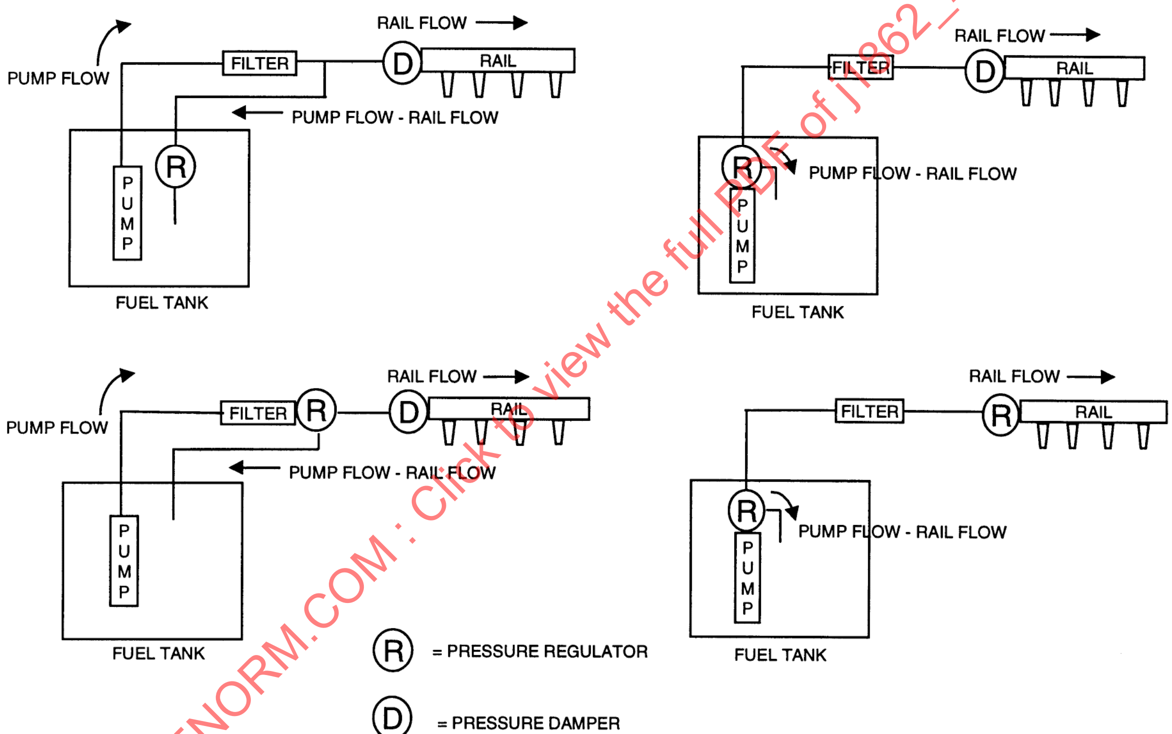

FIGURE 1B—RETURNLESS FUEL SYSTEM

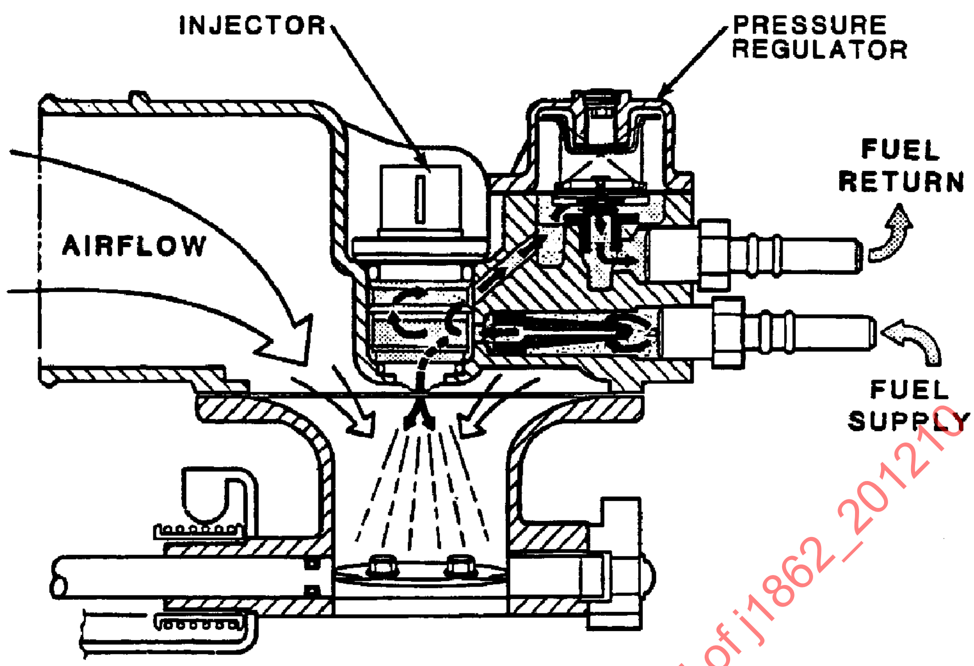

FIGURE 2—FUEL CHARGING ASSEMBLY-CFI-CENTRAL FUEL INJECTION

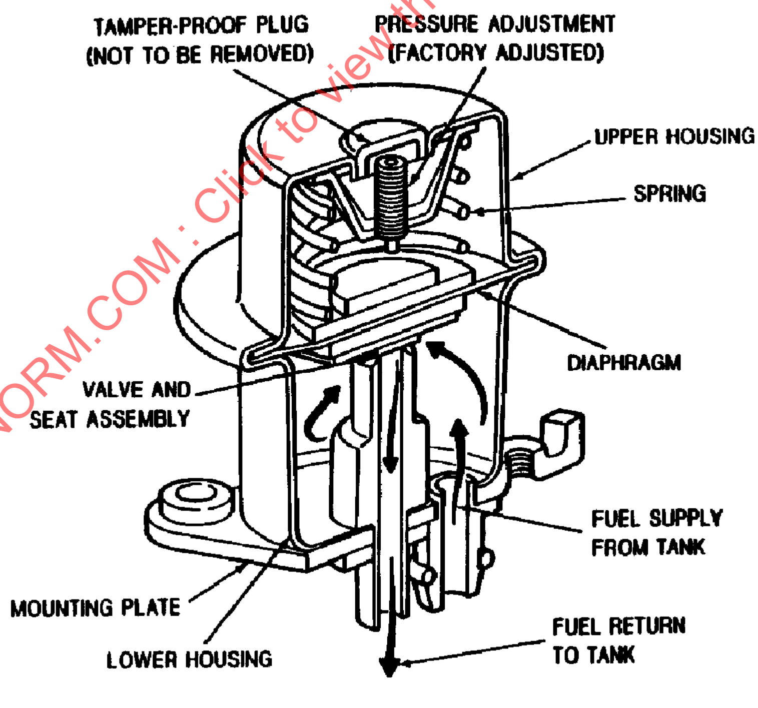

FIGURE 3—FUEL PRESSURE REGULATOR (NON-REFERENCED)

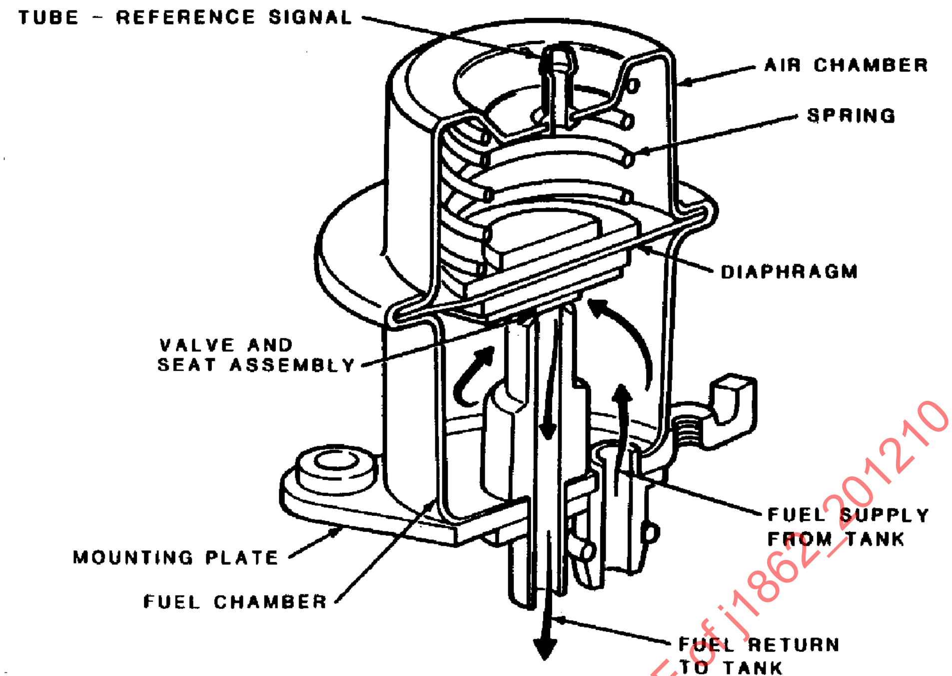

FIGURE 4—FUEL PRESSURE REGULATOR (REFERENCED)

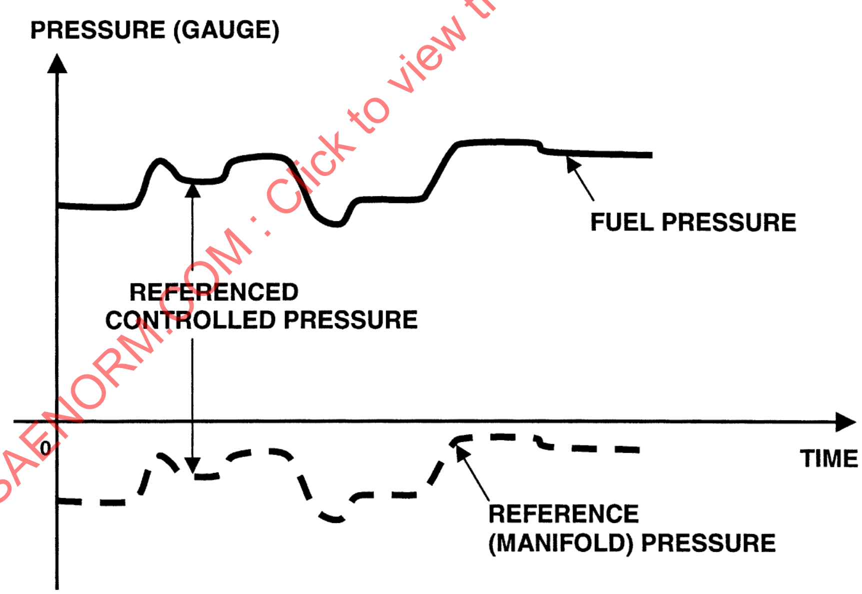

FIGURE 5A—FUEL PRESSURE RELATIONSHIP TO REFERENCE PRESSURE

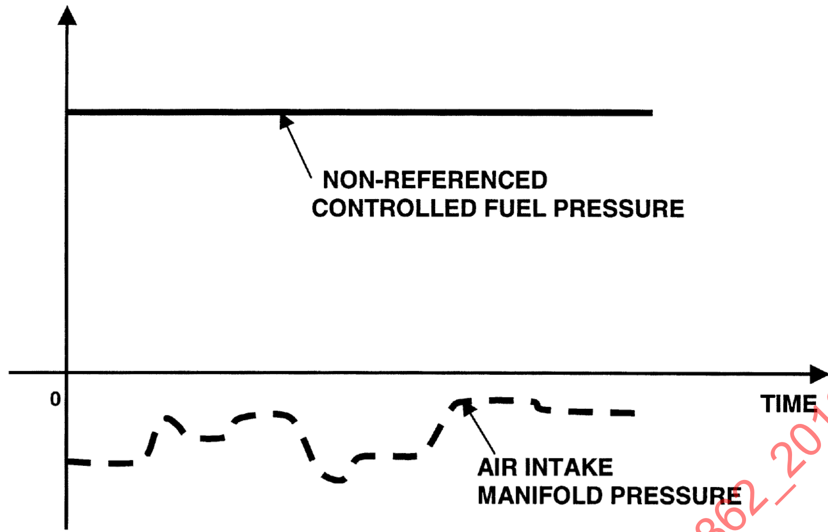

FIGURE 5B—NON-REFERENCED CONTROLLED FUEL PRESSURE

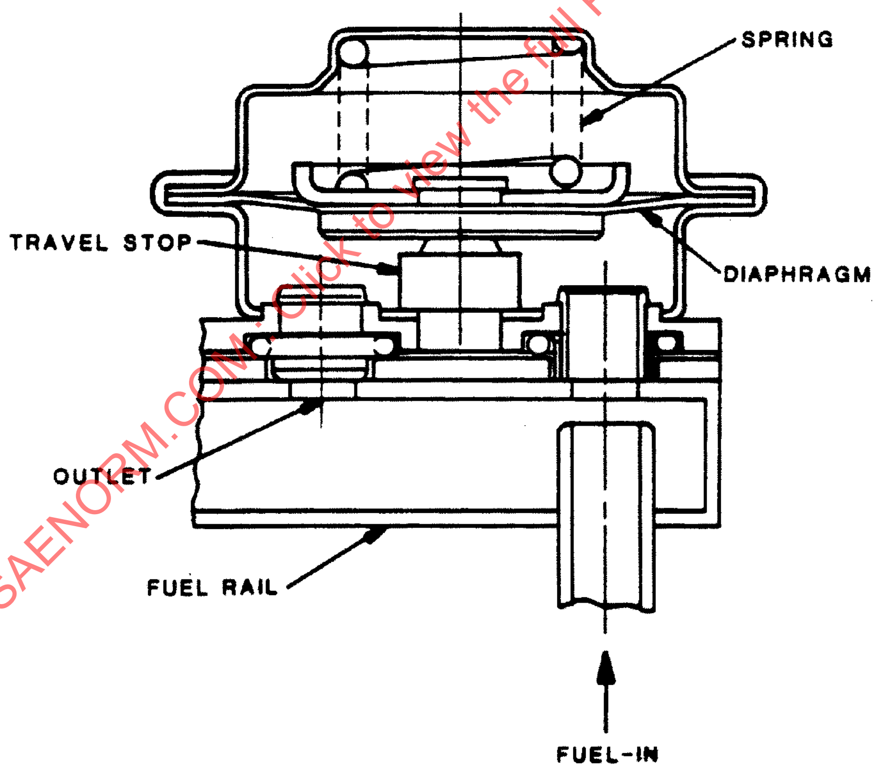

FIGURE 6—FUEL PRESSURE DAMPER (MECHANICAL SPRING)

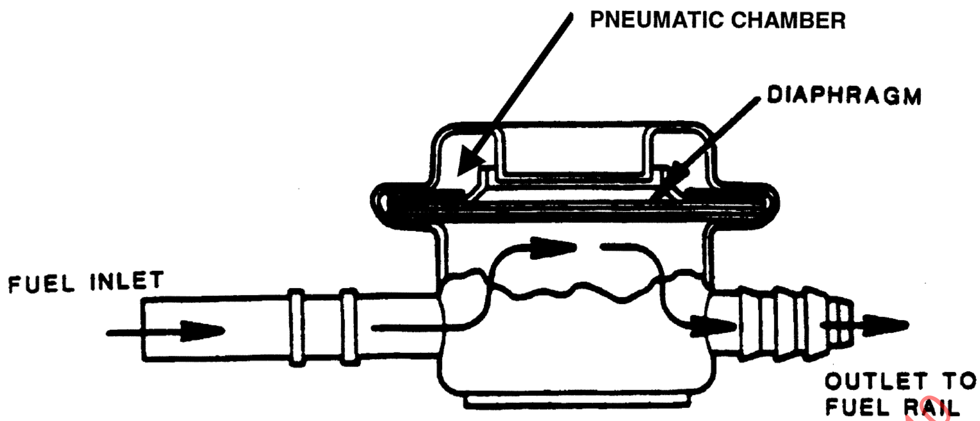

FIGURE 7—FUEL PRESSURE DAMPER (HYDRAULIC SPRING)

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FIGURES

1. Scope—This SAE Recommended Practice promotes uniformity in the evaluation and qualification tests conducted on fuel pressure regulators and pressure dampers used in gasoline engine applications. Its scope is limited to fuel pressure regulators and dampers used in automotive port and throttle body fuel injection systems where fuel supply pressure is below 1000 kPa. It is further restricted to bench type tests. More specifically, this document is intended for use as a guide to the following:

a. Identify and define those parameters that are used to measure fuel pressure regulator and pressure damper characteristics of performance. The parameters included in this document are:

   1. Slope
   2. Operating Flow Range
   3. Repeatability
   4. Hysteresis
   5. Dynamic Response

b. Establish test procedures and recommend test equipment and methods to measure and quantify these parameters.
c. Establish test procedures and recommend test equipment and methods to quantify simulated field reliability over the life of the component.
d. Standardize the nomenclature as related to fuel pressure regulation and pressure damping for fuel injection systems.
e. Except where stated, test results are recorded for individual parts. Where population characteristics are reported, the sample size, selection method, and analysis technique must be explicitly stated.

2. References

2.1 Applicable Publications—The following publications form a part of the specification to the extent specified herein. Unless otherwise indicated, the latest revision of SAE publications shall apply.

2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J306—Automotive Gear Lubricant Viscosity Classification
SAE J308—Axle and Manual Transmission Lubricants
SAE J310—Automotive Lubricating Greases
SAE J313—Diesel Fuels
SAE J814—Engine Coolants
SAE J1541—Fuel Injection Nomenclature—Spark Ignition Engines

2.1.2 ASTM—Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM B 117—Salt Spray (Fog) Testing
ASTM D 56—Flash Point by Tag Closed Tester
ASTM D 86—Distillation of Petroleum Products
ASTM D 128—Test Methods for Analysis of Lubricating Grease
ASTM D 323—Test Method for Vapor Pressure of Petroleum Products (Reid Method)
ASTM D 445—Test Method for Petroleum Products
ASTM D 471-79—Test Method for Rubber Property—Effect of Liquids
ASTM D 893—Test for Insolubles in Lubricating Oils
ASTM D 1266—Test Method for Sulfur in Petroleum Products (Lamp Method)
ASTM D 1298—Test for Density and Specific Gravity
ASTM D 1319—Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption
ASTM D 1744—Water in Liquid Petroleum Products
ASTM D 2699—Test Method for Research Octane Number of Spark-Ignition Engine Fuel
ASTM D 3231—Test Method for Phosphorus in Gasoline
ASTM D 3237—Test Method for Lead in Gasoline by Atomic Absorption Spectrometry

2.1.3 Federal Publications—Available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

40 CFR 86.113-82—Fuel Specification of Emission Regulations Test Procedure
49 CFR 571-116—Motor Vehicle Hydraulic Brake Fluid

3. Performance Characteristics

3.1 Pressure Regulator

3.1.1 Set Point Pressure

a. Definition—The test fluid pressure to which the regulator is set at a specified fluid flow rate. It is specified as pressure (in kPa) at a fluid flow rate (in g/s).
b. Background—The regulator set point pressure determines the nominal operating pressure for a fuel injection system. It is critical to the design of the system that this pressure be known and controlled. The specified regulator set pressure is meaningless without the corresponding flow rate since the pressure will vary as a function of flow rate. The set point specified for different applications may differ due to the differences in required injector flow rates.
c. Objective—To measure the regulator set point pressure at the specified set point flow rate.
d. Test Apparatus—See 6.2.1, 6.2.4, and 6.2.9.
e. Test Conditions—Refer to 5.1 through 5.6.
f. Test Method:

1. Slowly increase test fluid pressure until fluid just starts to flow through the regulator (approximately 1.0 g/s).
2. Gradually increase the fluid flow until the specified set point flow rate is achieved (within ±0.5 g/s). Do not allow the flow to exceed the specified flow rate; if so, restart the procedure.
3. Allow the flow to stabilize for 15 to 30 s then record the regulator inlet pressure.

g. Data Required—Record the regulator inlet pressure, outlet pressure, and actual fluid flow rate. Report set point pressure as: xxx.x kPa at specified set point flow rate.

h. Reported Population Data—Measure the regulator set point pressure for a random sample of regulators representative of a normal production distribution. Determine the sample mean (X_S) and sample standard deviation (s). Report the population set point as the sample mean (X_S) ± four times the sample standard deviation (4 s): xxx.x ± xx.x kPa. Also report the 4 s as a percentage of X_S: ±xx.x%.

3.1.2 SLOPE

a. Definition—The change in regulator pressure over a linear flow range which results from a change in fluid flow rate through the regulator, all other parameters remaining constant. It is specified as pressure change per unit flow rate (i.e., kPa/(g/s)) between well defined lower and upper flow rates. A positive slope represents increasing pressure with increasing flow rate (see Figure 8).
b. Background—An ideal regulator maintains the desired fuel system pressure regardless of changes in fuel flow rate through the regulator, all other conditions remaining constant. However, with most production regulators the fuel system pressure varies from the desired pressure as a function of fuel flow rate through the regulator. This variation of pressure with respect to flow rate should be very close to linear over the operating flow range, and a low value for the slope is generally desired.
It is important when designing/specifying a fuel injection system to know the regulator slope. The fuel flow rate through the regulator will vary due to a variety of factors which can include engine load, rpm, battery voltage, and others. Subsequent changes in fuel system pressure, due to flow variation, will change injector flow, which has to be considered in the fuel injection system design.
c. Objective—To measure the change in regulator pressure with change in fluid flow rate, from lower to upper flow rate limit, through the regulator and to establish the regulator slope. The lower and upper flow rate limits are specific to a regulator design and application.
d. Test Apparatus—See 6.2.1, 6.2.4, and 6.2.9.
e. Test Conditions—See 5.1 through 5.6.

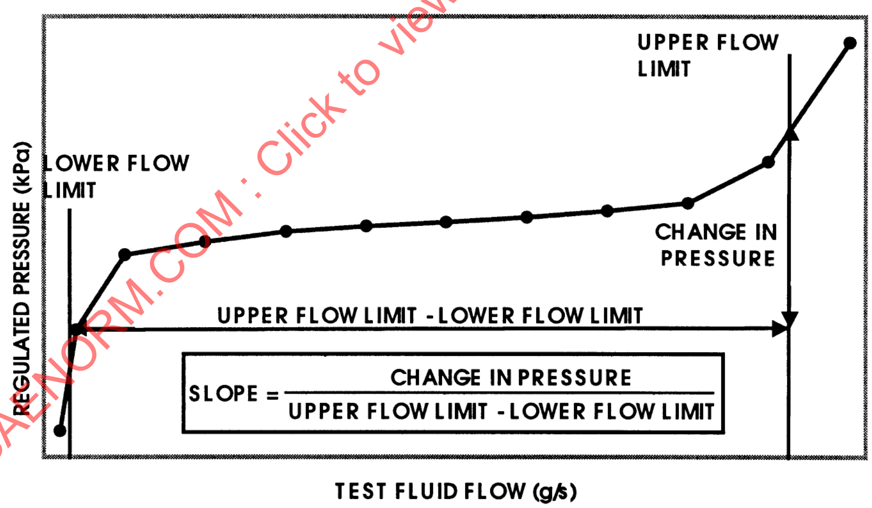

FIGURE 8—REGULATOR SLOPE

f. Test Method:

1. From the set point flow rate, with the regulator air side at ambient pressure, reduce the flow rate to 1 to 2 g/s and allow the regulator to stabilize for 15 to 30 s.
2. Gradually increase the flow rate to the specified lower flow rate limit, allow the regulator to stabilize for 15 to 30 s, and record the regulator inlet pressure. Do not allow the flow rate to exceed this flow value prior to making the pressure measurement. If it does, restart the procedure.
3. Continue with this same procedure, making regulator pressure measurements at specified flow rates between the lower and upper flow rate limits.

g. Data Required—A minimum of the previous four measurements should be made from the specified lower to upper flow rates inclusive. More intermediate points may be used if desired.
Determine the best fit slope for the data using least squares linear regression analysis techniques for data reduction. If data varies by more than ±2% from linear, the lower and/or upper specified limits may have to be reset or the larger error from linear must be noted with the slope.
Report slope as: xx.x kPa/(g/s) over the specified flow rate range.

h. Reported Population Data—Determine the regulator slopes for a random sample of regulators representative of a normal production distribution. Determine the sample mean (X_s) and standard deviation (s) of the slopes. Report the population slope as the sample mean (X_s) ± four times the sample standard deviation (4 s): xx.xx ± x.x kPa/(g/s) over the specified flow range.

3.1.3 OPERATING FLOW RANGE

a. Definition—The range of fluid flow rate over which the pressure regulator response is linear (to within 2%) with respect to flow rate Figures 9A and 9B.
b. Background—The flow range should equal or exceed the operating flow range the regulator will be exposed to in an actual application.
c. Objective—To measure the minimum and maximum regulator fluid flow rates between which the regulator pressure response is linear with respect to flow rate.
d. Test Apparatus—See 6.2.1, 6.2.4, and 6.2.9.
e. Test Conditions—See 5.1 through 5.6.
f. Test Method:

1. Slowly increase test fluid pressure until fluid just starts to flow through the regulator (approximately 1.0 g/s).
2. Gradually increase flow rate, while measuring regulator pressure, until the pressure response becomes nonlinear or the test stand capability is reached. Allow regulator to stabilize at each measurement point.

g. Data Required—Flow rate measurement increments must be small enough to accurately determine the flow range, within ±10% at minimum flow rate, ±5% at maximum.
Using least squares linear regression analysis for data reduction, for the data points in the specified flow rate range, determine the minimum and maximum regulator fluid flow rates between which the regulator pressure response is linear with respect to flow rate to within ±2%. If the maximum flow rate is beyond the capability of the test stand (at least 75 g/s), specify the test stand maximum flow rate followed by a plus sign.
Report operating flow range of the test specimen as—xx.x g/s to xxx g/s. See Figure 9A.

h. Reported Population Data—Measure the regulator pressures at a series of flow points as specified for a random sample of regulators representative of a normal production distribution. Determine the sample mean pressure (X_i) and standard deviation (s_i) at each flow point. Determine the slope over the specified flow rate range using least squares linear regression of the mean pressure values (X_i). Plot the deviation from the determined slope and the ±4 s; values for each flow point (see Figure 9). The maximum value of the operating flow range is the flow value where the +4 s_i pressure deviates by 2% from the linear regression slope, and the minimum value of the operating flow range is the flow value where the –4 s_i pressure deviates by 2% from the linear regression slope. Report the population operating flow range as: xx.x g/s to xxx g/s minimum. See Figures 9B.

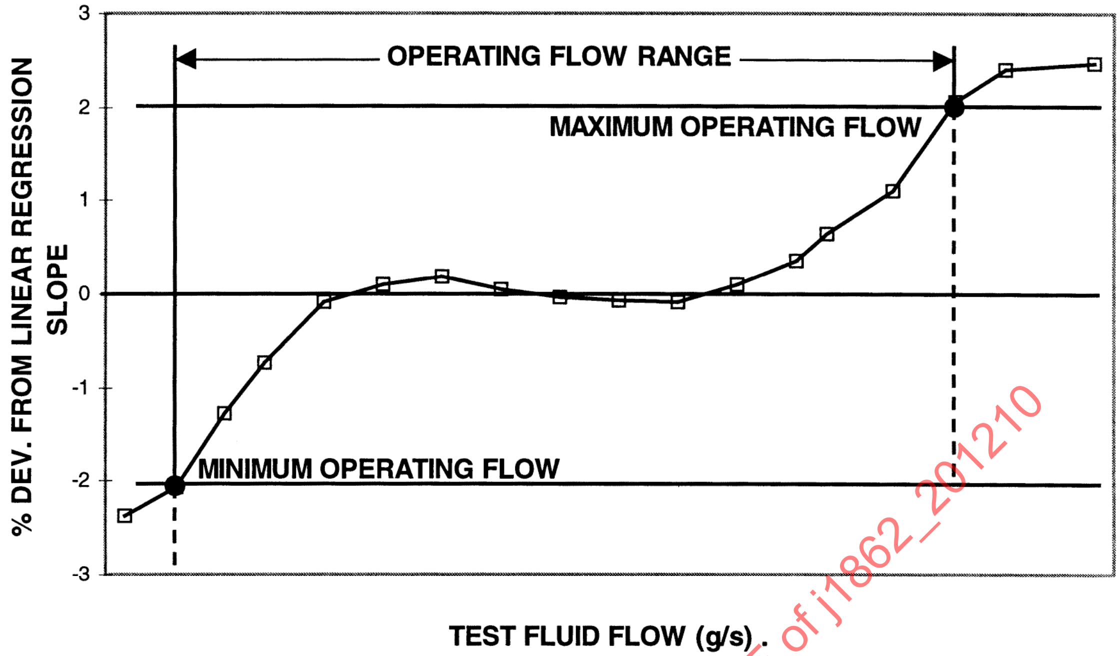

FIGURE 9A—PRESSURE REGULATOR FLOW RANGE

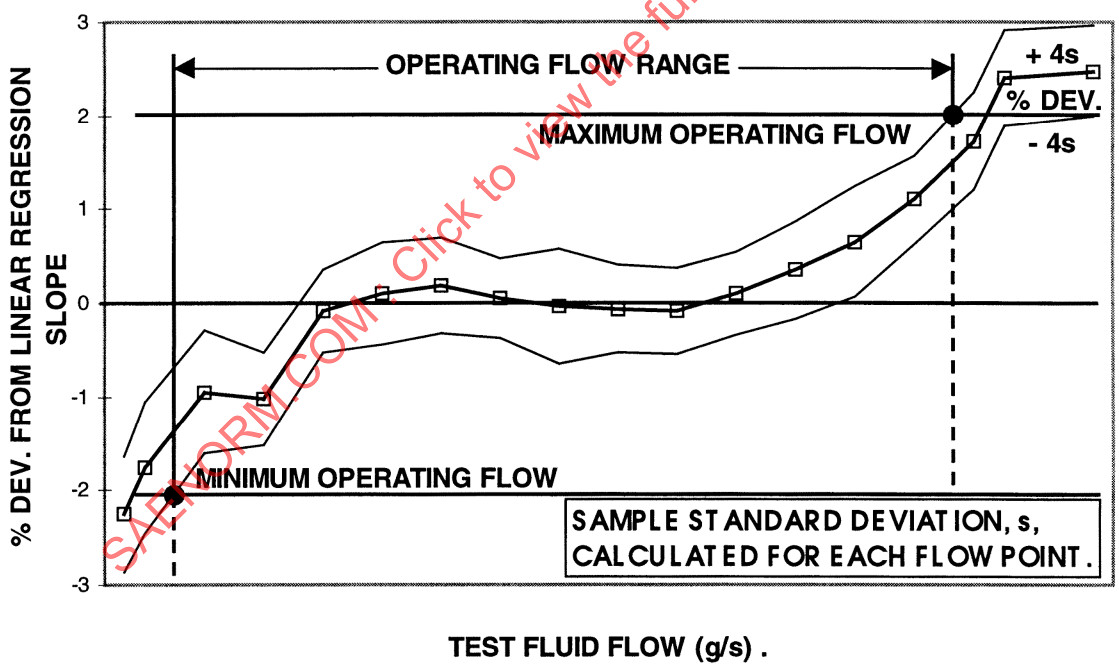

FIGURE 9B—PRESSURE REGULATOR POPULATION FLOW RANGE

3.1.4 REPEATABILITY

a. Definition—The variability in the set point pressure for a given regulator over a number of repeated pressure on-off cycles.
b. Background—An ideal regulator would produce the same set point pressure every time it is cycled from zero flow rate to the set point flow rate. Repeatability is important so that the fuel system pressure is predictable for consistent fuel system performance.
c. Objective—To determine the variability of the set point pressure for a fuel pressure regulator.
d. Test Apparatus—See 6.2.1, 6.2.4, and 6.2.9.
e. Test Conditions—See 5.1 through 5.6.
f. Test Method:

   1. Use the test method defined in 3.1 to determine the regulator set point pressure.
   2. After taking the set point pressure measurement, gradually reduce pressure in the regulator to zero and allow the regulator to relax for 15 to 30 s.
   3. Repeat the previous procedure to obtain 20 set point pressure measurements.

g. Data Required—Determine the test specimen mean set point pressure and standard deviation for the previous pressure measurements.
   The repeatability is defined as four times the standard deviation as a percentage of the test specimen measurements mean.
   Report repeatability as: ±xx.x%
h. Reported Population Data—For a random sample size of regulators, determine the sample mean set point pressure (X_i) and the standard deviations of the individual regulator set pressure measurements. The population repeatability is defined as four times the sample mean standard deviation (mean of individual regulator set pressure standard deviations) as a percentage of the mean set point pressure (X_i). Report as: ±xx.x%.

3.1.5 HYSTERESIS

a. Definition—The change in regulator set point pressure as a result of approaching the set point flow from high flow versus approaching from low flow.
b. Background—An ideal regulator would maintain the same set point pressure regardless of whether the fluid flow through the regulator has exceeded or has been less than the set point flow. Variability in set point pressure due to hysteresis has the same effect as variation due to repeatability.
c. Objective—To determine the hysteresis of a fuel pressure regulator by measuring the set point pressure when approaching the set point flow rate from both directions.
d. Test Apparatus—See 6.2.1, 6.2.4, and 6.2.9.
e. Test Conditions—See 5.1 through 5.6.
f. Test Method:

   1. Use the method defined in 3.1 to determine the set point pressure as approached from a lower flow rate.
   2. After taking the set point pressure measurement, gradually increase the fluid flow rate to the upper flow rate limit.
   3. Gradually reduce the fluid flow rate through the regulator to the set point flow rate and allow the regulator to stabilize for 15 to 30 s. Record the regulator inlet pressure. Do not allow the flow to fall below the set point flow rate prior to making this measurement. If so, restart the procedure.

g. Data Required—The hysteresis reported is the difference in increasing and decreasing flow set point pressure measurements as a percent of the set point pressure measured with increasing flow.
   Report hysteresis as: xx.x%

h. Reported Population Data—Measure the regulator set point pressure with increasing and decreasing flow for a random sample of regulators representative of a normal production distribution. Make 20 measurements of each regulator and determine the difference between the increasing flow and decreasing flow set pressures. Determine the maximum difference for each regulator. Next, determine the sample mean and standard deviation of the maximum differences. Report the population hysteresis as ±4 s as a percent of the population set point pressure: ±xx.x% ((4 s/set point pressure) x 100).

3.1.6 Dynamic Response

a. Definition—The change in regulator pressure, which results from a change in the reference pressure signal being applied to the "air side" of the fuel pressure regulator. The response of the pressure regulator to a change in the reference signal consists of both the degree of regulator pressure change as well as of the time required to respond to changes of the reference signal.
b. Background—The fuel system pressure is controlled by the pressure regulator relative to a reference pressure signal applied to the "air side" of the regulator. The reference signal is usually air cleaner pressure (CFI) or intake manifold pressure (MPI). It will be assumed that the desired change in system pressure will equal the change in reference pressure unless otherwise specified.
c. Objective—To measure the response time and accuracy of regulated pressure change of a fuel pressure regulator relative to a change in the reference signal.
d. Test Apparatus—See 6.2.1 through 6.2.5, and 6.2.9.
e. Test Conditions—See 5.1 through 5.6.
f. Test Method:

   1. Start the test with the regulator operating at set point pressure and flow rate, and ambient pressure for the reference signal.
   2. Apply a sudden change in reference signal pressure (not longer than 50 ms to achieve 90% of the final value), maintain a constant flow rate, and trace the regulator pressure.

g. Data Required—Perform the previous test with reference signal of 10 and 50 kPa vacuum and 10 and 50 kPa pressure (±1 kPa). Additional reference signal values are optional.
   Determine the stabilized regulator pressure with the new reference signal pressure. Express the change of regulator pressure as a percentage relative to the change in signal pressure.
   Determine the time required for the regulated pressure to reach 90% of its final value as measured from the time that the reference pressure achieves 90% of its final value.
   Report regulator response as: xx.x% response accuracy, xx.x ms response time, with xx kPa vacuum/pressure signal. Reference Figures 10A and 10B.
h. Reported Population Data—Determine the response time and response accuracy for each regulator in a random sample of regulators representative of a normal production distribution. Report the mean response time and mean response accuracy of the sample.

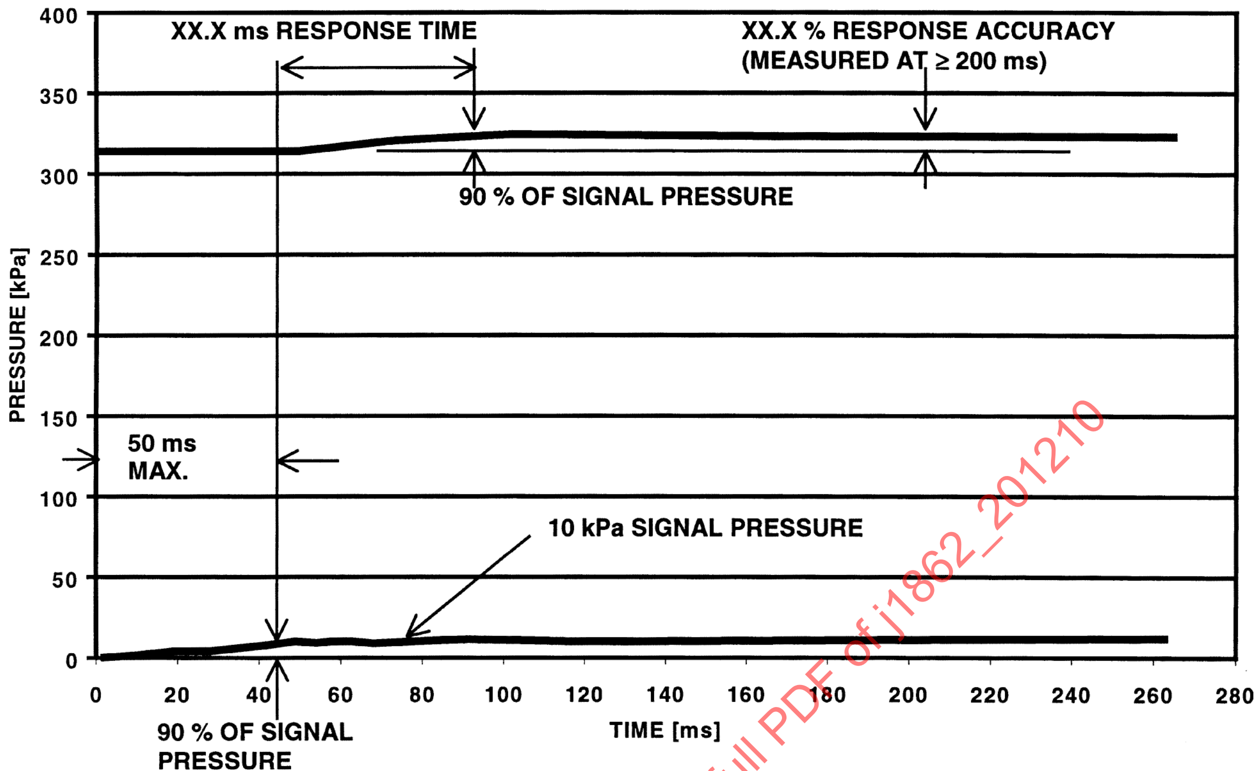

FIGURE 10A—EXAMPLE OF DYNAMIC RESPONSE (10 KPA SIGNAL PRESSURE)

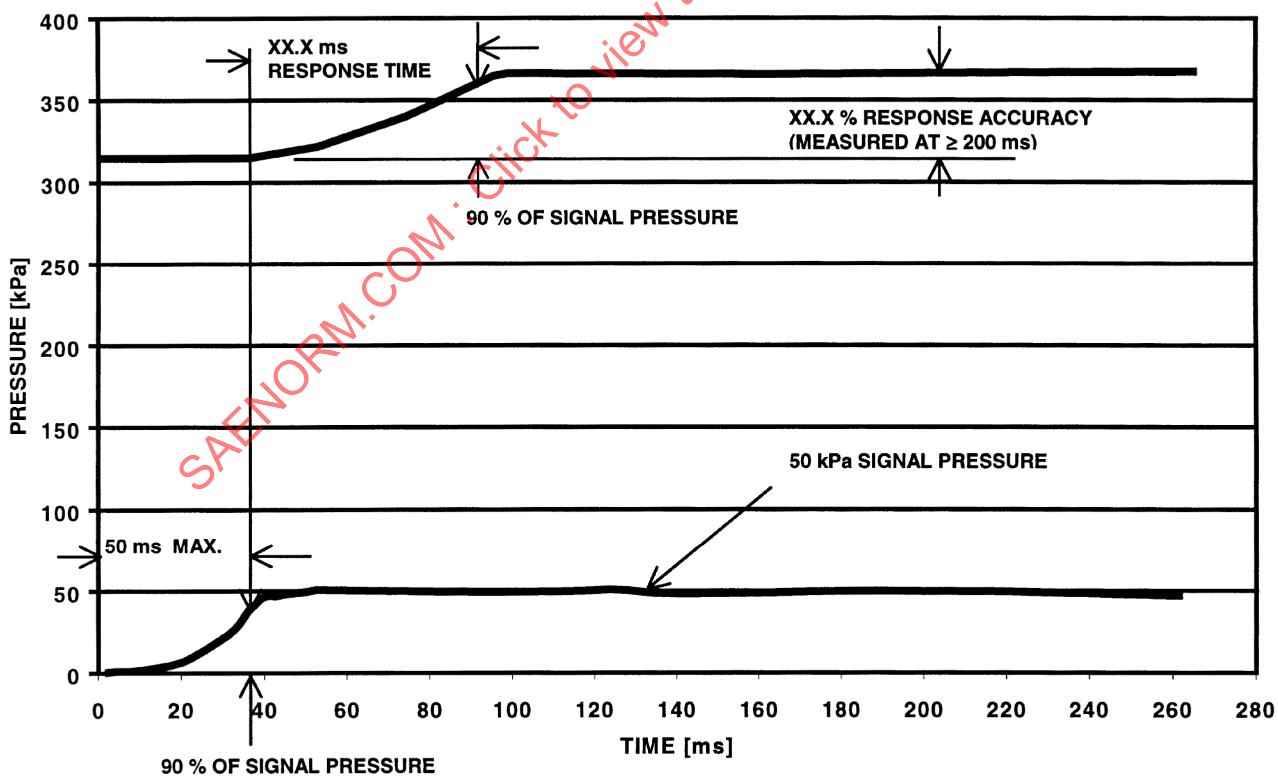

FIGURE 10B—EXAMPLE OF DYNAMIC RESPONSE (50 KPA SIGNAL PRESSURE)

3.1.7 INTERNAL LEAKAGE (LEAKDOWN)

a. Definition—The fluid leakage from the inlet of the regulator to the lower pressure regulator outlet, at a pressure below the regulator set pressure.
b. Background—A regulator can be designed to either shut off fuel flow (checking) or allow fuel flow through the regulator (bleed-down) when the fuel system pump is de-energized. The purpose, respectively, is to maintain pressure in the system, or bleed-off pressure in the system, after the pump is de-energized.
c. Objective—To measure the internal leakage of a fuel pressure regulator.
d. Test Apparatus—See Figure 11.
e. Test Conditions—See 5.1 through 5.6.
f. Test Method–Fluid (for Shutoff or Bleed-Down Regulators):

   1. Start the test with the regulator operating at set point pressure and flow rate and ambient pressure for the reference signal.
   2. Reduce the regulator inlet pressure to 80% of set pressure, and maintain regulator pressure at that level with the regulator outlet at ambient pressure. Allow regulator to stabilize for 60 s minimum.
   3. Measure the mass of fluid that leaks out the outlet for a 60 s minimum time period.

g. Data Required–Fluid—Report regulator leakdown as: xx.x g/s test fluid at xxx.x kPa.

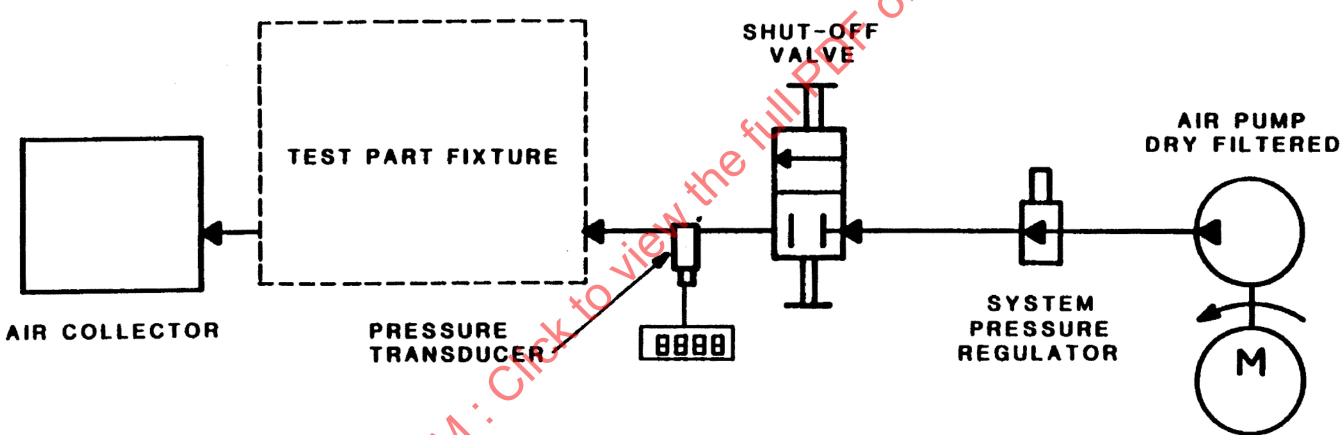

FIGURE 11—INTERNAL LEAKAGE TEST STAND

h. Test Method–Air (Optional Method for Shutoff Regulators)—Regulator must be empty of all fluid.

   1. Apply dry, filtered air at the set pressure for 30 s minimum to dry the regulator interior and sealing surfaces. The airflow rate or pressure may need to be adjusted to prevent harmful vibration of internal components.
   2. Reduce the regulator pressure to 80% of set pressure to the regulator inlet with the regulator outlet at ambient pressure. Allow the regulator to stabilize for 60 s minimum.
   3. Measure the volume of air that leaks out the outlet for a 60 s minimum time period.

i. Data Required–Air—Convert measured volume of air over a measured time period to a standard airflow rate. Scc/min.
   Report regulator leakdown as—xx.x Scc/min air at xxx.x kPa.
j. Reported Population Data—Determine the leak rate (either air or fluid) for each regulator in a random sample representative of a normal production distribution. Using the mean leak rate and standard deviation for the sample, determine the 4 s upper bound (x + 4 s) and report its value as the maximum population leak rate.

3.2 Pressure Damper Performance

a. Definition—The attenuation effectiveness and characteristics of a pressure damper on a test fixture.
b. Background—The ideal pressure damper would remove all pressure pulsations in the fuel system. The pressure trace of the output of the damper would then indicate only the nominal static pressure with no ripple or noise on the trace. Further, the ideal damper would eliminate all noise over the entire spectral bandwidth of interest, typically DC (static) to 5000 Hz. In actuality, pressure damper performance might not be equally effective over the entire spectrum of frequencies, thus, the same damper might appear quite effective in one application and ineffective in another.
c. Objective—To define an overall acceptance test of a pressure damper for a particular application, and to suggest techniques for characterizing damper performance over an entire bandwidth.
d. Test Apparatus—See Figure 12.

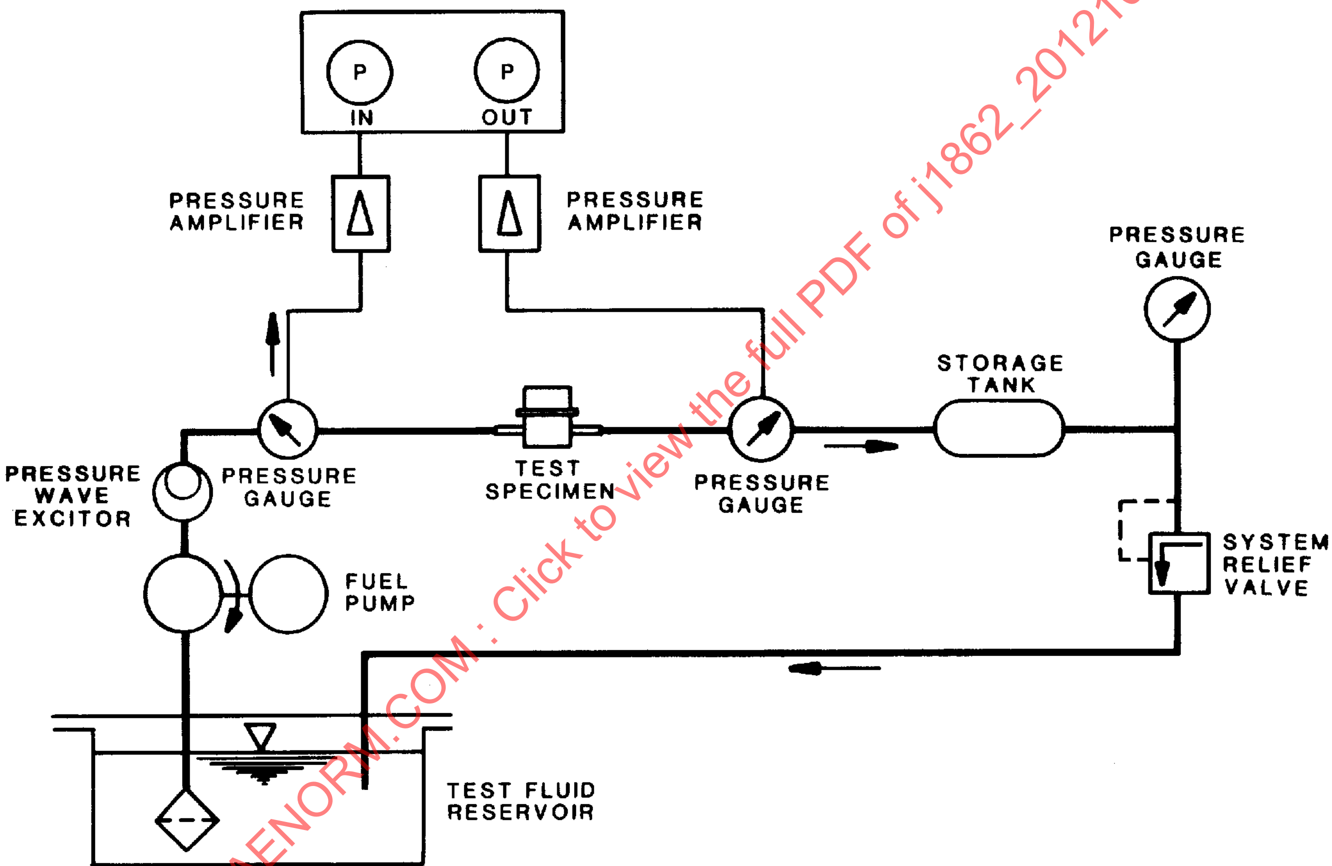

FIGURE 12—PRESSURE DAMPER PERFORMANCE TEST STAND

e. Test Conditions—See Section 5.

f. Test Method:

1. Part 1–Overall Acceptance Test—For this test, a good high speed system digital voltmeter is necessary, which can store multiple readings (at least 1000), average those readings, find maximum/minimum, and read true root mean square voltages (rms).
   The basic test procedure involves obtaining three pieces of data from the input pressure trace, and the output pressure trace, then comparing the measurements and expressing them in terms of percent differences. This test should be performed at the intended system nominal pressure and at points over the range of fuel system gauge pressures in steps of 10 kPa. (i.e., for a normally aspirated engine at 300 kPa, take readings at 200, 210, 220...300 kPa). The three readings are:

   a. Average Static Pressure Level—This is determined by taking 1000 readings of the DC equivalent (static) pressure level both at the inlet and outlet, and calculating the average of those pressure readings at each location (x_{in} and x_{out}). The ideal pressure damper has x_{in} and x_{out} equal, which means that no pressure drop has occurred through the device.

   NOTE—For flow related calculations, the inlet is the side nearest the flow source; for attentuation related calculations, the inlet is the side nearest the acoustic source.

   b. Random Pressure Noise–Efficiency—This value is the peak-to-peak reading determined from the maximum and minimum values from the same 1000 readings taken in part 1. The value characterizes random pressure excursions present on the trace, and is to be reported as the difference between them (maximum-minimum) for the inlet and outlet traces. The final reported value is the ratio of the outlet to the inlet expressed in percent ((out/in) x 100).

   c. Root/Mean Square Pressure Ripple—With the pressure traces AC coupled to the digital voltmeter, the true rms value is obtained. This measurement characterizes periodic pressure disturbance with the difference between the in and out values indicating the device effectiveness. Report the ratio of the outlet to the inlet expressed in percent ((out/in) x 100).
   Figure 13 represents an example of the pressure damper overall acceptance.

2. Part 2–Characterizing Damper Performance—This tests attempts to characterize a pressure damper for any application by measuring the performance characteristics in the frequency domain. A fast Fourier transform (FFT) spectrum analyzer is required for this test, preferably a two channel condition would be one in which the input pressure trace contains random noise throughout the entire spectral bandwidth of DC to 5000 Hz.

   The input and output pressure traces are AC coupled to the spectrum analyzer, and a transmissibility trace is obtained. This trace is a good qualitative indication of the performance of the damper over the entire bandwidth. The ideal pressure damper would demonstrate equal performance over the entire display the power spectral density (PSD) of the input and output traces. A visual comparison of the two traces would yield the same basic information as the transmissibility trace but with less detail.

   Figure 14 represents an example of the pressure damper frequency domain.

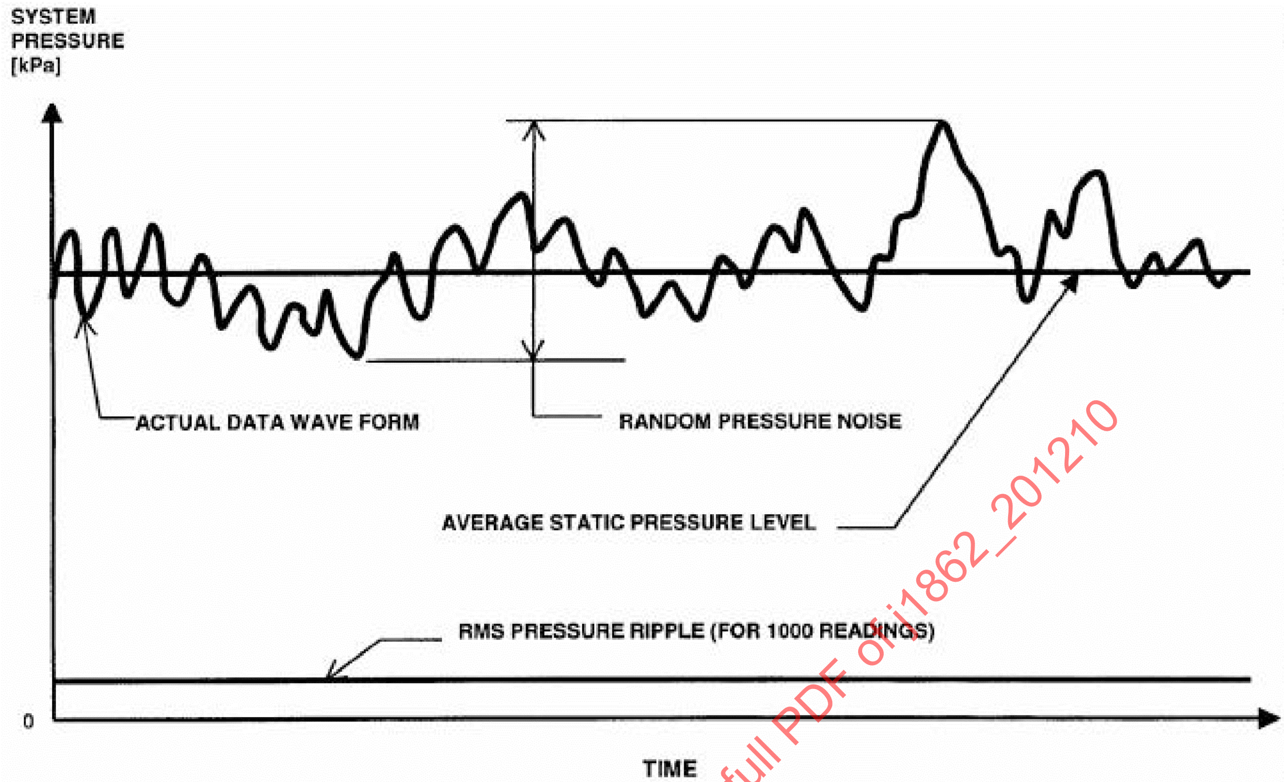

FIGURE 13—PRESSURE DAMPER OVERALL ACCEPTANCE

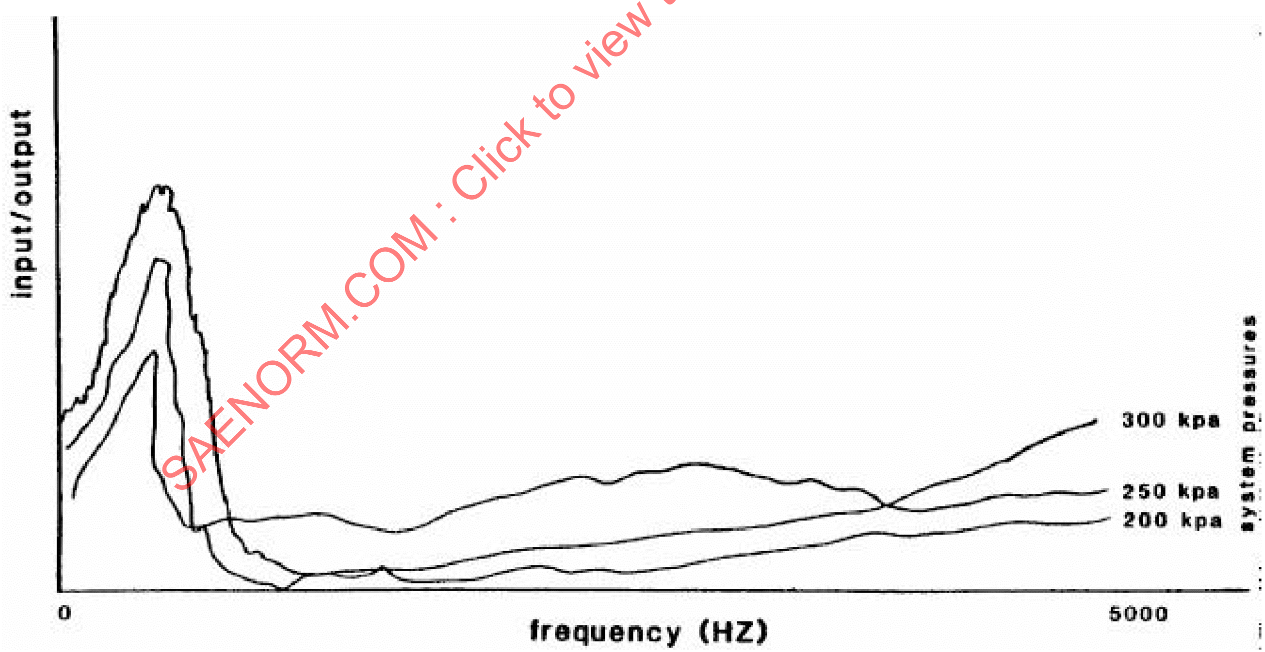

FIGURE 14—EXAMPLE OF PRESSURE DAMPER FREQUENCY DOMAIN

3. Part 3–Insertion Loss Method—This test method will determine the performance of a damper by comparing the pressure wave magnitude with and without the damper installed in the test circuit, see Figure 12. A calibration test unit, made from a rigid conduit, is first tested to establish a baseline RMS value on the pressure damper performance test stand. Performance testing of the pressure damper is performed after the test stand underwent the calibration procedure with all the conditions remaining constant.
   The test output is measured in terms of the RMS value of 10 pressure wave forms. The mean RMS value is divided by the calibration value and used as the test result.

   a. Test Procedure:

      1. Adjust pressure regulator to specified operating pressure.
      2. Adjust heat exchanger to maintain specified fluid temperature.
      3. Adjust injector driver to specified frequency and pulse width.
      4. Attach calibration test unit to test stand.
      5. Open bleed valve.
      6. Wait for air to bleed from system.
      7. Close bleed valve.
      8. Turn on injector signal.
      9. Wait for 1 min.
      10. Acquire 10 RMS readings form the dynamic pressure transducer.
      11. Record the average RMS value of the 10 data samples.
      12. Remove calibration test unit form test stand.
      13. Attach pressure damper test unit to test stand.
      14. Open bleed valve.
      15. Wait for air to bleed from system.
      16. Close bleed valve.
      17. Turn on injector signal.
      18. Wait for 1 min.
      19. Acquire 10 RMS readings from the dynamic pressure transducer.
      20. Record the average RMS value of the 10 data samples.
      21. Remove pressure damper test unit from test stand.
      22. Repeat steps 13 to 21 for each pressure damper.
      23. Repeat steps 4 to 12.

g. Data Required:

   1. Test results of:

      a. Average static pressure level
      b. Random pressure noise–efficiency
      c. rms pressure ripple as shown on Figures 13 and 14.

   2. Specify the excitor characteristics and method.
      Minimum signal level or acoustic source should be identified specifically.

h. Reported Population Data—Report the mean and 4 s values on a random sample size of dampers.

3.3 External Leakage

3.3.1 EXTERNAL LEAKAGE–FUEL SIDE

a. Definition—Leakage from the fuel side of the regulator or damper to the exterior and to the air side of the device.
The fuel in the pressure regulator or pressure damper should be contained in a closed, safely sealed cavity.
b. Objective—To measure the fuel side external leakage.
c. Test Apparatus—See Section 6.
d. Test Conditions—See 5.2, 5.5, and 5.6.
e. Test Method—Drain fuel from the component.

1. Apply dry, filtered air at set pressure for 30 s to dry the interior. The airflow rate or pressure may need to be adjusted to prevent harmful vibration of internal components.
2. Apply air at 1.5 times set point pressure ±7 kPa to the inlet and outlet simultaneously. Allow the specimen to stabilize for 60 s minimum.
3. Measure the volume of air that leaks to the exterior and to the air side of the specimen during a 60 s minimum time period.

f. Data Required—Convert measured volume of air over a measured time period to a standard airflow rate, Scc/min.
Report fuel side external leakage as—xx.x Scc/min air at the pressure specified in 3.3.1e (2).
g. Reported Population Data—Determine the leak rate for each specimen in a random sample of regulators or dampers representative of a normal production distribution. Using the mean leak rate and standard deviation for the sample, determine the 4 σ upper bound (x + 4 s) and report its value as the maximum population leak rate.

3.3.2 EXTERNAL LEAKAGE—AIR SIDE

a. Definition—Leakage from the air side of the regulator or damper to the exterior and to the fuel side of the regulator, for those devices referenced to an air pressure source.
b. Background—If the device is referenced to a remote pressure source (versus simply vented to ambient), it is generally desirable that the “air-side” be sealed to prevent air leakage to the signal source.
c. Objective—To measure the air side external leakage.
d. Test Apparatus—See Section 6.
e. Test Conditions—See 5.2, 5.5, and 5.6.
f. Test Method:

1. Apply dry, filtered air at 1.5 times set point pressure to the air side of the specimen. Allow it to stabilize for 60 s minimum.
2. Measure the volume of air that leaks to the exterior and to the fuel side of the specimen during a 60 s minimum time period.

g. Data Required—Convert measured volume of air over a measured time period to a standard airflow rate, Scc/min.
Report air side external leakage as—xx.x Scc/min air at 1.5 times set point pressure.
h. Reported Population Data—Determine the leak rate for each specimen in a random sample of regulators or dampers representative of a normal production distribution. Using the mean leak rate and standard deviation for the sample, determine the 4 s upper bound (x + 4 s) and report its value as the maximum population leak rate.

3.4 Presentation of Regulator and Damper Data—The data recorded should include as minimum:

a. Regulator model/serial number
b. Test stand number and last calibration date
c. Test date
d. Test fluid type
e. Ambient and fluid temperature
f. Requested data

4. Application Related Parameters and Tests

4.1 Structural Integrity

a. Definition—The ability of the physical construction of a fuel pressure regulator or pressure damper to withstand the environment.
b. Background—To determine the physical integrity of the fuel pressure regulator or pressure damper design and construction when subjected to extreme environmental conditions. Also, the design must withstand the initial installation and field service handling.

4.1.1 VIBRATION

a. Objective—To measure changes in the functional characteristics and evaluate the construction of the device after being subjected to vibration inputs.
b. Test Specimen Conditions—See 5.1 through 5.6.
c. Test Method:

1. Measure test specimen initial characteristics per 3.1.1, 3.1.2, 3.1.7, and 3.3 for regulators and 3.2 and 3.3 for dampers.
2. Test specimen must be filled with test fluid during testing.
3. Subject the regulator to a sinusoidal vibration linear sweep of 50-500-50 Hz over 10 min with 40 g peak-to-peak for 8 h each in three mutually perpendicular axes. One axis must be along the direction of action of the valve (see 6.2.6).
4. Retest the specimen on completion.
5. Test the specimen per 4.1.3.

d. Data Required—Report the percent deviation of the values measured before and after the test.
e. Optional–Random Vibration Application Test—As a further optional test, a tape can be made of the actual vehicle full load vibration characteristics as a function of the engine rpm. This tape can be played back through an electrodynamic vibration machine on a single axis basis to simulate the actual vehicle environment. Also, simultaneous three axis (spatial) testing is possible; however, the control is not as precise as these testing machines are typically mechanical in nature.
The duration of the test and pass/fail criteria is left up to the user.
f. Reported Population Data—Report the upper bound of percent deviations (x + 4 s) on a random sample of regulators or dampers, that is representative of normal production.

4.1.2 SHOCK

a. Objective—To measure changes in the functional characteristics and evaluate the mechanical construction of the fuel pressure regulator or damper after being subjected to a mechanical impulse load (shock).
b. Test Specimen Conditions—See 5.1 through 5.6.
c. Test Method:

   1. Measure test specimen per 3.1.1, 3.1.2, 3.1.7, and 3.3 for regulators and 3.2 and 3.3 for dampers.
   2. Apply an acceleration of 100 g's to the test specimen over a 5 ms period and repeat three times in each axis.
   3. The acceleration is to be applied in each of the three perpendicular axes with one axis in the direction of action of the valve/diaphragm.
   4. Retest the specimen on completion.
   5. Test the specimen per 4.1.3.

d. Data Required—Report the percent deviation of the values measured before and after the tests.
e. Reported Population Data—Report the upper bound of percent deviations (x + 4 s) on a random sample size of regulators or dampers.

4.1.3 BURST

a. Objective—To determine the pressure at which the regulator or damper will develop an external leak and/or a fuel leak path to the air side of the diaphragm.
b. Test Apparatus—Figure 15—Hydraulic pump and fixture capable of performing the burst pressure test as described in the test method section. Proper safety precautions must be taken due to the high pressures and catastrophic nature of failures. The test is to be performed in an enclosure suitable to contain any failure of components.
c. Test Conditions—See 5.1 to 5.3, otherwise the test fluid and conditions should be specified. For safety reasons, do not use a gas or fuel for burst testing.
d. Test Method:

   1. Gradually apply a pressure of 1000 kPa ± 20 kPa to the fuel chamber of the specimen and maintain for a period of 60 s.
   2. Slowly increase pressure to test points in increments of 100 kPa holding at each point for 10 s until failure is reached.

e. Data Required—Record the pressure reading taken before the test point at which a sudden drop in pressure (greater than 200 kPa) takes place.
f. Reported Population Data—Report the lower bound of the sample population data (x –4 s) on a random sample of regulators or dampers.

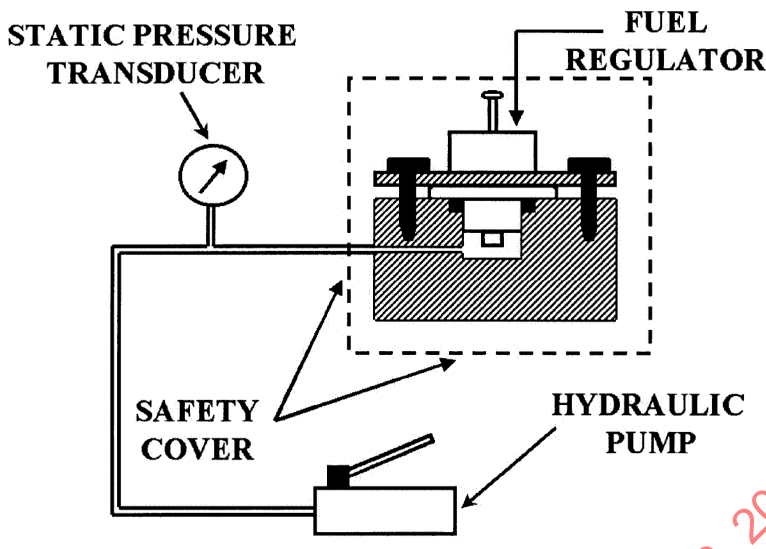

FIGURE 15—PRESSURE REGULATOR PROOF PRESSURE/BURST TEST STAND

4.1.4 PROOF PRESSURE

a. Objective—To verify that the functional performance of a regulator or a damper remains within certain limits after a specified pressure is applied for a required length of time. As subjected to this test procedure, the specified pressure, or proof pressure, is 1000 kPa or twice the set point pressure, whichever is higher.
b. Test Apparatus—See Figure 15.
c. Test Conditions—See 5.1 to 5.3, otherwise the test fluid and conditions should be specified.
d. Test Method

   1. Measure test specimen before test per 3.1.1, 3.1.2, 3.1.7 3.3 for regulators and 3.2 and 3.3 for dampers.
   2. Seal outlet and apply the specified proof pressure to inlet for one minute.
   3. Retest specimen per 3.1.1, 3.1.2, 3.1.7, and 3.3 for regulators and 3.2 and 3.3 for dampers.

e. Data Required—Report the percent deviation of the values measured before and after the tests.
f. Reported Population Data—Report the lower bound of percent deviations (X–4 s) on a random sample.

4.1.5 PHYSICAL TESTS

a. Connection Integrity—All fuel and vacuum connections must be tested according to the schedule in Table 1. The specific test requirements are dependent on the construction method used for the production of the regulator or damper assembly and usage in normal conditions in the vehicle application. Leakage is to be determined as in 3.3 both before and after the test.
b. After performing the leak tests, perform a burst test per 4.1.3.

TABLE 1—PHYSICAL TESTS

PULL TEST	TORQUE TEST[1]	BENDING TEST
Apply 600 N	Apply 20 N·m torque	Perform 30°bend

1. Applicable for tubes with thread or hexagon feature at the base.

4.2 Durability–Life-Cycling

a. Definition—The ability of the regulator or damper to function consistently over a given period of time, which would be representative of vehicle life.
b. Background—To determine the ability of the regulator or damper to fulfill performance requirements during and after a simulation of the parts life cycle under normal and extreme environmental conditions.

4.2.1 FLOW CYCLING

a. Objective—To measure the functional changes and leakage of the regulator or damper due to high speed/long duration flow cycling.
b. Test Apparatus—See Section 6.
c. Test Conditions—See Section 5.
d. Test Method:

1. Measure the specimen per 3.1.1, 3.1.2, 3.1.7, and 3.3 for regulators and 3.2 and 3.3 for dampers.
2. Flow cycle the specimen between 25 and 10 g/s. Use a square wave duty cycle as shown in Figure 16. The test duration is 100 million cycles at a frequency of 33.33 Hz (30 ms period) followed by 200 million cycles with a frequency of 100 Hz (10 ms per period).
3. Retest the specimen on completion per step 1.
4. Test the specimen per 4.1.3.

e. Data Required—Report the percent deviation between the before and after readings and burst test results.
f. Reported Population Data—Report the upper bound of percent deviations (x +4 s) on a random sample of regulators or dampers.

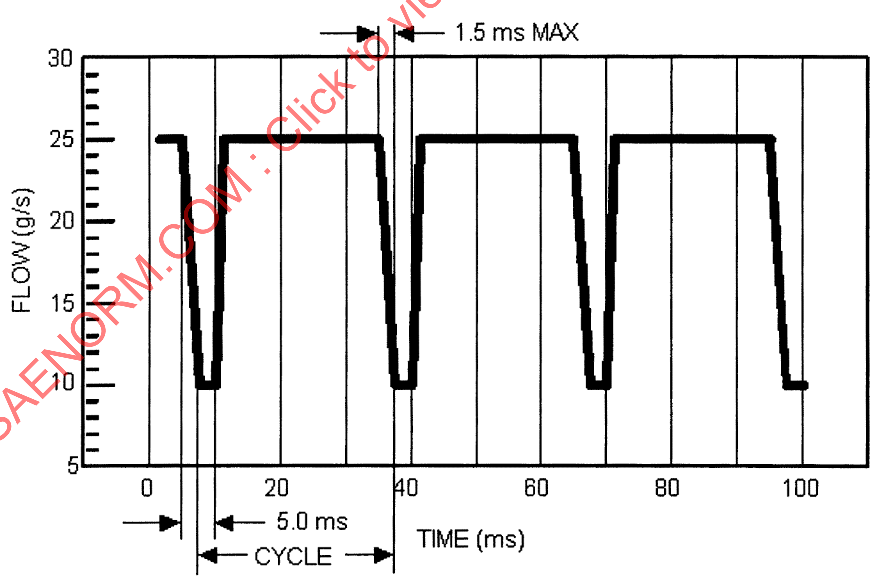

FIGURE 16—FLOW CYCLE SCHEDULE

4.2.2 PRESSURE CYCLING

a. Objective—To measure the functional changes and leakage of the regulator or damper due to pressure cycling.
b. Test Apparatus—See Section 6.
c. Test Conditions—See Section 5.
d. Test Method:

1. Measure the specimen per 3.1.1, 3.1.2, 3.1.7, and 3.3 for regulators and 3.2 and 3.3 for dampers.
2. Pressure cycle the specimen between 5% of set point pressure and the set point pressure. Use a square wave duty cycle consisting of a frequency of 0.1 Hz (10 s period). The test is performed with gasoline as a test fluid at a temperature of 15 to 25 °C. The test duration is 60 000 cycles (to simulate 150 000 miles). Reference Figure 17.
3. Retest the specimen on completion.
4. Test the specimen per 4.1.3.

e. Data Required—Report the percent deviation between the before and after readings.
f. Reported Population Data—Report the upper bound of percent deviations (x +4 s) on a random sample of regulators or dampers.

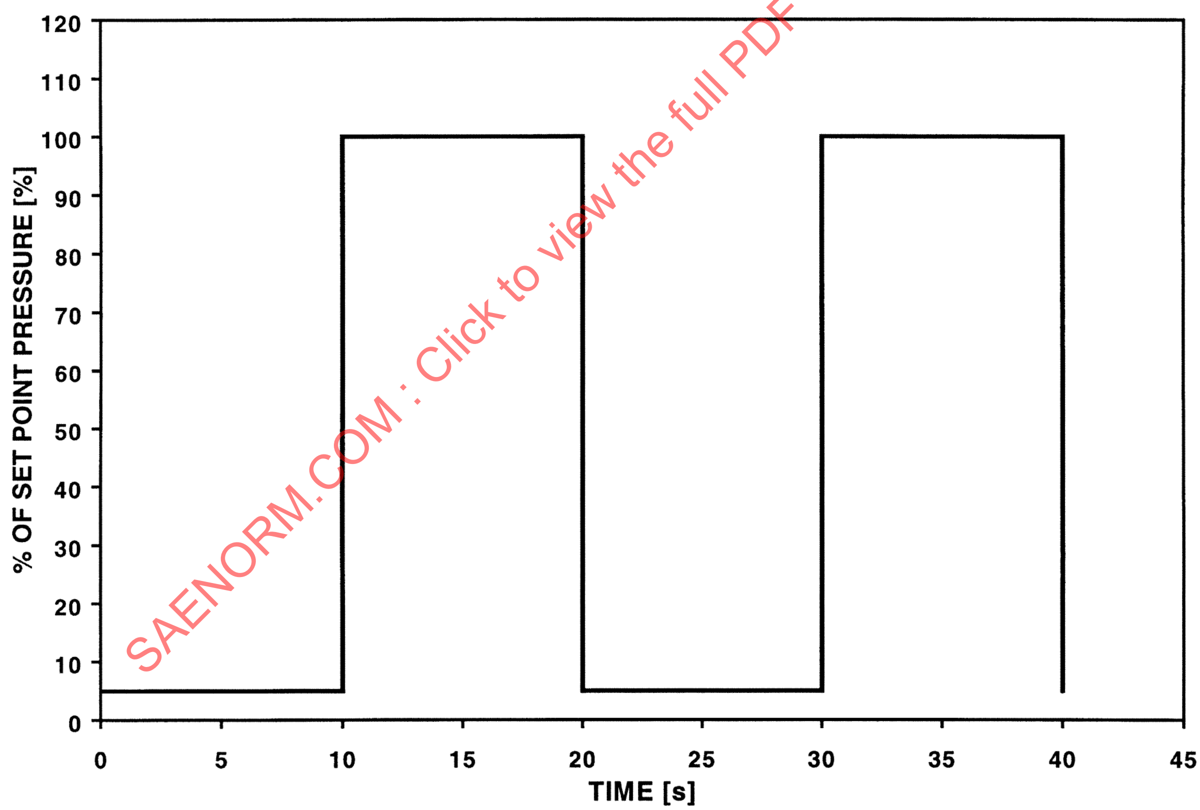

FIGURE 17—PRESSURE CYCLE SCHEDULE

4.2.3 THERMAL CYCLING

a. Objective—To measure the functional changes and leakage of the regulator or damper due to thermal cycling.
b. Test Apparatus—See Section 6.
c. Test Conditions—See Section 5.
d. Test Method:

1. Measure specimen performance per 3.1.1, 3.1.2, 3.1.7, and 3.3 for regulators and 3.2 and 3.3 for dampers.
2. The specimen must be empty of all fuel.
3. Temperature cycle the regulator for 10 cycles between –40 and 125 °C. Each cycle has a duration of 3 h per cycle with 1 h transitions and 0.5 h holding periods (see Figure 18).
4. Retest the specimen on completion as per step (1).
5. Test the specimen per 4.1.3.

e. Data Required—Report the percent deviation between the before and after readings.
f. Reported Population Data—Report the upper bound of percent deviations (x +4 s) on a random sample of regulators and dampers.

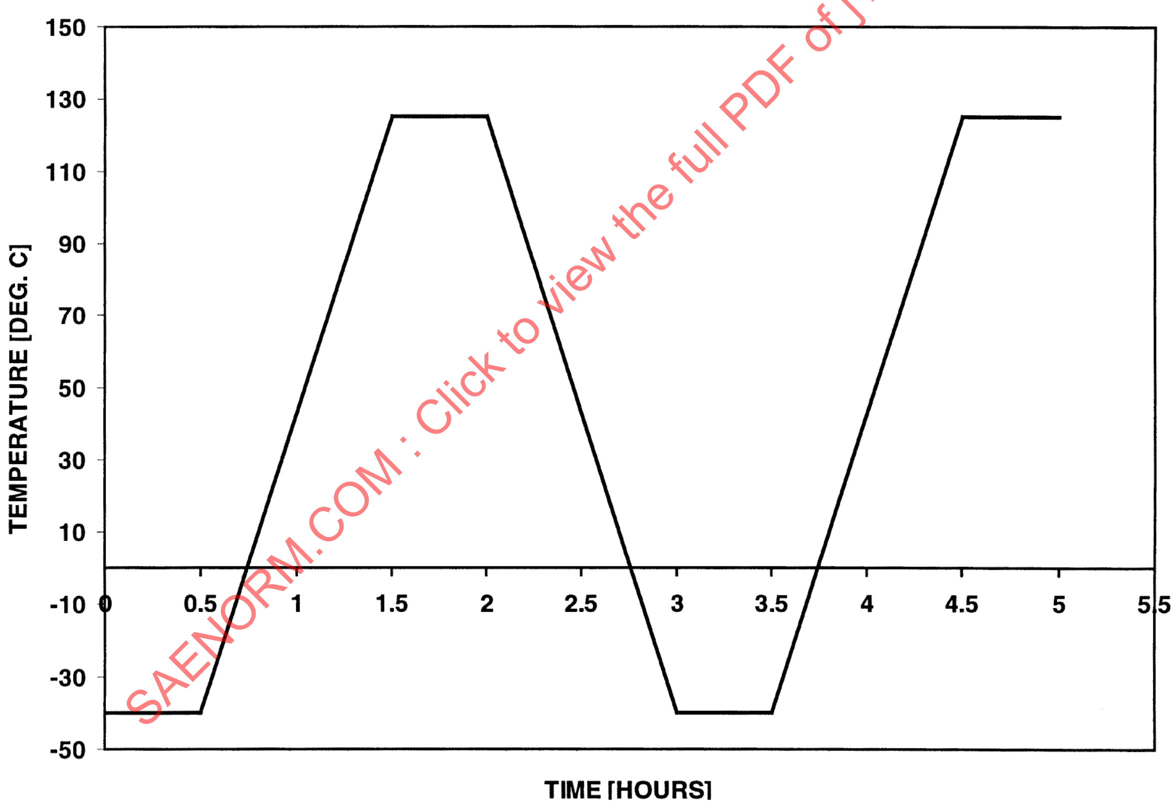

FIGURE 18—THERMAL CYCLE SCHEDULE