SAE The Engineering Society For Advancing Mobility Land Sea Air and Space®
INTERNATIONAL
400 Commonwealth Drive, Warrendale, PA 15096-0001

SURFACE VEHICLE STANDARD

Submitted for recognition as an American National Standard

SAE J1668

REAF. APR1999

Issued 1993-06-30
Reaffirmed 1999-04

Superseding J1668 JUN93

# Diesel Engines—Fuel Injection Pump Testing



**1. *Scope*—**The correct setting and adjustment of fuel injection pumps requires standardized testing conditions.

This SAE Standard summarizes the design and operating parameters for test benches so that, using certain information supplied by the pump manufacturer, the pump test schedule, and certain information supplied by the test bench manufacturer, it can be determined whether a particular test bench is suitable for driving a particular injection pump.

This document is in most cases a summary of the ISO Standard 4008, Parts 1, 2, and 3 and is intended to provide its critical aspects. Standard ISO 4008 should be referred to for more details.

**1.1 Field of Application—**This document is primarily applicable to test benches suitable for the calibration of fuel injection pumps for diesel engines requiring a fuel delivery of up to 300 mm$^3$/st/cylinder at full load.

## 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 J967—Calibration Fluid
SAE J968—Calibrating Nozzle and Holder Assemblies
SAE J1549—Diesel Fuel Injection Pump—Validation of Calibrating Nozzle Holder Assemblies

2.1.2 ANSI PUBLICATION—Available from ANSI, 11 West 42nd Street, New York, NY 10036-8002.

ANSI/ASME B40.1-1985

2.1.3 ISO PUBLICATIONS—Available from ANSI, 11 West 42nd Street, New York, NY 10036-8002.

ISO 4008—Part 1, Fuel injection pump testing—Dynamic conditions
ISO 4008—Part 2, Fuel injection pump testing—Static conditions
ISO 4008—Part 3, Fuel injection pump testing—Application and test procedures
ISO 4020-2—Fuel filters for automotive compression-ignition engines—Part 2, Test values and classification
ISO 8984—Testing of fuel injectors for compression-ignition engines

**2.2 Other Publications**

"Fuel Injection and Controls," 1962 by P. Burman and F. De Luca

***3. Dynamic Timing***

**3.1 Speed Variation at Constant Load—**The mean speed of the driveshaft under any steady admissible load shall not vary more than ± 1/4% above 800 rpm and ± 2 rpm below 800 rpm for at least 1 min.

**3.2 Flywheel Inertia—**The test bench flywheel shall ensure that the instantaneous speed drop of a pump during injection (i.e., cyclic speed variation) shall be less than 1% at any critical calibration point. Based on this criterion, the required flywheel inertia can be calculated from Equations 1 and 2:

$$I = \frac{Q_{max} \times p_{pa}}{1.31 \times n^2} \qquad \text{(Eq. 1)}$$

or

$$Q_{max} = \frac{I \times n^2 \times 1.31}{p_{pa}} \qquad \text{(Eq. 2)}$$

where:

$I$ = Moment of inertia (kg·m$^2$)
$Q_{max}$ = Pump delivery at calibration point (mm$^3$/st/outlet)
$p_{pa}$ = Peak Line Pressure (bar)
$n$ = Pump Test Speed (rpm)

To prevent torsional resonance with other mass in the transmission, the flywheel shall be as close to the coupling output as possible.

**3.3 Driveshaft Stiffness—**The maximum instantaneous angular driveshaft deflection under any operating conditions shall be 0.02 degrees.

The required driveshaft stiffness is calculated as shown in Equation 3:

$$S_d = \frac{Q_{max} \times p_{pa}}{22.4} \qquad \text{(Eq. 3)}$$

where:

$S_d$ = Driveshaft Stiffness (Nm/$^o$)
$Q_{max}$ = Maximum pump delivery (mm$^3$/st/outlet)
$p_{pa}$ = Peak Line Pressure (bar)

The driveshaft is considered to be the part connecting the flywheel to the test bench coupling. (On some test benches there is no driveshaft because the coupling is mounted directly to the flywheel).

**3.4 Coupling Stiffness—**The maximum instantaneous angular deflection of the drive coupling under operating conditions shall be 0.1 degree.

The required coupling stiffness is given by Equation 4:

$$S_c = \frac{Q_{max} \times p_{pa}}{125.6} \qquad \text{(Eq. 4)}$$

where:

$S_c$ = Coupling Stiffness (Nm/$^o$)
$Q_{max}$ = Maximum pump delivery (mm$^3$/st/outlet)
$p_{pa}$ = Peak Line Pressure (bar)

In Equations 1 to 4, it is assumed that the mean injection pressure is represented by a sine wave and the injection duration is 10 degrees of pump rotation.

**3.5 Pump Mounting Stiffness and Alignment—**The injection pump mounting shall be stiff enough to ensure that deflection of the pump body flange (or base bracket) about its driveshaft is less than 0.02 degree with respect to ground during injection. Special apparatus to measure pump mounting stiffness is fully described in ISO 4008 Part 1.

In addition, the pump mounting shall align the pump driveshaft with the test bench output within 0.13 mm radially and 0.05 degree angularly (or 0.25 mm over 300 mm length).

**3.6 Backlash—**There shall be no backlash between the flywheel and the pump drive coupling.

**3.7 Angular Creep—**There shall be no angular movement between connecting parts situated between the flywheel and the pump drive coupling when subject to torque reversals equal to twice the peak injection torque according to Equation 5:

$$T \geq Q_{max} \qquad \text{(Eq. 5)}$$

where:

T = Peak injection torque (N·m)
$Q_{max}$ = Numeric value of pump max delivery

The formulae for driveshaft and coupling stiffness as well as limits for pump mounting stiffness and angular creep were derived during extensive testing.

**3.8 Power Output—**Test bench power output may be significantly less than the drive motor rated power and is not constant through the speed range. It depends on the type of transmission used. Therefore, output power shall be checked using a dynamometer connected to the test bench driveshaft, and results plotted on a graph as shown in Figure 1. Speed droop (no load to full load) if any, and speed variation at constant load over 1 min shall also be measured using a dynamometer.

**3.9 Conditions—**In order to meet 3.2, 3.3, 3.4, 3.5, and 3.8 of this part of the Standard, the test bench manufacturer and the injection pump manufacturer must provide information to the user to enable him to determine the suitability of a certain test bench to test and calibrate a specific injection pump.

a. Test bench manufacturer shall publish

1. Continuous horsepower at the drive coupling available to drive the injection pump. This should be presented in the form of a graph as shown in Figure 1. If maximum horsepower is given, then maximum duration, ambient temperature, or other conditions and limitations must be stated.
2. Flywheel moment of inertia (kg·m$^2$)
3. Coupling stiffness (Nm/°)
4. Driveshaft stiffness (Nm/°)
5. Flange and/or base bracket stiffness (Nm/°)

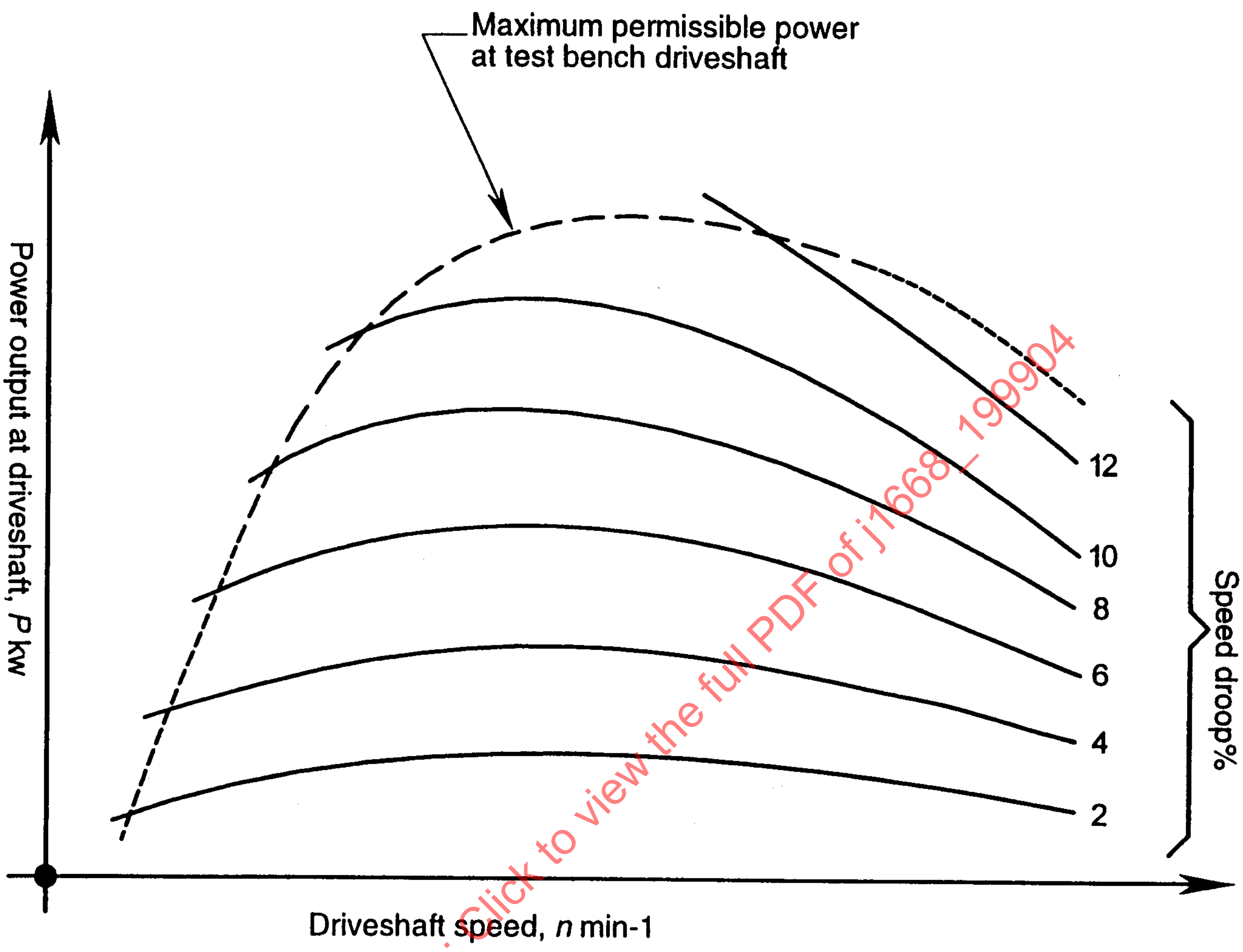




FIGURE 1—POWER CURVE SAMPLE

Furthermore, the test bench manufacturer shall provide a graph showing the permissible operating envelope based on formulae given in 3.2, 3.3, and 3.4. For simplicity, a peak injection pressure of 628 bar is assumed for this graph. If actual peak pressure is not 628 bar, then fuel delivery must be corrected as described in 3.10 in order to use the graph. An example of the graph is shown in Figure 2. (If the curve showing the stiffness of the flange or base brackets lies outside of the permissible operating envelope, it does not have to be shown in the graph.)

b. Injection pump manufacturer shall publish

1. Maximum horsepower that the injection pump absorbs
2. Fuel delivery ($mm^3$/stroke)
3. Peak injection pressure (bar)

at each critical test point in the pump specification.

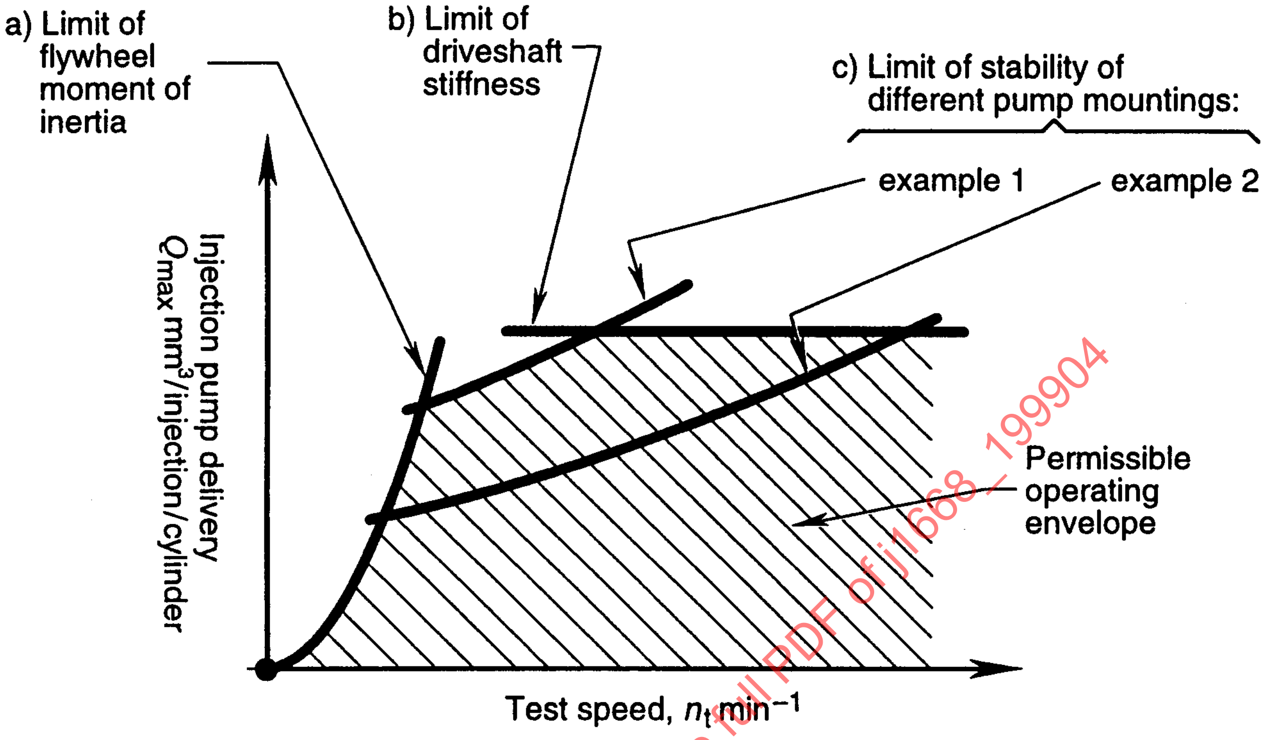


FIGURE 2—PERMISSIBLE OPERATING ENVELOPE



If horsepower is not specified, it can be approximated by Equation 6[1]:

$$HP = \frac{p_{pa} \times Q \times n \times 1.66 \times 10^{-9}}{\eta} \quad \text{(Eq. 6)}$$

where:

HP = Horsepower (kW)
$P_{pa}$ = Peak injection pressure (bar)
Q = Fuel delivery (including retraction volume) ($mm^3$/st)
n = Number of injections per minute
$\eta$ = 0.75 (accounting for pump efficiency and effect of retraction volume)

**3.10 Application and Use of Given Information—**Assume a 6-cylinder pump delivers 180 $mm^3$/st at 600 rpm with a peak injection pressure of 800 bar.

a. Step 1—Determine Corrected Fuel Delivery—From Figure 3, correction factor at 800 bar is 1.27 (800/628). Therefore, the corrected delivery will be 1.27 x 180 = 228.6 $mm^3$/st.

b. Step 2—Plot the point on the graph (Figure 2) where the corrected delivery (228.6 $mm^3$/st) intersects the speed (600 rpm). This must be within the operating envelope of the test bench (shaded area in Figure 2).

c. Step 3—Calculate power requirement.

1. Reference: Derived from a formula given in "Fuel Injection and Controls."

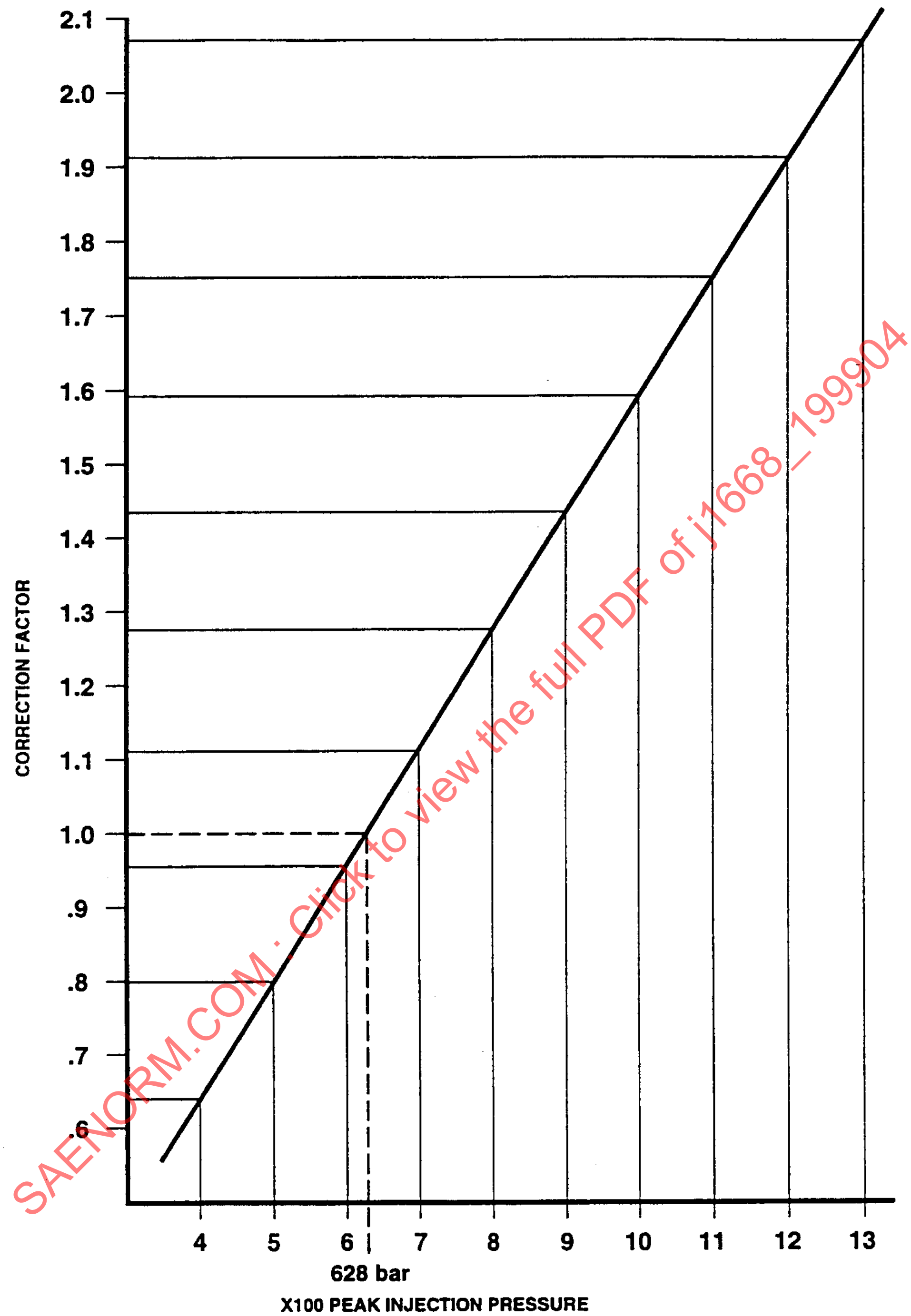




FIGURE 3—CORRECTION FACTOR FOR PEAK INJECTION PRESSURE

If not given by the pump manufacturer, calculate HP from Equation 6. In this case see Equation 7:

$$HP = \frac{800 \times 180 \times 3600 \times 1.66 \times 10^{-9}}{0.75} \quad \text{(Eq. 7)}$$

Plot this point on graph (Figure 1). It must lie below the dotted curved line for the test stand to be capable of running this particular pump.

## *4. Static Requirements*

**4.1 Delivery Measurement System—**The calibration fluid delivered from each test injector shall be routed to the device for measuring delivery and displaying it directly or by simple calculation as an average expressed in cubic millimeters per stroke per outlet.

There shall be provision for observing visually, or by other suitable means, the moment when flow from any of the test injectors stops.

4.1.1 METHOD OF TESTING THE PUMP DELIVERY MEASUREMENT SYSTEM—Each test bench make and model shall pass the acceptance test. This test shall consist of:

a. Type Test—To be performed on at least one sample test bench and is aimed at proving the capability of a design to achieve the desired accuracy; a sophisticated apparatus is required.

   Allowable error shall not exceed 1% if no specific instructions are given by the test stand manufacturer regarding graduate selection or stroke count; error shall not exceed 2% if instructions are given.

b. Field Test—To be performed periodically in the field on all test benches to ensure continued satisfactory operation; this test requires no special apparatus. Graduate zero error shall not exceed 0.5% of its maximum capacity. Count error shall not exceed one turn.

The complete test procedure for the Type and Field Tests are found in ISO 4008, Part 2, Annex A. An alternate and equally acceptable Type Test by weight method is described in Appendix A.

If graduates are used, the minimum pitch of graduations shall be at least 1 mm.

One graduation shall not be greater than 1% of the total volume. A certain number of graduations from zero upwards may be omitted.

If a digital display is used, then, at a minimum, fuel delivery shall be displayed in $mm^3$/st with a resolution of 0.1 $mm^3$/st.

**4.2 Calibration Fluid System—**The calibration fluid supply shall be at a flowrate of at least 2.5 times the delivery flow rate from the pump under test.

At any supply pressure over 0.3 bar, the maximum pressure fluctuation (from peak to peak) shall be no more than 5% of the reading with the supply connection capped off.

Calibration fluid temperature, as measured immediately behind the bulkhead supply connection, must be held to 40 °C ± 2 °C, irrespective of the pump demand.

The supply pipe shall be 1 m + 0.1 m long with an inside diameter of at least 9.5 mm.

a. Temperature measuring accuracy: ± 0.5 °C @ 40 °C
b. Filtration: according to ISO 4020-2
c. Calibration fluid heater, if installed, shall be designed so as not to cause breakdown of the fluid

**4.3 Other Requirements**

4.3.1 PRESSURE AND VACUUM MEASURING INSTRUMENTS

a. Accuracy: ANSI/ASME B40.1-1985 Grade A (2-1-2% FS) or better

4.3.2 DRIVESHAFT TACHOMETER

a. Analog: Not acceptable
b. Digital: Resolution 1 rpm
c. Accuracy: ± 1 digit

4.3.3 OUTPUT SHAFT ANGULAR MEASURING ARRANGEMENT

a. Resolution of angular readout: 1 degree max
b. Error between any two divisions: 15 min max
c. Datum mark shall not produce parallax error

## *5. Application and Equipment Maintenance Recommendations*

**5.1 Test Benches—**When a statement of ISO Test Condition is requested it shall conform with Annex E to ISO 4008, Part 3.

**5.2 Test Injectors—**All calibrating nozzle and holder assemblies conforming to the appropriate Standard must be accompanied by documentation (marking or labels in packaging) supplied by the manufacturer and vouching for their conformance to the document.

Other test injectors and nozzles may be specified in the appropriate pump test specifications.

For purposes of maintenance, a record shall be kept of the number of pumps tested with each test injector set.

For calibrating nozzle and holder assemblies and test injectors maintenance and servicing schedules, refer to Appendix B. It gives information on frequency of maintenance, testing procedure, recommended settings and limits for opening pressures, seat leakage, back leakage, and tightening torque values for nozzle retaining nuts and edge filter assembly (inlet studs).

### 5.3 Testing

5.3.1 TEST SCHEDULE—The test schedule shall contain all the necessary information and instructions necessary to set and test the pump in the field service environment.

It does not override a test bench manufacturer's instruction regarding a specific calibration system (for example, graduate drainage time, number of strokes over which to take a measurement, etc.).

5.3.2 TEST PROCEDURE—From the test plan, select the correct test injectors, pipes, mounting, and other accessories.

Ensure that the pump characteristics fit within the test bench operating envelope.

Operate the test bench according to its manufacturer's instructions. If none are available:

a. Graduates must be drained for 30 to 33 s.
b. Graduates must be filled to more than 50% of their capacity by selecting a suitable number of consecutive strokes.

PREPARED BY THE SAE DIESEL FUEL INJECTION EQUIPMENT STANDARDS COMMITTEE

## APPENDIX A

## ACCURACY TEST BY WEIGHT METHOD

***A.1 General***—The following test is designed to verify the accuracy of the test bench measuring system by the weight method. This test compares the fluid measured by the test bench measuring system (with graduates) with fluid measured by weight as delivered by a stable injection pump at controlled conditions. This method measures the weight of fluid delivered (in grams) over a large number of injection strokes. By knowing the fluid's specific gravity and temperature, the weight can be converted into volume and combined with the number of strokes, it can then be computed and expressed in cubic millimeters per stroke, which is the industry's basic unit for measurement of an injection pump delivery.

***A.2 Equipment Required***—See Table A1.

**TABLE A1—EQUIPMENT REQUIRED**

| Name | Description |
|---|---|
| Electronic Balance | Digital readout: 0 to 999.99<br>Capacity: 0 to 500 g<br>Resolution: 0.01 g<br>Precision: ±0.007 g<br>Error: 0.01 g |
| Glass Thermometer | Range: 15 to 40 °C (min)<br>Resolution: 0.1 °C |
| Cal. Fluid Temperature Measurement | Accuracy of measurement: ±0.5 °C<br>Calibrated @ 40 °C |
| Electronic Timer | Clock oscillator: 0.001 s/pulse<br>Accuracy: 0.01% |
| Tachometer/Counter | With preset count switch<br>Start/stop switch 0 to 999 rpm, 0 to 9999 counts<br>Accuracy: ±1 digit |
| Hydrometer | Specific gravity range: 0.760 to 0.830 g/cc<br>Resolution: 0.0005 (min) |
| Solenoid Valve | 3-way, 3/32 in orifice (min) |
| Glass Cylinder | Capacity: 250 mL ungraduated |
| Injection Pump | Inline single cylinder per SAE J1549(1) |
| Calibrating Nozzle Holders | SAE J968(1) |
| High Pressure Tubing | (Dependent on pump used) |
| Calibration Fluid | SAE J967 |

1. As an alternate an equally acceptable injection pump can be a fixed rack ("Reference Pump") and test injectors supplied for this purpose by the pump manufacturer.

***A.3 Preparation for Tests***—Withdraw a sample of calibration fluid from the test stand reservoir after some stirring and prior to operating the stand.

a. Set glass cylinder in an area where it will not be disturbed and temperature is fairly stable.

b. Immerse glass thermometer (or temperature sensor) and hydrometer into the glass cylinder.

c. Measure and record specific gravity and temperature ($SG_x$ and $t_x$ respectively) after the calibration fluid has soaked at a stable ambient temperature for a minimum of 6 h. Record temperature to a resolution of 0.1 °C and specific gravity to a resolution of 0.0005.

d. Connect plumbing and electrical connections according to Figure A1.

e. Mount injection pump on the stand using accessories in accordance with the test stand manufacturer's instructions.

f. Connect cable of digital tachometer in parallel with the test stand's pickup. If stand does not have any pickup (magnetic, optical, or other) one must be installed in order to obtain a digital display of test stand rpm and stroke counts.

g. Connect plastic tubing from solenoid valve port B to test stand reservoir (return flow).

h. Connect timer and switch in the circuit as shown and connect to wall outlet.

i. With the pump running and discharging fluid to port A of the de-energized solenoid valve, the fluid is routed through port B to the reservoir.

j. Reset scale display to read zero (see scale manufacturer's instructions).

k. Place empty and dry container on scale.

l. Preselect number of strokes on the stroke counter.

m. Press reset button on electronic timer.

***A.4 Test Schedule***—Operate injection pump at speeds, delivery settings, and with Calibrating Nozzle Holders of orifice sizes at speed settings and deliveries as shown in SAE J1549. At each speed setting the test shall be conducted first by routing the fluid to the graduate in the test stand and then to the container for measuring its weight. If design permits, switch fluid routing from the test stand graduate to the fluid weighing apparatus while pump is operating. As a single-cylinder pump is used, each graduate must be tested separately.

***A.5 Test Procedure***—Operate the stand, in accordance with test stand manufacturer's instructions, running the pump at 500 rpm to stabilize calibration fluid temperature and to warm up the complete system.

At each speed and orifice size combination run pump for a minimum of 10 min and then take readings. Take always three readings of graduates and calculate average. If the three readings are not within 0.5 cc there must be a problem with one or more of the following: test stand, pump, injector, or high-pressure fuel line. Correct the problem before continuing. Allow equal time to drain graduates (30 to 35 s). Read graduates as soon as foam disappears, if any.

To operate the fluid weight measuring apparatus (mass flow measuring device) refer to Figure A1.

When ready to take a reading, press start switch. This will simultaneously energize solenoid valve, start routing fluid into container on scale, start stroke counter, and start electronic timer.

At the start of the test, record temperature (t) of calibration fluid entering the container.

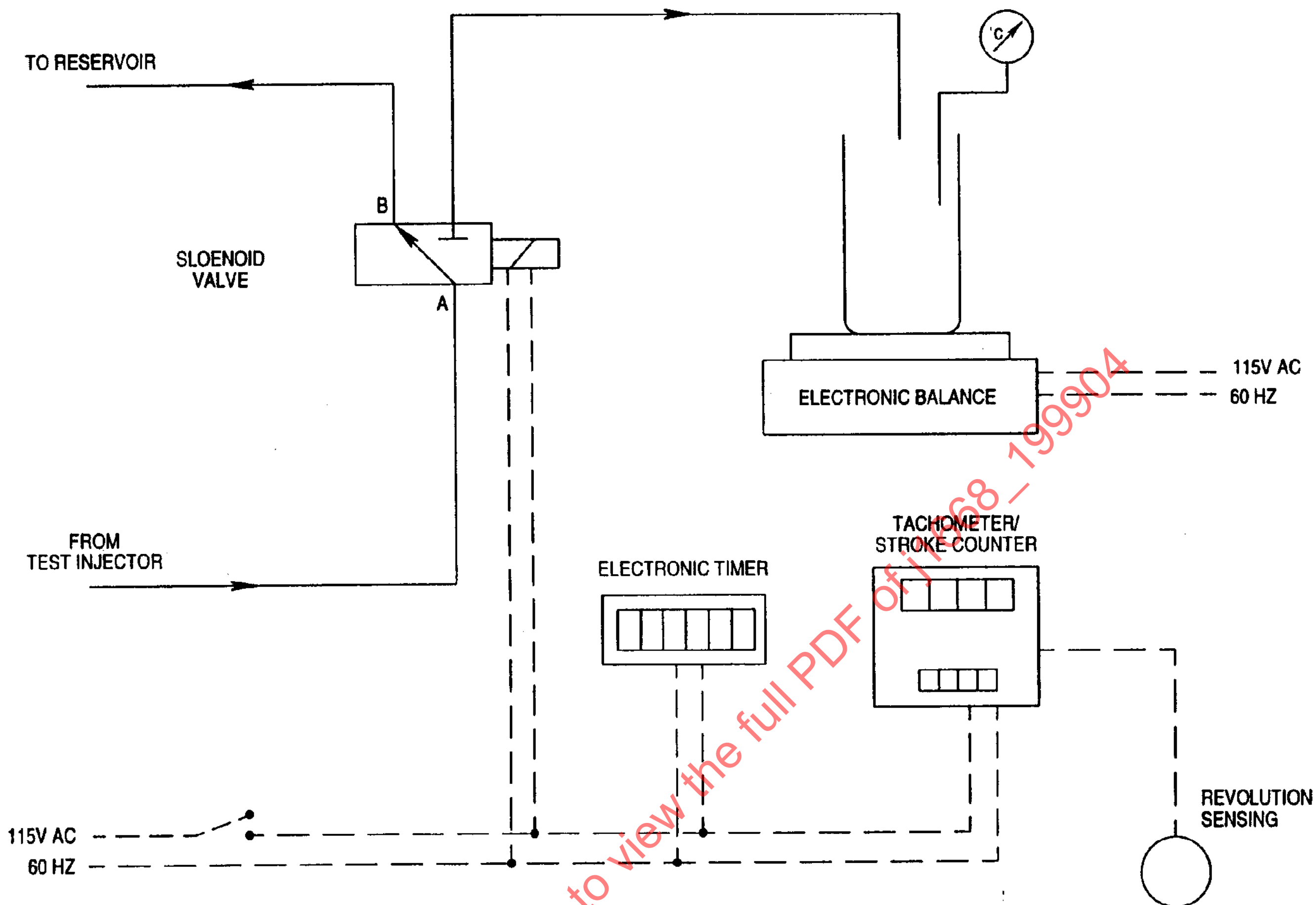




FIGURE A1—BLOCK DIAGRAM TEST SET UP—ACCURACY BY WEIGHT METHOD

After the preselected number of strokes is achieved, solenoid valve will de-energize, fluid will be diverted to the reservoir, electronic timer will stop and scale display will indicate weight. Record weight, the final fluid temperature (if different from before) and reading on electronic timer.

The previous tests must be performed with each graduate.

To calculate true or "absolute" fuel delivery as measured by the scale, use Equation A1:

$$Q_a = \frac{W \times 1000}{SG \times N} \qquad \text{(Eq. A1)}$$

where:

$Q_a$ = Delivery $mm^3/st$
W = Weight in grams
SG = Specific gravity g/cc at temperature (t)
N = Number of strokes

NOTE—To find specific gravity (SG) at temperature (t), use either a graph showing specific gravity change with temperature (available from the supplier of calibration fluid) or use Equation A2:

$$SG = SG_x - 0.00037(t - t_x) \qquad \text{(Eq. A2)}$$

where:

SG = Specific gravity g/cc at temperature (t)
$SG_x$ = Specific gravity g/cc at temperature ($t_x$)
$t_x$ = Temperature at which $SG_x$ was measured

0.00037 is the typical coefficient of cubic expansion for calibration fluid.

To verify rpm use Equation A3:

$$RPM_c = \frac{N \times 60}{T} \qquad \text{(Eq. A3)}$$

where:

$RPM_c$ = Calculated rpm
N = Number of strokes
T = Time in seconds

NOTE—Fill graduates to about 80% of capacity, by selecting the appropriate number of strokes but within capacity of the scale.