SURFACE VEHICLE RECOMMENDED PRACTICE	J2311™	NOV2020
	Issued 1999-01 Revised 2020-11 Superseding J2311 MAR2015	

Automatic Transmission Hydraulic Pump Test Procedure

RATIONALE

This document has been revised for clarification of test methods and to support advances in automatic transmission pump technology.

1. SCOPE

This SAE Recommended Practice provides a method to determine the performance characteristics of the hydraulic oil pumps used in automatic transmissions and automatic transaxles. This document outlines the specific tests that describe the performance characteristics of these pumps over a range of operating conditions and the means to present the test data. This document is not intended to assess pump durability.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, 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 J311 Fluid for Passenger Car Type Automatic Transmissions

SAE J1165 Reporting Cleanliness Levels of Hydraulic Fluids

SAE J1276 Standardized Fluid for Hydraulic Component Tests

2.1.2 ISO Publications

Copies of these documents are available online at http://webstore.ansi.org/.

ISO 1219-1 Fluid Power Systems and Components - Graphical Symbols and Circuit Diagrams - Part 1: Graphical Symbols for Conventional Use and Data-Processing Applications

ISO 1219-2 Fluid Power Systems and Components - Graphical Symbols and Circuit Diagrams - Part 2: Circuit Diagrams

ISO 4406 Hydraulic Fluid Power - Fluids - Method for Coding the Level of Contamination by Solid Particles

ISO 4409 Hydraulic Fluid Power - Positive-Displacement Pumps, Motors and Integral Transmissions - Methods of Testing and Presenting Basic Steady State Performance

ISO 4412-1 Hydraulic Fluid Power - Test Code for Determination of Airborne Noise Levels - Part 1: Pumps

ISO 4412-3 Hydraulic Fluid Power - Test Code for Determination of Airborne Noise Levels - Part 3: Pumps - Method Using a Parallelepiped Microphone Array

NFPA T2.6.1.R2 Method for Verifying the Fatigue and Static Pressure Ratings of the Pressure Containing Envelope of a Metal Fluid Power Component

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.2.1 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 J745 Hydraulic Power Pump Test Procedure

SAE J1116 Categories of Off-Road Self-Propelled Work Machines

3. DEFINITIONS

3.1 ACTUAL CAPACITY

Measured output flow at prescribed conditions of pressure, speed, and temperature. It is actual flow rate delivered from the pump discharge port while operating at the prescribed conditions.

3.2 ACTUAL DISPLACEMENT

See 3.24.

3.3 ACTUAL TORQUE

The measured input torque required to operate the pump at prescribed conditions of pressure, temperature, and speed. It includes frictional losses.

3.4 AERATION

The mixing beyond the solution point of gas and fluid so as to provide a fluid medium having two distinct phases, namely one liquid, and one gaseous.

3.5 AIRBORNE NOISE

Pressure fluctuation of the ambient air surrounding a vibrating element, the magnitude of the pressure fluctuations being sufficient for the human ear to sense sound.

3.6 AXIAL THRUST CAPACITY

The maximum externally applied force applied to the pump assembly allowable without negatively affecting performance. It may be applied to the housing which carries the force to ground or applied to the input shaft which transmits the force to the pumping elements.

3.7 BULK MODULUS

The reciprocal of compressibility. A measure of fluid “stiffness,” expressed in pressure units, defined as Differential Pressure/(Initial Volume - Final Volume).

3.8 CAVITATION

The formation of bubbles or vapor “cavities” in liquid when the local static pressure is reduced to below the fluid vapor pressure.

3.9 CAVITATION NOISE

The audible noise caused by the collapse of fluid vapor or entrained air upon pressurization.

3.10 CRITICAL INLET

That operating condition of constant speed, inlet temperature and decreasing suction pressure that result in less than complete filling of the pumping chamber.

3.11 DIRECTION OF ROTATION

When viewed from the pump drive shaft end, the clockwise (right hand) or counterclockwise (left hand) rotation of the shaft that produces discharge from the discharge port.

3.12 DISCHARGE PRESSURE

The static pressure at the pump discharge port, downstream of the confluence of all pumping chambers.

3.13 ENTRAINED AIR (AIR ENTRAINMENT)

The result of aeration. The mixture of undissolved gas, usually air, beyond the solution point, usually expressed in percent air by volume.

3.14 EROSION

The damage, loss of material, or permanent deformation of pressure containing surfaces as the result of collapsing bubbles, either from aeration or cavitation.

3.15 FLUID BORNE NOISE

The oscillations of fluid static pressure resulting from fluid disturbances due to discharging pump chambers, standing waves, oscillating valves, or other disturbances.

3.16 HEAD LOSS

A loss in total energy of a fluid in motion, usually the result of frictional losses in conduits, but often includes component losses (orifices, valves, etc.) and energy loss from work exerted on the system. Also known as “pressure drop.”

3.17 HIGH-SPEED FILL LIMIT

The rotational speed at which the pump delivery/speed curve diverges from theoretical. It is differentiated from “critical inlet” in that the inlet port is unrestricted. The divergence results from the inability of the available inlet energy to accelerate the inlet fluid to a velocity equal to the moving pump inlet chambers. “Theoretical HSFL” is calculated assuming no inlet losses.

3.18 HYDRAULIC OUTPUT POWER

The fluid power, expressed in watts, available to do useful work. See Equation 1.

$$P_{out} = \frac{Q_a \times (p_d - p_i)}{60} \quad \text{(Eq. 1)}$$

3.19 INLET PRESSURE

The static pressure at the pump inlet port upstream of the pumping chambers.

3.20 LEAKDOWN RATE

The rate, expressed in time units, that characterizes the ability of a pump assembly with all ports closed and sealed to maintain a vacuum above a specified level. A measure of air infiltration.

3.21 MAXIMUM RATED PRESSURE

The maximum functional discharge pressure, excluding tolerances and pulsation, the pump is designed to operate at continuously for a specified period.

3.22 MAXIMUM RATED SPEED

The maximum input speed the pump is designed to operate at continuously for a specified period.

3.23 MAXIMUM RATED TEMPERATURE

The maximum fluid temperature at the pump inlet that the pump is designed to operate continuously for a specified period.

3.24 MEASURED DISPLACEMENT

The measured amount of volume displaced through one revolution by a positive displacement pump. The measured displacement does not include any losses for internal pump leakage. May also be known as “actual displacement.”

3.25 MECHANICAL EFFICIENCY

The ratio, expressed in percent, of potential torque to actual torque. See Equation 2.

$$E_m = \frac{T_p}{T_a} = \frac{D_m \times (p_d - p_i)}{(2 \times \pi \times T_a)} \times 100\% \quad \text{(Eq. 2)}$$

3.26 MECHANICAL INPUT POWER

The mechanical (shaft) power, expressed in watts, consumed by the pump. See Equation 3.

$$P_{in} = \frac{T_a \times N \times 2 \times \pi}{60} \quad \text{(Eq. 3)}$$

3.27 OVERALL EFFICIENCY

The ratio, expressed in percent, of output power to input power. See Equations 1, 4, and 5.

$$E_o = \frac{P_{out}}{P_{in}} \times 100\%$$ (Eq. 4)

Where fluid or hydraulic output power is expressed, in watts, as shown in Equation 1, and mechanical input power is expressed, in watts, as shown in Equation 3.

3.28 OVER PRESSURE RATING

The maximum discharge pressure the pump is expected to endure without permanent damage. After exposure to this condition, and upon return to operation within designed maximum ratings (see 3.21 through 3.23), all performance requirements must be met.

3.29 OVER SPEED RATING

The maximum input speed the pump is expected to endure without permanent damage. After exposure to this condition, and upon return to operation within designed maximum ratings (see 3.21 through 3.23), all performance requirements must be met.

3.30 OVER TEMPERATURE RATING

The maximum inlet temperature the pump is expected to endure without permanent damage. After exposure to this condition, and upon return to operation within designed maximum ratings (see 3.21 through 3.23), all performance requirements must be met. See Figure 1.

3.31 POTENTIAL CAPACITY

The potential output flow at a given speed, expressed in L/min. It is a function of the measured displacement, D_m, and input speed, N. It assumes 100% volumetric efficiency and differs from theoretical capacity only in the use of measured displacement versus theoretical displacement. See Equation 5.

$$Q_m = \frac{D_m \times N}{1000}$$ (Eq. 5)

3.32 POTENTIAL TORQUE

The torque required to rotate the pump input shaft due to a specified pressure rise between pump inlet and discharge ports. It is a function of measured displacement, D_m, and differential pressure, and does not include frictional losses. See Equation 6, expressed in Nm.

$$T_p = (p_d - p_i)\,\frac{D_m}{2 \times \pi \times 1000}$$ (Eq. 6)

3.33 POWER LOSS

The power lost by the pump, usually in the form of heat, expressed in watts. It is the difference between input and output power. See Equation 7.

$$P_l = P_{in} - P_{out}$$ (Eq. 7)

3.34 PRESSURE RIPPLE

The peak-to-peak amplitude of fluid pressure oscillations.

3.35 PUMP DELIVERY

The measured flow rate from the discharge port at a specified gauge pressure, inlet temperature, and input speed. See 3.1.

3.36 RADIAL BEARING CAPACITY

The maximum permitted force applied to the pump support bearing, defined as a radial force at a specified speed and duration.

3.37 RATED FATIGUE PRESSURE

That pressure which the pressure containing envelope can sustain for 10×10^6 cycles without failure, defined as any fracture, crack, excessive seal leakage caused by deformation, or any permanent deformation which interferes with related component function.

3.38 SLIP FLOW

The difference between pump delivery (actual flow) and potential capacity, usually referred to as “internal leakage.” In the absence of a measured displacement, the difference between pump delivery (actual flow) and theoretical capacity.

3.39 SOUND POWER

The measure of total sound energy radiated from a theoretical point source, expressed in decibels.

3.40 TARE TORQUE

The torque required to overcome bearing and seal drag, and is not a component of the lost work due to pumping mechanism inefficiency. Typically included in pump assembly measurements to ascertain total power draw.

3.41 THEORETICAL CAPACITY

The theoretical output flow at a given speed, expressed in L/min. It assumes 100% volumetric efficiency, is independent of discharge pressure, and is a function of theoretical displacement and input speed, N, similar to Equation 5.

3.42 THEORETICAL DISPLACEMENT

The calculated volume displaced by the pump mechanism in one rotation. It is derived from the geometry of the pumping mechanism and assumes 100% volumetric efficiency.

3.43 THEORETICAL TORQUE

The torque required to rotate the pump input shaft due to a specified pressure rise between pump inlet and discharge ports. It is a function of theoretical displacement rather than measured displacement, D_m. See Equation 6.

3.44 TORQUE RIPPLE

The peak-to-peak amplitude of torsional oscillations measured at the pump input shaft.

3.45 VOLUMETRIC EFFICIENCY

The ratio, expressed in percent, of pump delivery to potential capacity. In the absence of a measured displacement, potential capacity may be replaced with theoretical capacity. See Equation 8.

$$E_v = \frac{Q_a}{Q_p} \times 100\% \tag{Eq. 8}$$

4. SYMBOLS

E_m = Mechanical efficiency (%)

E_o = Overall efficiency (%)

E_v = Volumetric efficiency (%)

Q_t = Theoretical capacity (L/min)

Q_a = Actual capacity (L/min)

Q_p = Potential capacity (L/min)

D_m = Measured displacement - (actual displacement) (cc/rev)

N = Pump rotational speed (rpm)

P_{out} = Hydraulic power output (W)

P_{in} = Mechanical power Input (W)

P_l = Power loss (W)

T_t = Theoretical (input) torque (Nm)

T_a = Actual (input) torque (Nm)

T_p = Potential (input) torque (Nm)

p_i = Pump inlet pressure (kPa)

p_d = Pump discharge pressure (kPa)

W = Power units (W)

L/min = Flow rate units (L/min)

Nm = Torque units (Nm)

4.1 Symbols in Figures 2A to 2C

M = Motor

P|1 = Discharge pressure

P|2 = Inlet pressure

T|1 = Sump temperature

T|2 = Inlet temperature

RV1 = Relief valve 1

SORV1,2 = Solenoid-operated directional valve 1 and 2, respectively

TV1,2,3,6 = Throttle valve or variable orifices 1, 2, 3, and 6, respectively

SOVA, B = Shut-off valve A and B, respectively

FM1 = Flow meter 1

S1 = Input speed sensor

TQ = Torque meter

TR = Temperature regulator

5. TEST PREPARATION

During installation of the pump into a mounting fixture, special attention should be focused on properly aligning the pump, torque transducer, and drive motor. These component centerlines should be aligned to within 0.025 mm (0.001 inch) or within "pump design sheet" (see Figure 1) requirements, whichever is more restrictive. Final alignment must be verified, and documented in accordance with laboratory practice approved by customer.

5.1 Material and Apparatus

5.1.1 Test Fluid

Test fluid and properties shall be as specified by the customer or per SAE J1276. The fluid must be identified on the pump build sheet, test data sheets, or laboratory log. Fluid properties must be included in any report.

5.1.2 Reservoir

The inlet circuit should include a sight glass to verify no visible air is in the inlet stream. To minimize aeration, returning fluid from all circuits other than atmospheric drain lines shall enter the reservoir at a point below the surface of the fluid and shall be diffused in such a manner as to minimize turbulence in the reservoir. Include a "re-circulation circuit" to minimize inlet losses if the application provides such a feature. See Figures 2A through 2C.

Filtration shall be provided to maintain fluid cleanliness level, as defined by SAE J1165, within the pump manufacturer's recommendations. The test circuit and reservoir shall be configured to replicate as closely as practical the characteristics of the given application, e.g., inlet pressure drop, velocity, etc. See Figure 1. The pump design sheet must accompany each test specimen model.

A temperature probe shall be placed as close as practical to the inlet strainer and within the stream lines of the inlet flow to record inlet fluid temp.

Appropriate fluid conditioning and auxiliary circuits must be installed to control temperature and cleanliness. The system may be designed to also provide hydraulic signals for integral pump controls. See Figures 2A through 2C.

Pump Design Sheet		
Parameter	**Units**	**Design Requirement**
Ratings		
Pump Theoretical Displacement	CC/rev	
Theoretical High Speed Fill Limit	RPM	
Rated Fatigue Pressure	kPa	
Rated Sound Power (@ tbd RPM, tbd kPa)		
Rated External Radial Load	N	
Rated Axial Thrust Load	N	
Max Rated Speed	RPM	
Min Rated Speed (idle)	RPM	
Max Overspeed	RPM	
Max Rated Pressure	kPa	
Max Overpressure	kPa	
Min Inlet Pressure	kPa	
Max Rated Inlet Temperature	°C	
Max Inlet Over Temperature	°C	
Min Flowrate (@ tbd RPM, tbd kPa)	lpm	
Operating Environment		
Fluid Cleanliness Level (ISO code)		
Drive alignment		
Max Angular Error	Degrees	
Min Offset Error	mm	

Figure 1 - Pump design sheet

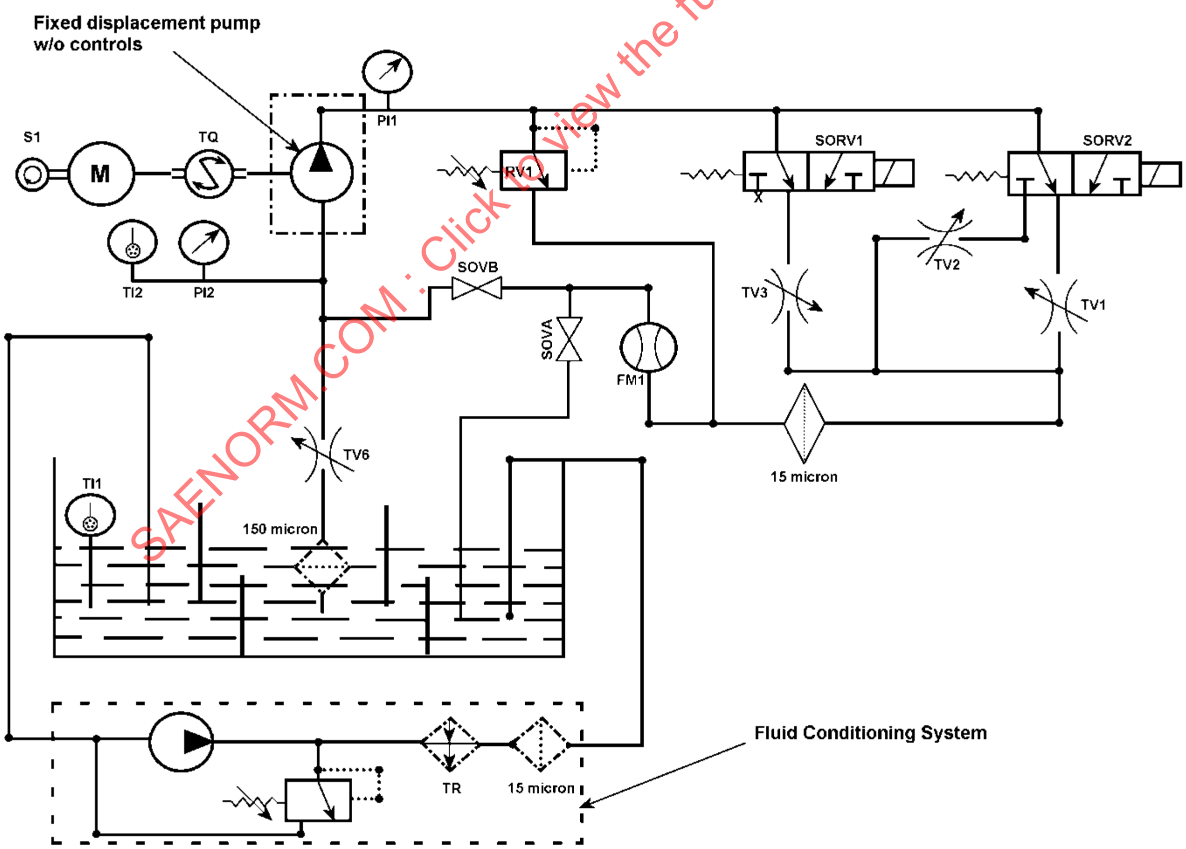

Figure 2A - Test circuit - fixed displacement pump

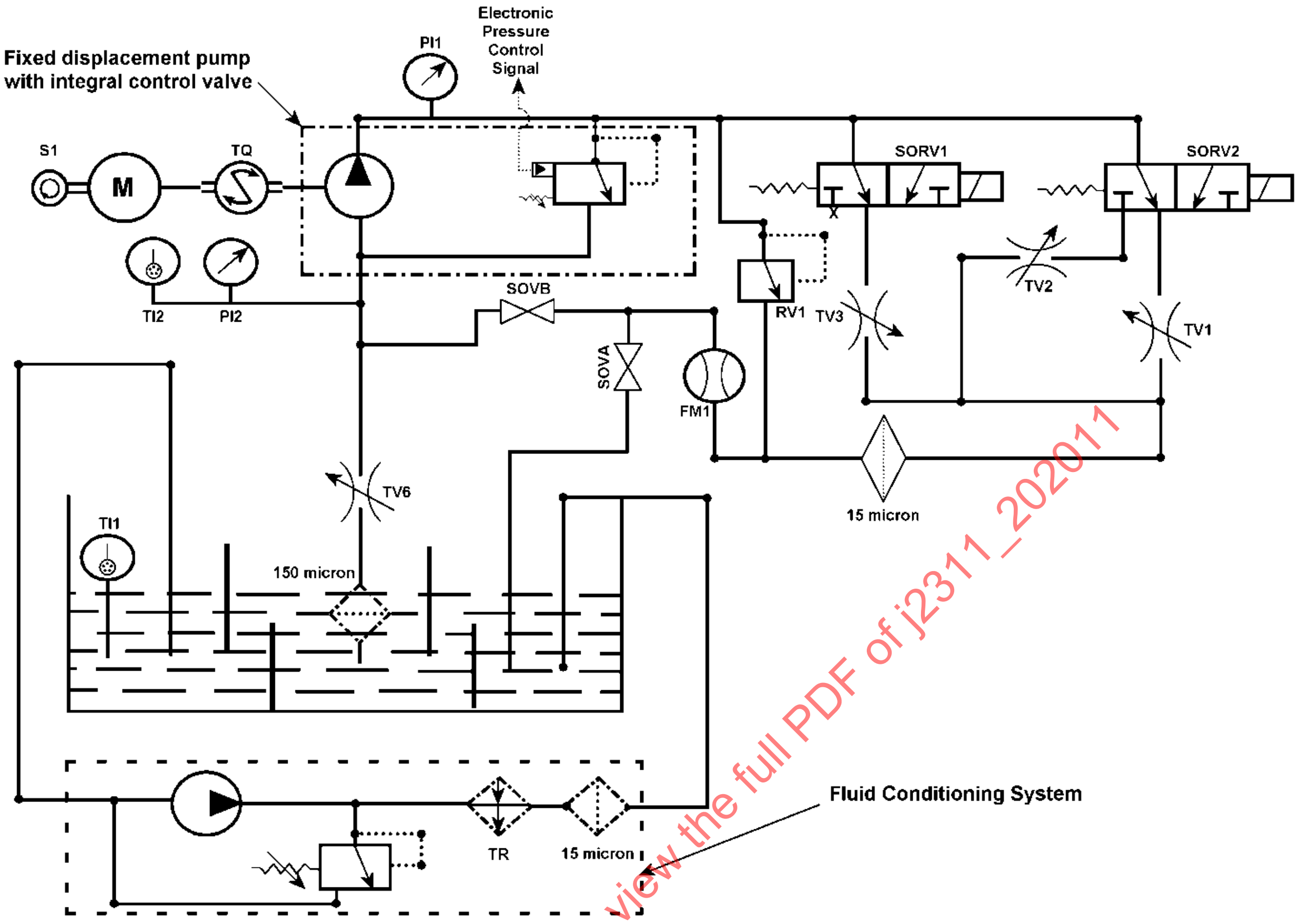

Figure 2B - Test circuit - fixed displacement pump with integral pressure control

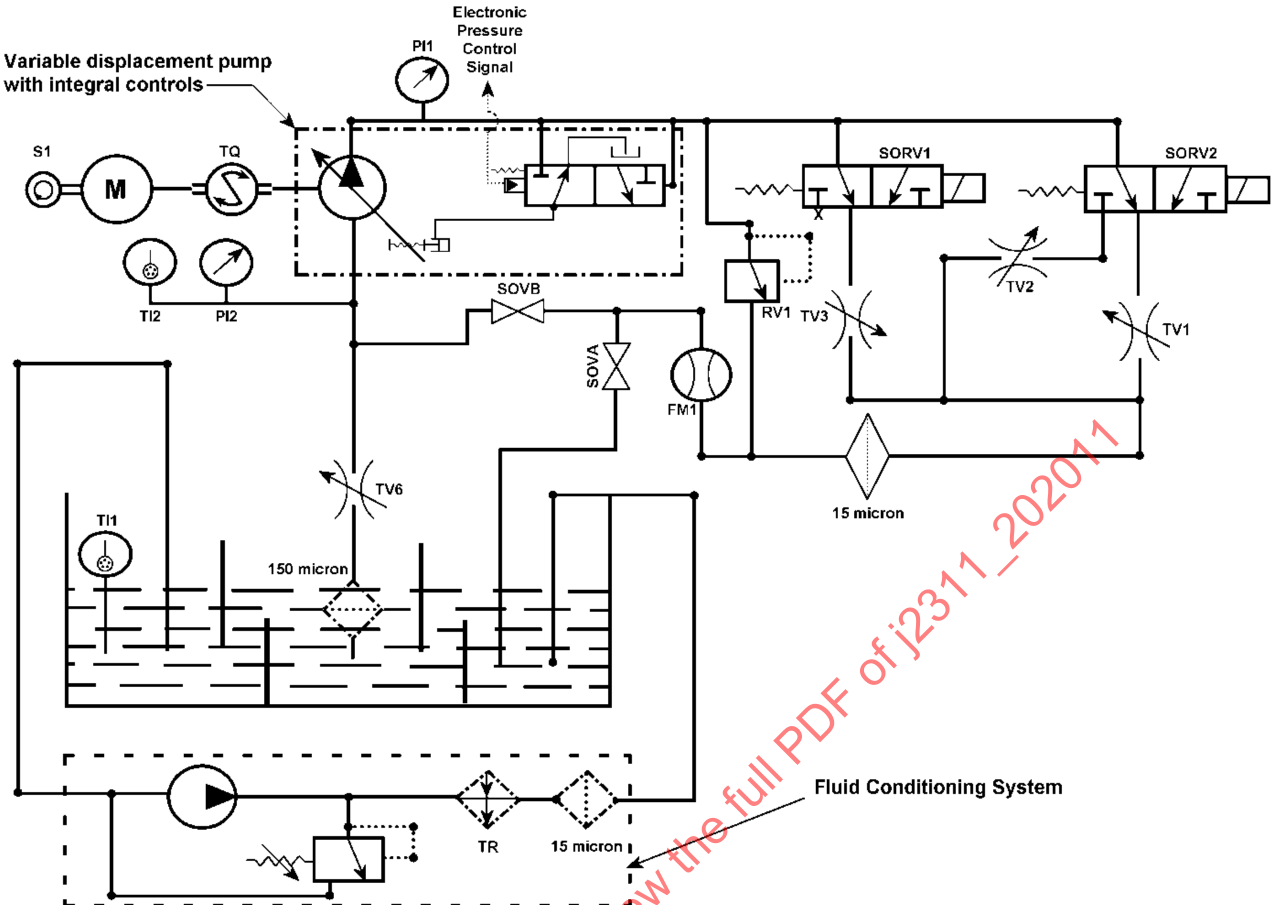

Figure 2C - Test circuit - variable displacement pump with integral pressure compensator (main pressure regulator) control

5.1.3 Data Acquisition Equipment

Verify calibration of all data acquisition equipment and record in test log or data sheet. Install instrumentation sufficient to obtain the data in Table 1:

Table 1 - Data acquisition equipment

Data	Units	Calibration Range
Input shaft speed	rpm	0-8000
Input torque	Nm	0-60
Discharge flow, low-range	L/min	0.1-50
Discharge flow, high-range	L/min	5-200
Discharge pressure, low range	kPa	0-700
Discharge pressure, high range	kPa	0-3500
Pressure control signal	kPa	0-700
Boost pressure signal	kPa	0-3500
Inlet temperature	°C	0-150
Response	real time	DC-2 kHz

NOTE: Some transmission applications may require different calibration ranges. See Figure 1.

5.1.4 Accuracy

Conduct pump testing while maintaining the control and measurement accuracy shown in Table 2:

Table 2 - Instrumentation accuracy

Parameter	Accuracy	Instrumentation
Torque	±1%	Measure only
Pressure	±1%	Measure and control
Speed	±1%	Measure and control
Temperature	±3 °C	Measure and control
Flow Rate	±1%	Measure only

NOTE: The manufacturer or customer needs may require refinement in the accuracy of one or more parameters. Any deviations from the latter requirements must be noted.

5.2 Pre-Test

The inlet restriction as shown in Figures 2A through 2C should be adjusted to match the pressure drop that replicates the functional pressure drop as installed in the application. The inlet supply to the pump assembly should include an inlet screen/filter that replicates the production intent or application. Any inlet condition not so arranged must be detailed on the pump data sheet, the build sheets, or laboratory test log.

5.2.1 Pump Build Sheet

All test units should have a pre-build inspection completed that verifies the actual build dimensions and geometry. See Figures 3A through 3E for examples.

Gear Pump Build Sheet		
Pump Identification:		
Inspected by:		
Date of Inspection:		
	Measurement	**Method**
Pocket Depth:		
Pocket Flatness:		
Pocket OD:		
Rotor, Inner, Major Diameter:		
Rotor, Inner, Minor Diameter:		
Rotor, Inner, Thickness:		
Rotor/Pocket Clearance, Inner:		
Rotor, Outer, Major Diameter:		
Rotor, Outer, Minor Diameter:		
Rotor, Outer, Thickness:		
Rotor/Pocket Clearance, Outer:		
Rotor/Pocket OD Clearance, Outer:		
Tip Clearance (Gerotor Type)		
Inner Tip Clearance to OD (crescent type):		
Outer Tip Clearance to ID (crescent type):		
Eccentricity:		

Figure 3A - Pump build sheet

Vane Pump Build Sheet		
Pump Identification:		
Inspected by:		
Date of Inspection:		
	Measurement	Method
Pocket Depth:		
Pocket Flatness:		
Cover Flatness		
Rotor OD:		
Rotor Slot Width:		
Rotor Thickness:		
Rotor/Pocket Clearance:		
Vane Height:		
Vane Length:		
Vane Thickness:		
Vane/Rotor Slot Clearance:		
Vane/Pocket Clearance:		
Bore Ring ID:		
Bore Ring Thickness:		
Bore Ring to Pocket Clearance:		
Eccentricity:		
Support Ring Diameter:		
Vane to Bore Clearance:		

Figure 3B - Pump build sheet (vane pump)

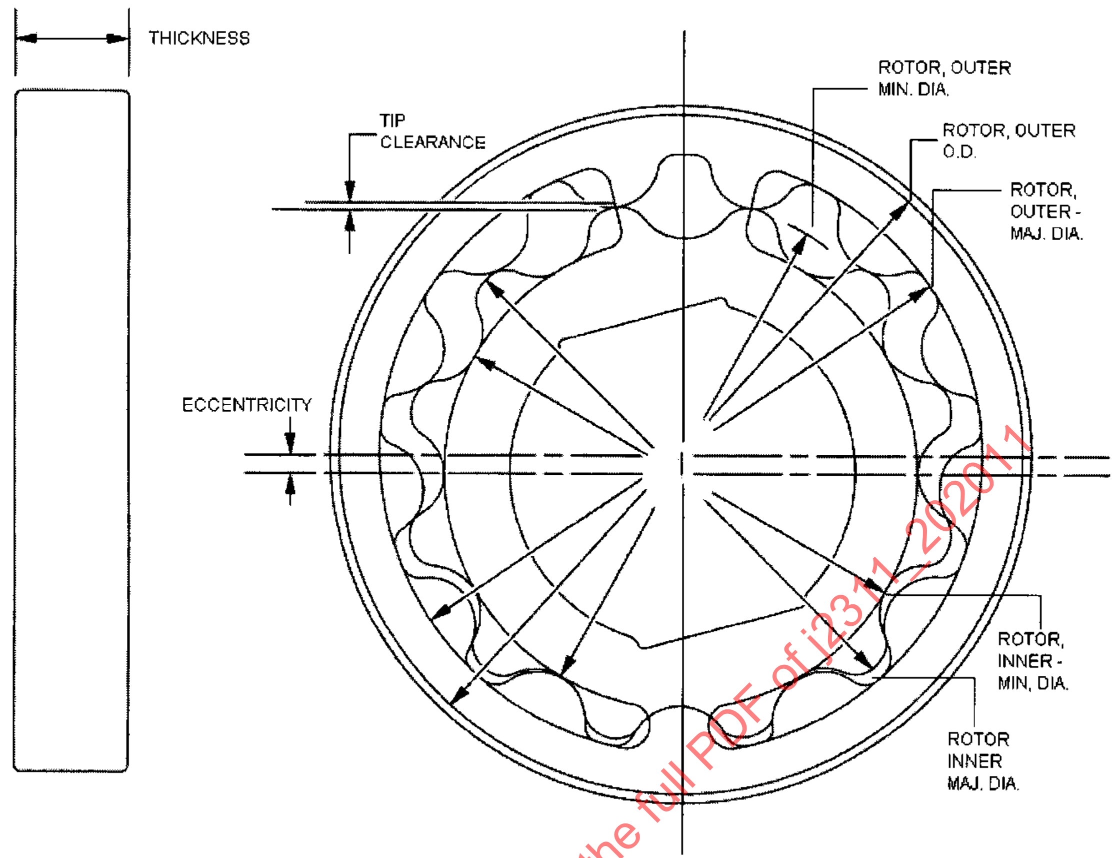

Figure 3C - Gear pump rotor build parameters

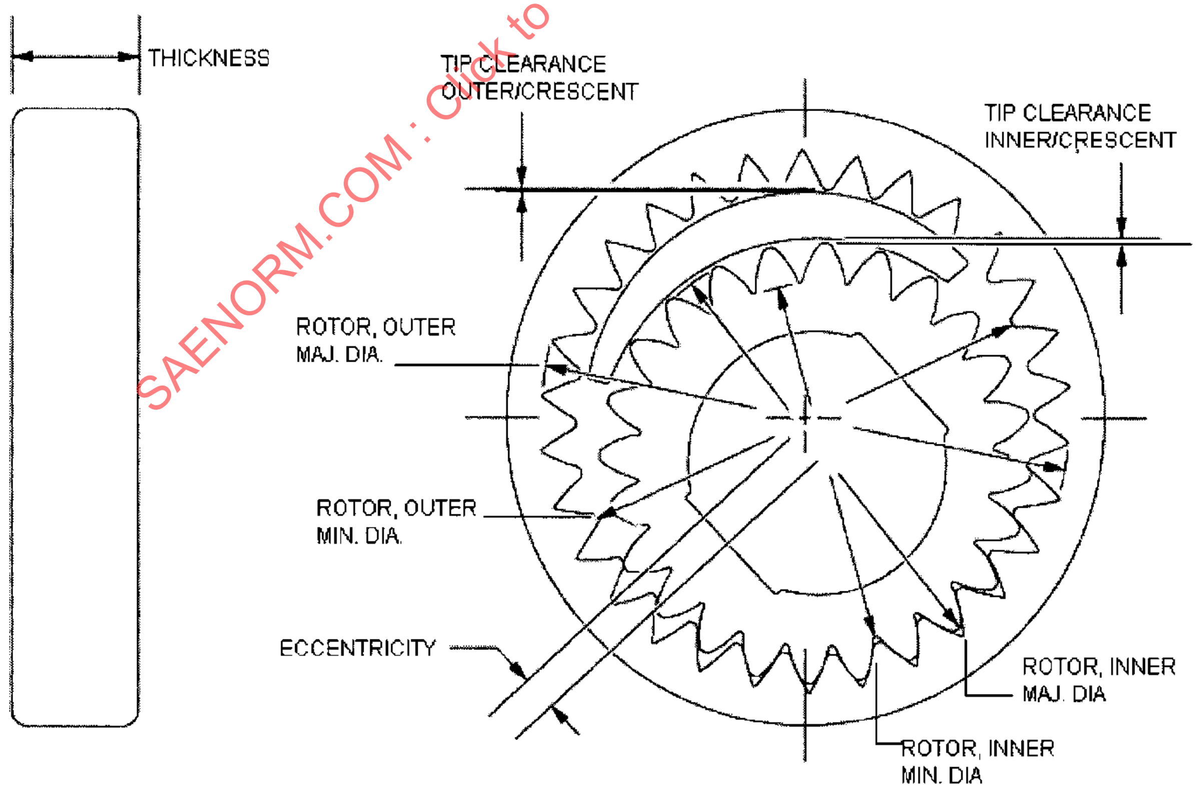

Figure 3D - Crescent gear build parameters

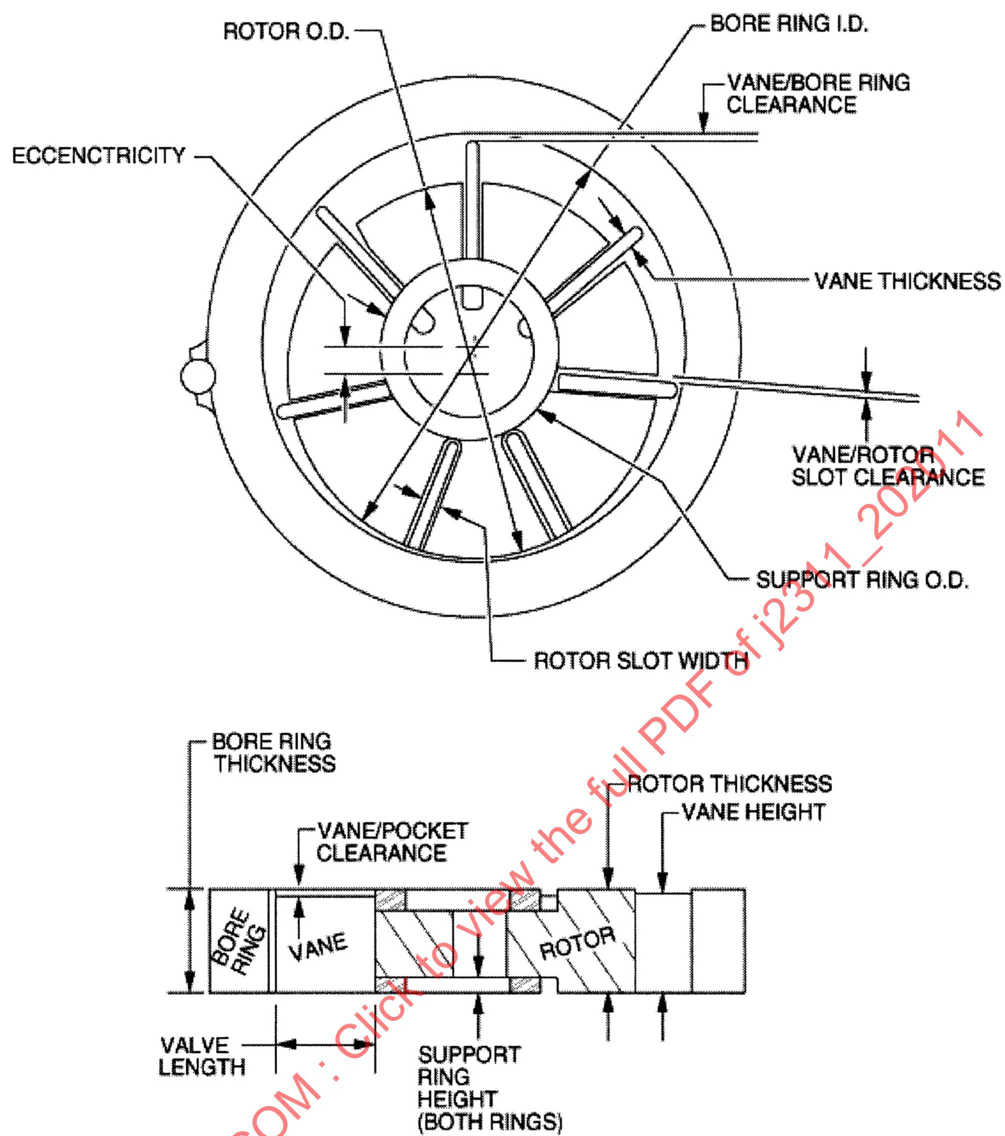

Figure 3E - Variable vane build parameters

5.2.2 Pre-Conditioning (Optional)

New pump assemblies (less than 0.5 hour of logged operation) should be conditioned by operating the pump at the specified conditions shown. Record pump speed, flow, torque, discharge pressure, and inlet temperature. When complete, tear down pump, and visually inspect components for distress.

After the pump is properly conditioned, it should be operated at condition #6.) in Table 3 for 30 minutes, during which time the torque should be monitored. If the torque remains stable and does not deviate by more than 5%, the pump may be considered sufficiently conditioned for testing.

Table 3 - Preconditioning operating conditions

	Time (min)	Speed (rpm)	Discharge Pressure (kPa)	Inlet Temp (°C)
1	5	500	350	20 ± 02
2	5	1000	700	35 ± 10
3	5	1400	700	50 ± 10
4	5	1400	1000	60 ± 10
5	10	1800	1000	80 ± 10
6	10	1800	1400	90 ± 02

5.2.3 Measured Displacement

The calculation for volumetric efficiency requires the measured displacement of the pump be used. This value should be determined empirically. Use a complete pump assembly that has successfully completed pre-conditioning. Operate the pump in a test circuit similar to that illustrated in Figures 2A through 2C at the conditions listed in Table 4. Record pump speed, discharge flow, and discharge pressure. Divide the measured flow by the indicated speed to determine the “measured displacement.” A graphical or linear regression analysis can be used to determine the “actual displacement” or “measured displacement” at zero discharge pressure.

Table 4 - Measured displacement test

Input Speed (rpm)	Discharge Pressure (kPa)	Inlet Temperature (°C)
400, 700, and 1000	175, 350, and 525	30 °C ± 3 °C

5.2.4 Tare Torque

Lubricate input drive shaft seal with manufacturer-specified lubricant. Install the test pump assembly (without displacement mechanism; e.g., gears, vanes, rotors) on the mounting adapter. Apply test fluid at 14 to 35 kPa to seal and/or shaft bearing drain and verify flow. The bearing and seal must be supplied with lubricant in a manner that replicates the quantity (flow rate) and pressure of in-service use. With the assembly firmly bolted to the adapter, increase the input drive shaft speed from 500 to maximum rated speed in 500 rpm increments. Record speed and torque. Complete this procedure three times. Stop the drive between runs and verify transducer error or drift and compensate accordingly.

6. PERFORMANCE TESTS - FIXED AND VARIABLE DISPLACEMENT PUMPS

6.1 High-Speed Fill Limit (HSFL)

With discharge pressure and inlet oil temperature held constant, accelerate the pump from “idle” (minimum rated speed, or 1000 rpm, whichever is less) at a steady rate not to exceed 1500 rpm/min to maximum rated speed. Record the output flow versus speed continuously. Complete this procedure for discharge pressures of 850 kPa and 1550 kPa, and inlet temperatures of 35 °C and 90 °C; total of four curves. The point at which the delivery curve diverges from a parallel to the theoretical flow is the high-speed fill limit (HSFL). See Figure 4.

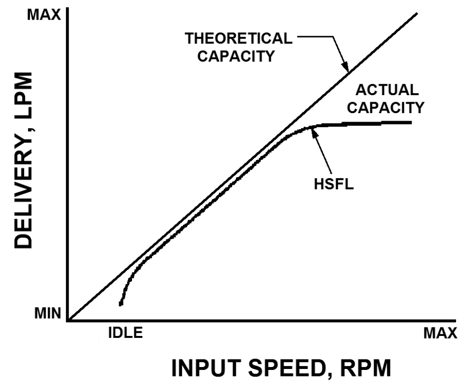

Figure 4 - Typical HSFL curve fixed displacement pump

6.2 Critical Inlet

With test conditions set to conditions listed in Table 5, throttle the pump inlet at a rate no faster than 70 kPa/min until delivery is reduced by 50% or inlet pressure reaches 500 mm Hg (vacuum). Record inlet pressure versus pump delivery. See Figure 5.

Table 5 - Critical inlet and auto prime test conditions

Speed	Discharge Pressure (kPa)	Inlet Temperature (°C)	Pump Delivery
Idle (or 1000 rpm, whichever is lower) (for auto-prime, accelerate to idle at 500 to 750 rpm/s)	350, 1200, and 1900	35, 90, and 135	Full delivery (fixed units)
1500 rpm and 2500 rpm (for auto-prime, accelerate to speed at 1000 to 1500 rpm/s)	350, 1200, and 1900	35, 90, and 135	25%, 50%, and max (variable units)

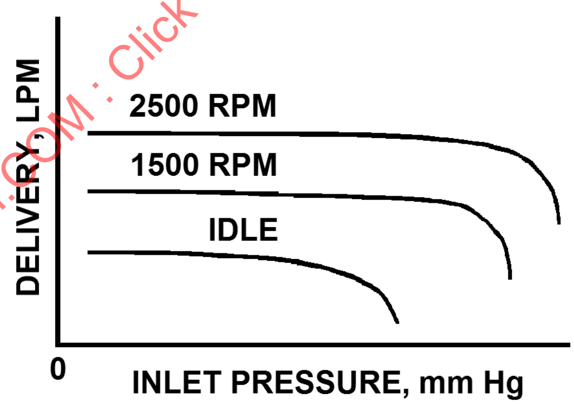

Figure 5 - Typical critical inlet curve fixed displacement pump

6.3 Auto Prime

Operate the pump to assure a functional unit and set load controls to provide discharge pressure and temperatures listed in Table 5. Stop the pump and drain all displacement element cavities and the complete inlet path. Alternately, use a setup pump to establish load controls. After establishing that the test samples are functional units, disassemble, clean, and reassemble prior to test, or test as received from production processes. Assure that the suction inlet is submerged below the fluid surface and the suction head properly replicates the application, e.g., equivalent head loss, gravitational elevation, etc. Accelerate the pump to the listed speed at the listed acceleration rate (see Table 5). Monitor discharge flow. Record flow versus time; t = 0 at start of shaft rotation, t = end when delivery is at full capacity, steady, and without evidence of air.

6.4 Erosion (Cavitation Resistance)

With the specimen pump idling at 1000 to 2000 rpm and 850 kPa discharge pressure, heat the reservoir tank to the test temperature (see Table 6 for test conditions). After the tank has reached test temperature and stabilized, accelerate the pump to test speed, set the pressure, and flow controls to the required level and lock the controls. Maintain these conditions for the listed period. At the end of this test period, decelerate the pump to idle speed, 850 kPa and cool the system down. Tear down unit and inspect for erosion damage.

Table 6 - Erosion test conditions

Speed	Discharge Pressure	Inlet Temperature	Inlet Press	Pump Delivery	Duration
Max rate	Max rated	Max rated	Min rated	Max actual capacity (full displacement)	2.0 hours

6.5 Performance Test - Fixed or Variable Displacement Units, Full Delivery

6.5.1 Fixed Displacement

Operate the pump at the conditions shown in Table 7 and record speed, torque, flow, inlet pressure, discharge pressure, and inlet temperature.

6.5.2 Variable Displacement

Lock displacement mechanism at maximum displacement and repeat per 6.5.1.

6.5.3 Variable Displacement, Displacement Mechanism Functional

With the displacement mechanism and pressure compensator control functional, block compensator control valve in "full displacement" position, ensure the displacement mechanism is biased to full displacement and operate the pump at the conditions specified in Table 7 as in 6.5.2. Table 7 outlines two test arrays. The standard test array is a typical array that covers the breadth of the pump's operating conditions. The focused test array is an example of an array with refined test conditions, focusing on the pump's low speed operating conditions. Overlapping test conditions with the standard test array is recommended practice to confirm test repeatability. If the pump's input speed at the vehicle's idle condition is not within the range shown, the range should be extended to include that condition.

NOTE: For tests described in 6.5.1 and 6.5.2, fixed displacement pumps with integral relief valve and variable units with integral pressure compensator ("main pressure regulator"), the controls must be deactivated and active ports plugged to eliminate internal leakage attributable to those controls. Further, variable units must have the displacement mechanism blocked in the maximum displacement position. This will permit an accurate assessment of the pumping elements and housing assembly. For the test described in 6.5.3, the displacement mechanism must function freely under the influence of the bias control (e.g., "priming" spring) and the pressure compensator valve must be assembled, connected, and blocked in "full displacement" position. This will permit an accurate assessment of bias control effectiveness and performance with only bias control active.

Table 7 - Performance test conditions, full delivery

Speed (rpm)	Discharge Pressure (kPa)	Inlet Temperature (°C)
	Standard Test Array	
500 to maximum rpm in 500 rpm increments	350, 850, 1200, 1550, and 1900	35, 90, and 135
	Focused Test Array	
500 to 1000 rpm in 100 rpm increments	350, 485, 620 and 850	35, 90 and 135

NOTE: Future applications may require extended operating ranges, e.g., high-pressure pumps used in heavy-duty, high-speed, or CVT transmissions. See Figure 1. If extended ranges are specified, increase the test points in 350 kPa increments, and/or 45 °C.

6.6 Performance Test - Fixed or Variable Displacement Units, Partial Delivery

NOTE: For tests described in 6.6.1 and 6.6.2, test units must have displacement mechanism (variable units) and integral controls fully functional with the appropriate pilot signals applied ("boost" signals) such that output flow ("actual capacity") will overcome the hydraulic load circuit resistance. See Figures 2B and 2C. For 6.6.3, pilot signals must be vented, but all integral controls and displacement mechanism must be fully functional.

6.6.1 Fixed Displacement Units with Integral Pressure Relief Valve

Operate the pump drive at 50% of maximum rated speed, and adjust the test circuit load control to achieve 10% of maximum potential capacity (see Figure 1). See Table 8. Lock load controls and reduce drive speed to minimum rated speed ("idle"), then record speed, flow, torque, inlet and discharge pressure, and inlet temperature. Increase speed, discharge pressure, and temperature in the increments listed in Table 8 to complete the first series of data points. To prepare for the next data series, operate the pump drive at 50% of maximum rated speed, set and lock load controls, trim the test unit's integral control pilot signals ("boost" signals) to achieve the listed discharge pressure, and repeat the previous procedure as before. Repeat for every test condition specified. Present data in a form similar to Figure 6A.

6.6.2 Variable Displacement, Controls Active

With displacement mechanism and control valve fully functional, adjust pilot signals and load control as described in 6.6.1 and record data. Repeat for every test condition specified.

6.6.3 Integral Control Pressure Override Characteristic ("Minimum Line Flow Rate")

Calculate the theoretical capacity at 750 rpm (see 3.41); this flow rate shall be known as "min line flow" rate. Operate the pump at 50% of maximum rated speed, then adjust speed down and lock load controls to achieve "min line flow" rate.

NOTE: All pilot signals must be vented. Reduce drive speed to minimum rated speed ("idle"). Record data and accelerate the drive as done in 6.6.1 and 6.6.2. Present data in a form similar to Figure 6B.

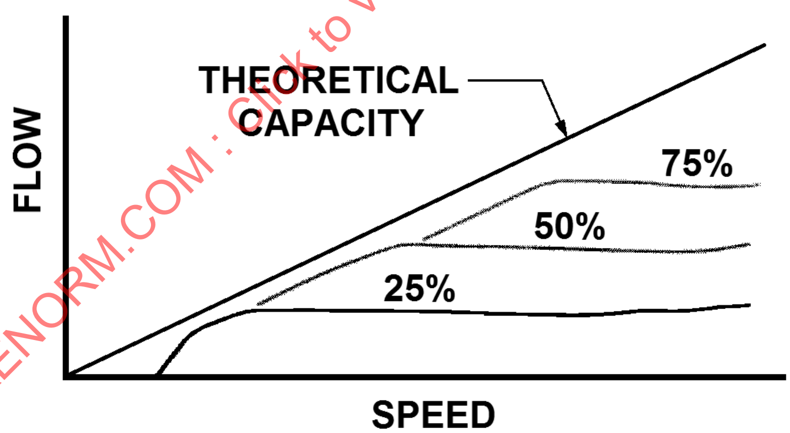

Figure 6A - Typical partial delivery curves

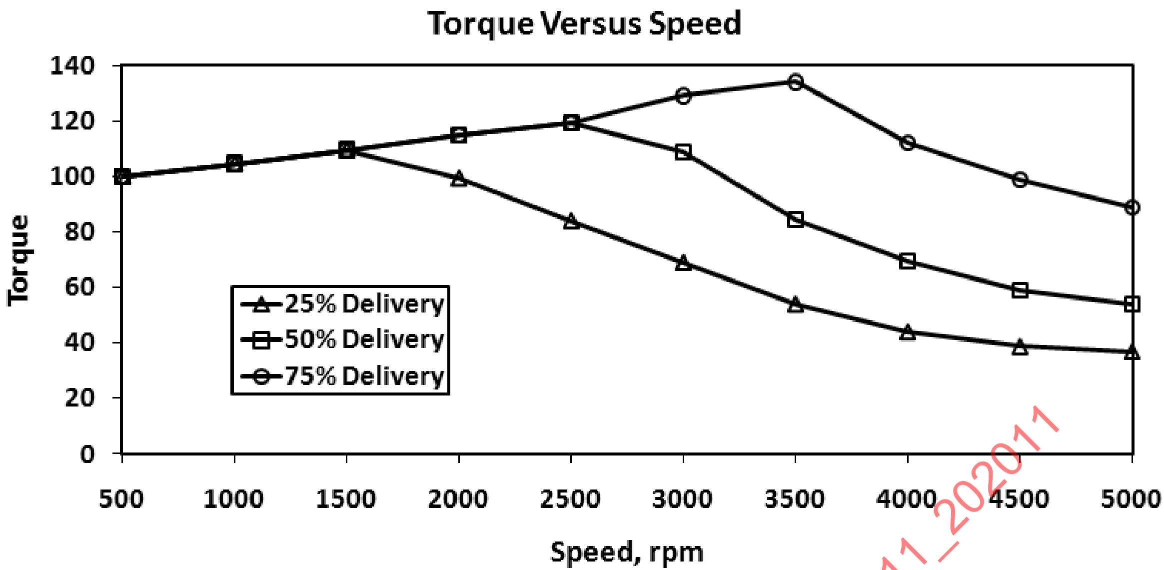

Figure 6B - Typical torque curves, at partial delivery

Table 8 - Performance test conditions, partial delivery

% Theo. Capacity	Speed (rpm)	Discharge Press (kPa)	Inlet Temp (°C)
10, 15, 20, and 25% of maximum theoretical capacity	500, 650 to maximum rated speed in 500 rpm increments	350, 550, 850, 1200, 1550, and 1900	35, 93, and 135

NOTE: Future applications may require extended operating ranges, e.g., high-pressure pumps used in heavy-duty, high-speed, or CVT transmissions. See Figure 1. If extended ranges are specified, increase the test points in 350 kPa increments, and/or 45 °C.

6.7 Thermal Shock

Operate the pump at maximum rated temperature until test stand and reservoir temperature stabilize. Lock controls to provide 1900 kPa discharge pressure at 2000 rpm, full delivery. Stop drive and permit test unit to cool. Maintain reservoir circulation and heat input to sustain elevated temperature. When test unit and reservoir differential temperature reach 65 °C (test unit 65 °C cooler than reservoir fluid), accelerate pump drive to 2000 rpm. Maintain speed and load for 5 minutes or until evidence of seizure is noted.

6.8 Fluid Borne Noise

See Figure 7. Discharge pressure pulsation is frequently of interest. The measurement of these pulsations requires careful build up of the test circuit. The discharge pipe (attached to the pump outlet port) must be sized to prevent standing waves, must be rigid, and of such a volume so as to minimize system reactance. The hydraulic load circuit must also be not reactive, i.e., throttle valves with lockable handles. Load circuits must not contain active pressure controls or compensating flow controls.

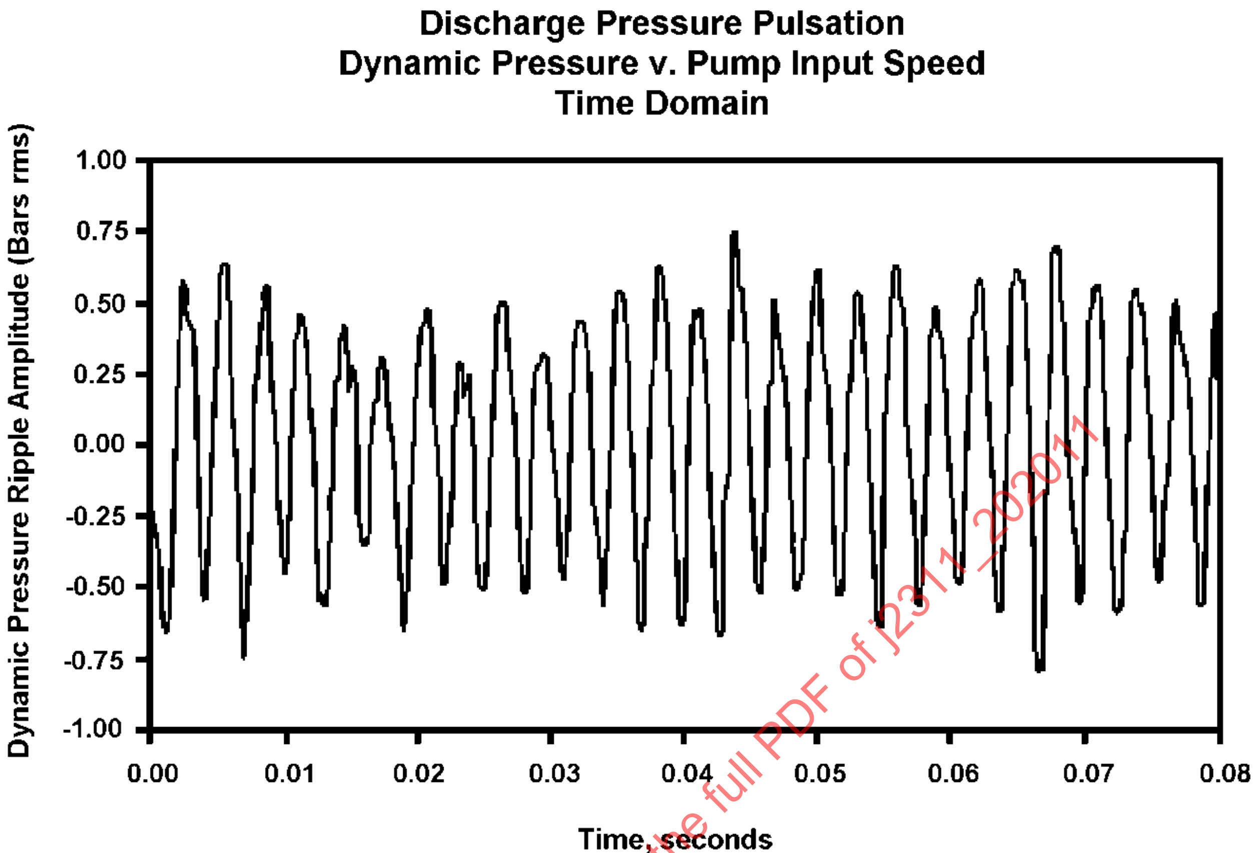

Figure 7 - Discharge pressure pulsation dynamic pressure ripple versus pump input speed time domain

6.9 Axial Thrust Capacity

External loads may be applied to the displacement machine via the input shaft. Reaction to these loads may occur through thrust bearings specifically designed to carry such loads or through the faces of pump gears or rotors. The capacity of such loads should be established to verify adequate safety factors exist. Install the test specimen in a fixture similar to that illustrated in Figure 8.

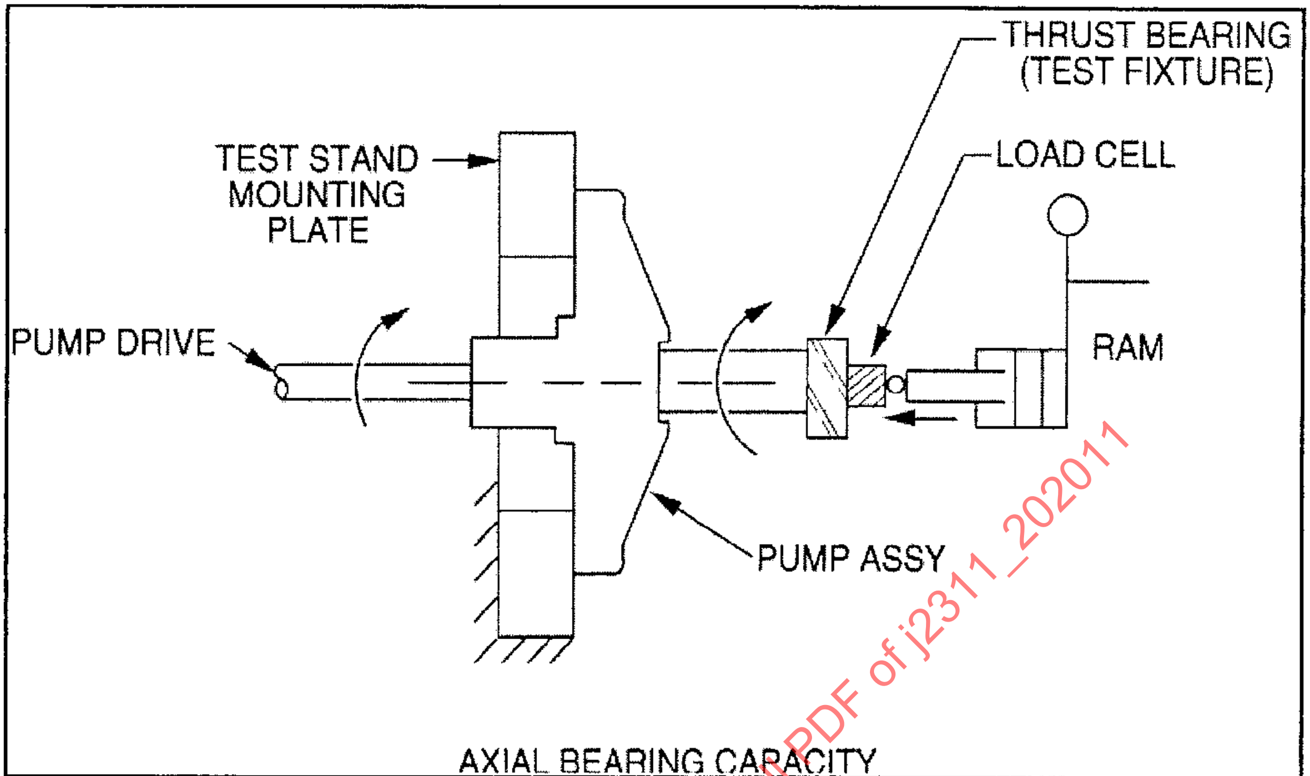

Figure 8 - Axial bearing capacity

NOTE: Each test specimen must be preconditioned per 5.2.2 prior to thrust testing. Verify build clearances, flatness, and surface condition on the appropriate build sheet and note such in the data log. Testing should continue until malfunction occurs or the design safety factor has been met. It is likely that more than one specimen will be consumed by this test.

Operate the test stand until test conditions stabilize to those listed in Table 9, thrust load = 0%. Set the initial axial thrust load (thrust load = 50%), collect required data, and advance to the next incremental load. Continue in this fashion until evidence of thrust capacity is established or adequate safety factor is verified. Note test conditions at termination of test. This test should be completed on a statistically sufficient number of specimens to verify design capacity.

Table 9 - Axial thrust test conditions

Input Speed	Discharge Pressure (kPa)	Inlet Temperature (°C)	Axial Thrust Load (%)
3000 rpm	1st series - 1200 2nd series - 350 3rd series - 350	35, 90, 135, or maximum rated	0, 50, 100, 150, 200, 250, or to SF listed on PD/ADS
1500 rpm	4th series - 1200 5th series - 350 6th series - 350	35, 90, 135, or maximum rated	0, 50, 100, 150, 200, 250, or to SF listed on PD/ADS
500 rpm	7th series - 1200 8th series - 350 9th series - 350	35, 90, 135, or maximum rated	0, 50, 100, 150, 200, 250, or to SF listed on PD/ADS

6.10 Radial Bearing Capacity

External loads may be applied to the displacement machine via the input shaft. Reaction to these loads may occur through shaft bearings, the OD surfaces of gears or rotors, or both. These loads may have their origins as externally applied static loads (coupling weight) or dynamic loads that increase with speed, i.e., unbalance. The capacity of such loads should be established to verify adequate safety factors exist. Install the test specimen in a fixture similar to that illustrated in Figure 9.

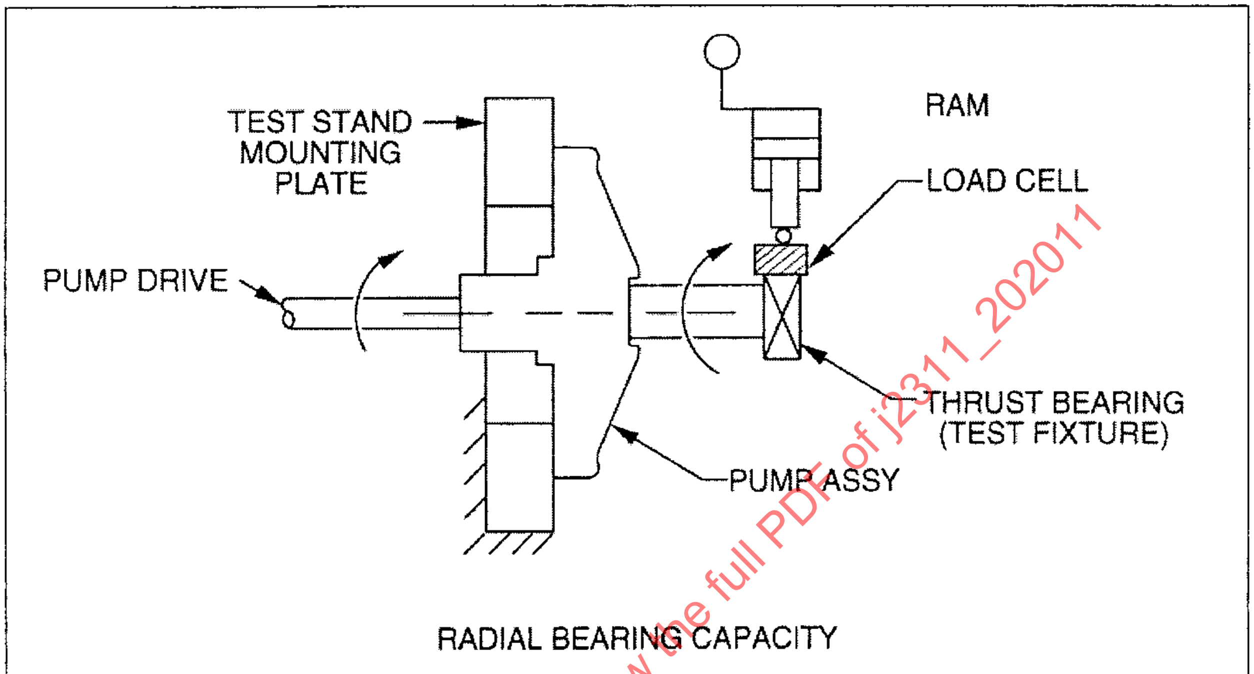

Figure 9 - Radial bearing capacity

NOTE: Each test specimen must be preconditioned per 5.2.2 prior to bearing testing. Verify build clearances, alignment, and surface condition on the appropriate build sheet and note such in the data log. Testing should continue until malfunction occurs or the design safety factor has been met. It is likely that more than one specimen will be consumed by this test.

Operate the test stand until test conditions stabilize to those listed in Table 10, bearing load = 0%. Set the initial radial bearing load (load = 50%), collect required data, and advance to the next incremental load. Continue in this fashion until evidence of radial capacity is established or adequate safety factor is verified. Note test conditions at termination of test. This test should be completed on a statistically sufficient number of specimens to verify design capacity.

Table 10 - Radial bearing capacity test conditions

Input Speed	Discharge Pressure (kPa)	Inlet Temperature (°C)	Radial Load Type (Static/Unbalance)	Radial Load (%)
3000 rpm	1st series -1200 2nd series - 350 3rd series - 350	35, 90, 135, or maximum rated	Static - Series 1A-3A Unbalance - Series 1B-3B	0, 50, 100, 150, 200, 250
1500 rpm	4th series -1200 5th series - 350 6th series - 350	35, 90, 135, or maximum rated	Static - Series 4A-6A Unbalance - Series 4B-6B	0, 50, 100, 150, 200, 250
500 rpm	7th series -1200 8th series - 350 9th series - 350	35, 90, 135, or maximum rated	Static - Series 7A-9A Unbalance - Series 7B-9B	0, 50, 100, 150, 200, 250
Maximum rated rpm	10th series -1200 11th series - 350 12th series - 350	35, 90, 135, or maximum rated	Static - Series 10A-12A Unbalance - Series 10B-12B	0, 50, 100, 150, 200, 250

6.11 Rated Fatigue Pressure (RFP)

Conduct test as required per NFPA T2.6.1.

6.12 Sound Power Rating

Conduct test as required per ISO 4412-1.

6.13 Stability, Response, and Recovery—Fixed and Variable Units with Integral Controls

Add a rapid shutoff valve (such as a direct solenoid operated valve) in series with the manual restrictor valve and connect a pressure transducer in the pump outlet line so that instantaneous pressure can be recorded against time on appropriate data acquisition equipment (e.g., oscilloscope). See Figures 2B and 2C. With the pump running at speeds listed in Table 11, set load control "TV1" to achieve 75% of theoretical capacity, and close TV2 and TV3. Set pilot signals to produce 75% of maximum rated pressure or 1550 kPa, whichever is greater, when discharge is directed through TV1. Set safety relief valve to 125% of maximum rated pressure.

Table 11 - Response, recovery, and stability test conditions

Speed	Discharge Pressure	Inlet Temperature (°C)	Pump Delivery
Idle (or 1000 rpm), 1500, 3000, 4500, and max rated speed	75% of max rated pressure	35, 90, and 135	Cycle from 75 to 0% and return to 75%

NOTE 1: Ensure that the safety relief valve (RV1 in Figures 2B and 2C) is set above the pump's integral control valve overshoot. This may be verified by gradually increasing the cracking pressure of RV1 until no change in the system response is noted, then increasing the cracking pressure another 10%. Alternatively, monitor the exhaust of the RV1.

NOTE 2: If pump displacement mechanism is not capable of zero displacement (variable units), open TV2 and TV3 sufficiently to provide a low flow path such that a flow slightly greater than pump delivery at minimum displacement may be diverted through that circuit when the rapid shut off valve is cycled. This low flow path should be adjusted to prevent over-pressurization and clipping by the safety relief valve, but be significantly less than the high flow path (TV1). Present test data in a format similar to that shown in Figures 10 and 11.