

SURFACE VEHICLE RECOMMENDED PRACTICE

SAE J2311

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Automatic Transmission Hydraulic Pump Test Procedure

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 Publications**—The following publications form a part of this specification to the extent specified herein. Unless otherwise specified, the latest issue of all publications shall apply.
 - 2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J1276—Standardized Fluid for Hydraulic Component Tests
SAE J1165—Reporting Cleanliness Levels of Hydraulic Fluids
 - 2.1.2 ISO PUBLICATION—Available from ANSI, 11 West 42nd Street, New York, NY 10036-8002.

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

SAE J745—Hydraulic Power Pump Test Procedure
SAE J1116—Categories of Off-Road Self-Propelled Work Machines

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3. Definitions

- 3.1 Actual Capacity**—The 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 3.23.
- 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, the threshold of which is near 2.065×10^{-5} Pa.
- 3.6 Axial Thrust Capacity**—An externally applied force applied to the pump assembly. 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). Secant Bulk Modulus is the average between two points on the Bulk Modulus curve. The Tangent Bulk Modulus is the value at a specific point on the curve.
- 3.8 Cavitation**—The formation of bubbles or vapor "cavities" in liquid when the local static pressure is reduced to or below the fluid vapor pressure.
- 3.9 Critical Inlet**—That operating condition of constant speed and inlet temperature, and decreasing suction pressure artificially, that results in less than complete filling of the pumping chamber.
- 3.10 Direction of Rotation**—When viewed from the pump drive shaft end, the clockwise (right hand) or counter-clockwise (left hand) rotation of the shaft that produces discharge from the discharge port.
- 3.11 Discharge Pressure**—The static pressure at the pump discharge port, downstream of the confluence of all pumping chambers.
- 3.12 Entrained Air**—The result of aeration. The mixture of undissolved gas, usually air, beyond the solution point, usually expressed in percent air by volume.
- 3.13 Erosion**—The damage, loss of material, or permanent deformation of pressure containing surfaces as the result of collapsing bubbles, either from aeration or cavitation.
- 3.14 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. The resulting wave form has amplitude and frequency characteristics similar to airborne noise
- 3.15 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."

3.16 High-Speed Fill Limit—The rotative 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.

3.17 Hydraulic Output Power—The fluid power, expressed in power units, available to do useful work. See Equation 1.

$$H_{out}[W] = \frac{Q_a \times (P_d - P_i)}{60} \quad (\text{Eq. 1})$$

3.18 Inlet Pressure—The static pressure at the pump inlet port upstream of the pumping chambers.

3.19 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.

3.20 Maximum Rated Pressure—The maximum nominal (excludes tolerances and pulsation) discharge pressure the pump is designed to operate at continuously for a specified period.

3.21 Maximum Rated Speed—The maximum input speed the pump is designed to operate at continuously for a specified period.

3.22 Maximum Rated Temperature—The maximum fluid temperature at the pump inlet the pump is designed to operate at continuously for a specified period.

3.23 Measured Displacement—That measured amount of volume displaced through one revolution by a positive displacement machine. The Measured Displacement does not include any losses for pump internal leakage. May also be known as "Actual Displacement".

3.24 Mechanical Efficiency—The ratio, expressed in percent of Theoretical Torque to Actual Torque. See Equation 2.

$$E_m(\%) = \frac{T_t}{T_a} \times 100\% \quad (\text{Eq. 2})$$

3.25 Mechanical Input Power—The mechanical (shaft) power, expressed in power units, consumed by the pump. See Equation 3.

$$H_{in}[W] = \frac{T_a \times N}{9.549} \quad (\text{Eq. 3})$$

3.26 Overall Efficiency—The ratio, expressed in percent, of Output Power to Input Power. See Equation 4.

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

3.27 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 3.20 through 3.22) all performance requirements must be met. See Figure 1.

3.28 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 3.20 through 3.22) all performance requirements must be met. See Figure 1.

3.29 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 3.20 through 3.22) all performance requirements must be met. See Figure 1.

Pump Design/Application Data Sheet					Prod Des Engrt Program:	Latest Change Date/Initials
Description:					Reference	
Parameter	Value (units)	Sample Size	Acceptance Criteria Parameter	Reliability	Procedure	SDS Para. No. DVP&R
Application						
* Vehicle Line						
* Transmission Model(s)						
* Engine(s)						
Ratings						
* Pump Max The Capacity						
* Pump Theo Displacement						
* Theoretical HSEFL						
* Rated Fatigue Pressure						
* Rated Sound Power (@ xxx rpm, xxx kPa)						
* Rated External Radial Load (Safety Factor = xx.0)						
* Rated External Axial Thrust (Safety Factor = xx.0)						
* Max Rated Speed						
* Min. Rated Speed ("Idle")						
* Max. Over Speed						
* Max Rated Pressure (Discharge)						
* Max. Overpressure						
* Max Rated Inlet Temperature						
* Min. Rated Inlet Pressure						
* Min. Rated Inlet Temp.						
* Min. Line Flow Rate (@ xxx rpm, xxx kPa)						
Operating Environment						
* Fluid Cleanliness (ISO Code, 2/5/15 micron)						
* Drive Alignment						
Max. Angular Error						
Max. Offset Error						

FIGURE 1—PUMP DESIGN/APPLICATION DATA SHEET

3.30 Power Loss—The power lost by the pump, usually in the form of heat, expressed in power units. It is the difference between input and output power. See Equation 5.

$$H_l[W] = H_{in} - H_{out} \quad (\text{Eq. 5})$$

3.31 Pressure Ripple—The peak-to-peak amplitude of fluid pressure oscillations.

3.32 Pump Delivery—The actual flow rate from the discharge port at a specified pressure, inlet temperature, and speed.

3.33 Radial Bearing Capacity—The maximum permitted force applied to the input shaft the pump is required to support, e.g., offset load. May be specified as a moment and force, or force at defined distance from bearing.

3.34 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.

3.35 Slip Flow—The difference between Pump Delivery (actual flow) and Theoretical Capacity, usually referred to as "internal leakage."

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

3.37 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. May be included in Pump Assembly measurements to ascertain total power draw.

3.38 Theoretical Capacity—The theoretical output flow at a given speed. It assumes 100% volumetric efficiency, is independent of discharge pressure, and is a function of Measured Displacement, " D_m " and Input Speed, " N ." See Equation 6.

$$Q_t[\text{lpm}] = \frac{D_m \times N}{1000} \quad (\text{Eq. 6})$$

3.39 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.

3.40 Theoretical Torque—The theoretical torque required to rotate the pump input shaft due to an assumed 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 7.

$$T_t[\text{Nm}] = (P_d - P_i) \frac{D_m}{2 \times \pi \times 1000} \quad (\text{Eq. 7})$$

3.41 Torque Ripple—The peak-to-peak amplitude of torsional oscillations measured at the pump input shaft.

3.42 Volumetric Efficiency—The ratio, expressed in percent, of Pump Delivery to Theoretical Capacity. See Equation 8.

$$E_v[\%] = \frac{Q_a}{Q_t} \times 100\% \quad (\text{Eq. 8})$$

4. Symbols

E_m	≡	Mechanical Efficiency (%)
E_o	≡	Overall Efficiency (%)
E_v	≡	Volumetric Efficiency (%)
Q_t	≡	Theoretical Capacity (Lpm)
Q_a	≡	Actual Capacity (Lpm)
D_m	≡	Measure Displacement (cc/rev)
N	≡	Pump Rotational Speed (rpm)
H_{out}	≡	Hydraulic Power output (Watts)
H_{in}	≡	Mechanical Power Input (Watts)
H_l	≡	Power Loss (Watts)
T_t	≡	Theoretical (Input) Torque (Nm)
T_a	≡	Actual (Input) Torque (Nm)
P_i	≡	Pump Inlet Pressure (kPa)
P_d	≡	Pump Discharge Pressure (kPa)
W	≡	Power units, (Watts)
Lpm	≡	Flow rate units, (liters per minute)
Nm	≡	Torque units, (Newton-Meters)

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 in) or within "Pump Design/Application Data Sheet" (see Figure 1) requirements, whichever is more restrictive. Initially, all components should be checked with a dial indicator to obtain a coarse alignment. Final alignment must be completed, verified, and documented in accordance with local laboratory practice.

5.1 Material and Apparatus

- 5.1.1 **TEST FLUID**—Test fluid shall be per SAE J1276 (a non-synthetic based fluid, preferably "DEXRON III" or equivalent) and approved by the manufacturer of the unit. 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, return fluid for 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 1165, 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/Application Data 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).

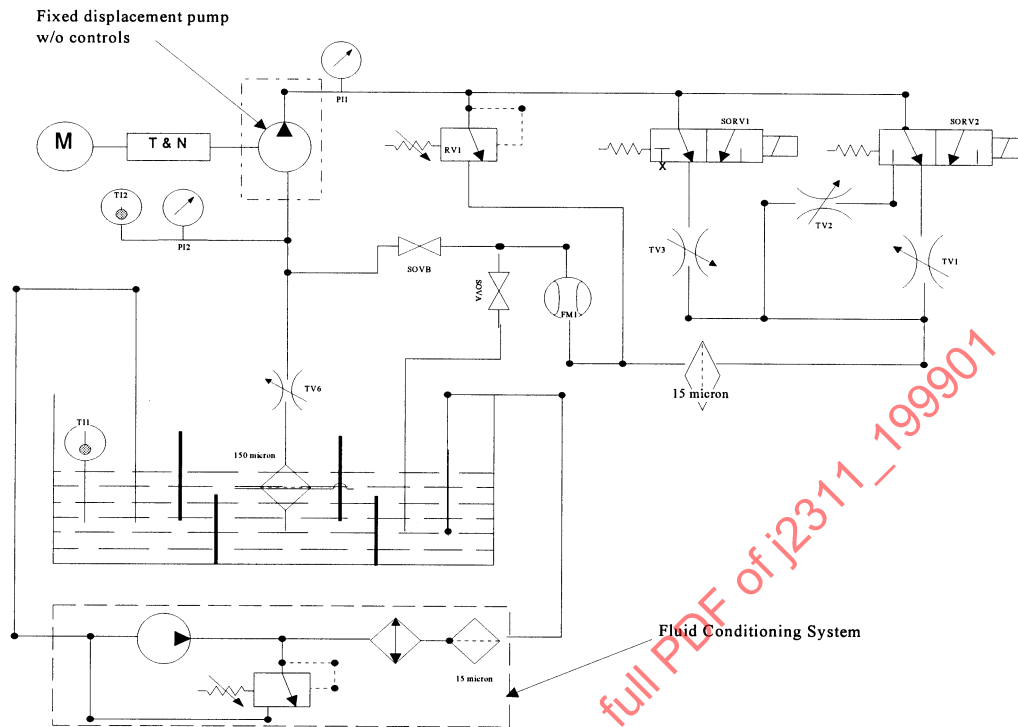


FIGURE 2A—TEST CIRCUIT FIXED DISPLACEMENT PUMP

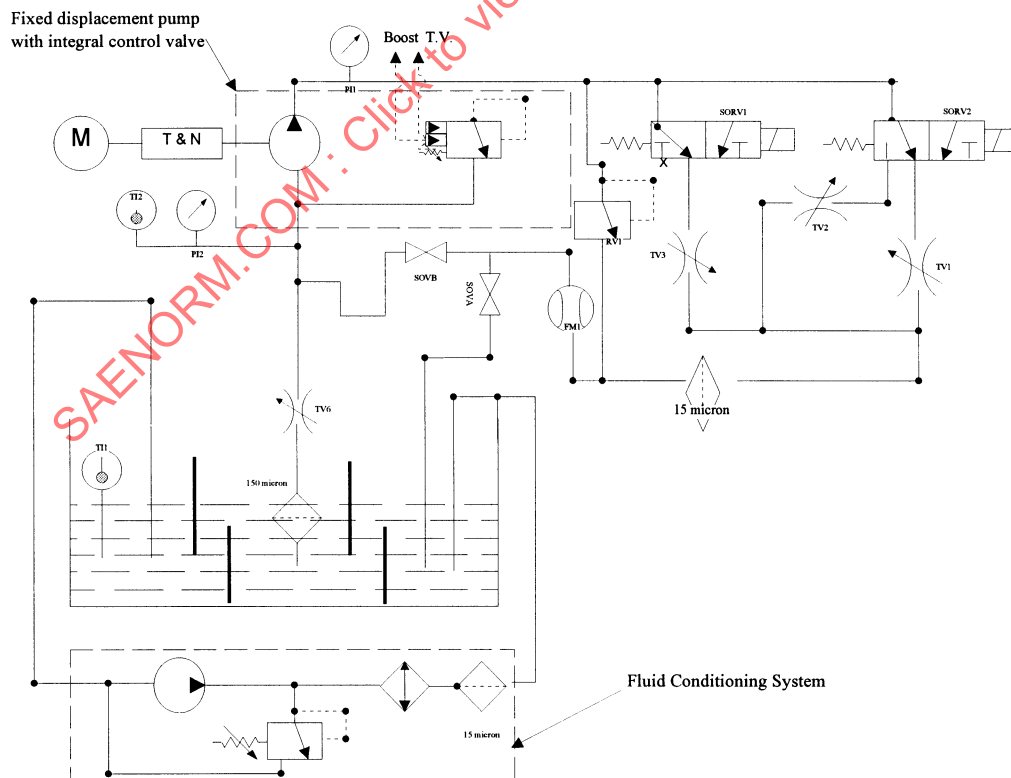


FIGURE 2B—TEST CIRCUIT FIXED DISPLACEMENT PUMP WITH INTEGRAL PRESSURE CONTROL

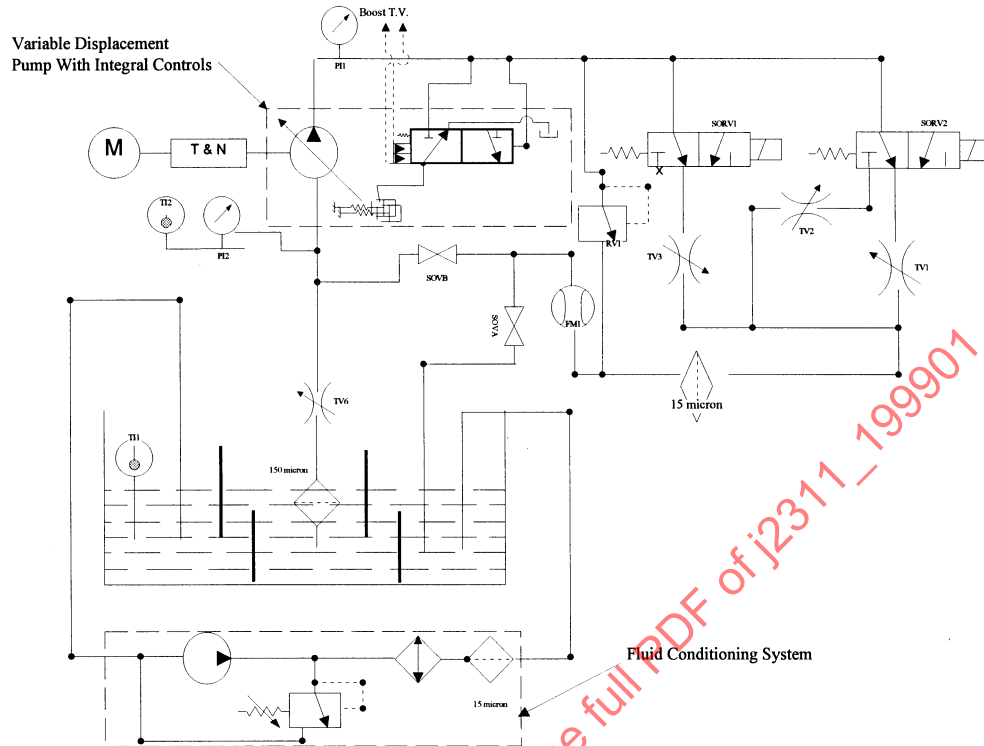


FIGURE 2C—TEST CIRCUIT—VARIABLE DISPLACEMENT PUMP WITH INTEGRAL PRESSURE COMPENSATOR (MAIN PRESSURE REGULATOR) CONTROL

- 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	lpm	0.1 - 50
Discharge Flow, high-range	lpm	5 - 200
Discharge Pressure, low range	kPa	0 - 700
Discharge Pressure, high range	kPa	0 - 3500
Throttle Valve Pressure Signal	kPa	0 - 700
Boost Pressure Signal	kPa	0 - 3500
Inlet Temperature	°C	0 - 150
Response	real time	d.c. - 2 kHz

NOTE—Future applications may require extended calibration limits, e.g., high-pressure pumps used in heavy-duty, high-speed, or CVT transmissions. 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	±0.2 Nm	Measure only
Pressure	±7.00 kPa	Measure and control
Speed: (Low Range)	±1 rpm (Disp Test)	Measure and control
Speed: (High Range)	±10 rpm (Perf. Test)	Measure and control
Temperature	±3 °C	Measure and control
Flow Rate: (Low Range)	±0.05 lpm	Measure only
Flow Rate: (High Range)	±0.10 lpm	Measure only

NOTE—Any deviations from the latter requirements must be noted.

- 5.2 Pre-test**—The inlet restriction as shown in Figures 2A through 2C, “Test Circuit,” should be adjusted to match the press drop that replicates the functional press drop as installed in the application. The inlet supply to the pump assembly should include an inlet screen/filter that replicates that planned for the 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 “Build Sheets,” Figures 3A through 6 for examples.
- 5.2.2 **PRE-CONDITIONING (OPTIONAL)**—New pump assemblies (less than 0.5 h 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 min 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

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Serial No.	Pump Freq. (No. of Chambers)	Model	Application	Source (Manufacturer)	Date	Requester	Remarks

Parameter	Value	Method	Insp. (initials/date)	Remarks
Gear Units				
Rotor, Inner, Maj. Dia				
Rotor, Inner, Minor Dia.				
Rotor, Inner, Thickness				
Rotor, Outer, Maj. Dia				
Rotor, Outer, Minor Dia				
Rotor, Outer, OD				
Rotor, Outer, Thickness				
Tip Clmc. (Gerotor, max.)				
Pocket Depth				
Rotor/Pocket Face Clmc – TOTAL				
Tip clmc. Inner/Crescent				
Tip clmc. Outer/Crescent				
C'Bore Dia				
C'Bore/Inner Rotor Brg. Eccentricity				
Surf. – Rotor Faces				
Surf. – Rotor, Outer OD				
Flatness – Rotor Faces				
Vane Units				
Rotor, vane slot width				
Rotor, Thickness				
Rotor, OD				
Rotor/Pocket Face clmc. (Bore Ring hgt.)				
Vane, Height				
Vane, Thickness				
Vane, Length				
Vane/Rotor slot clmc.				
Vane/Pocket Face clmc. (Bore Ring hgt.)				
Vane/Bore Ring (radial) clmc.				
Support Ring, Upper – OD				
Support Ring, Upper – height				
Support Ring, Lower – OD				
Support Ring, Lower – height				
Bore Ring, ID				
Bore Ring, Thickness				
Bore Ring/Rotor Brg. Eccentricity				
Surf. – Rotor Faces				
Flatness – Rotor Faces				

FIGURE 3A—PUMP BUILD SHEET

Serial No.	Pump Freq. (No. of Chambers)	Model	Application	Source (Manufacturer)	Date	Requester	Remarks

Parameter	Value	Method	Insp. (initials/date)	Remarks
Materials				
Housing				
Rotor(s).				
Vanes				
Ring				
Covers				
Wear Plates				
Surf. – C'Bore (gear Units)				
Surf. – Ring ID				
Surf. – Wear Plate				
Flatness – Pocket Face				

FIGURE 3B—PUMP BUILD SHEET (CONTINUED)

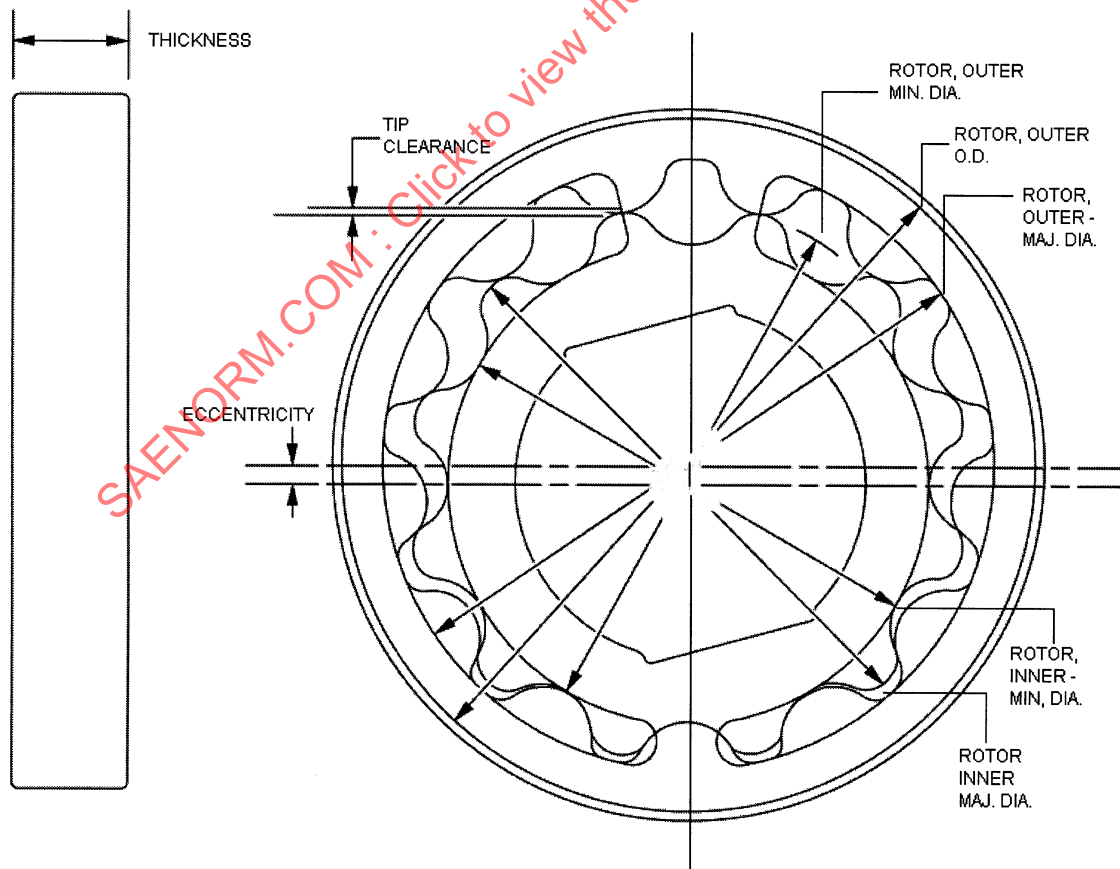


FIGURE 4—GEROTOR BUILD PARAMETERS

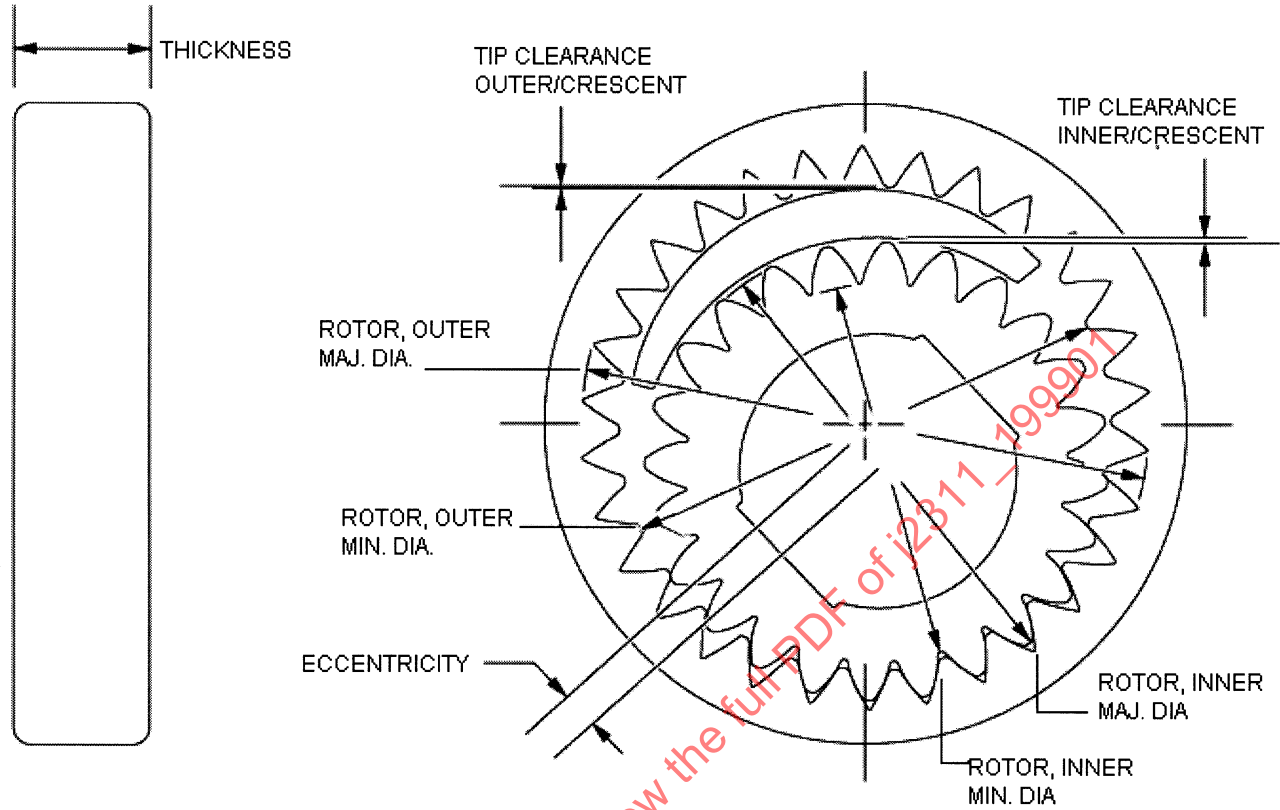


FIGURE 5—CRESCENT GEAR BUILD PARAMETERS

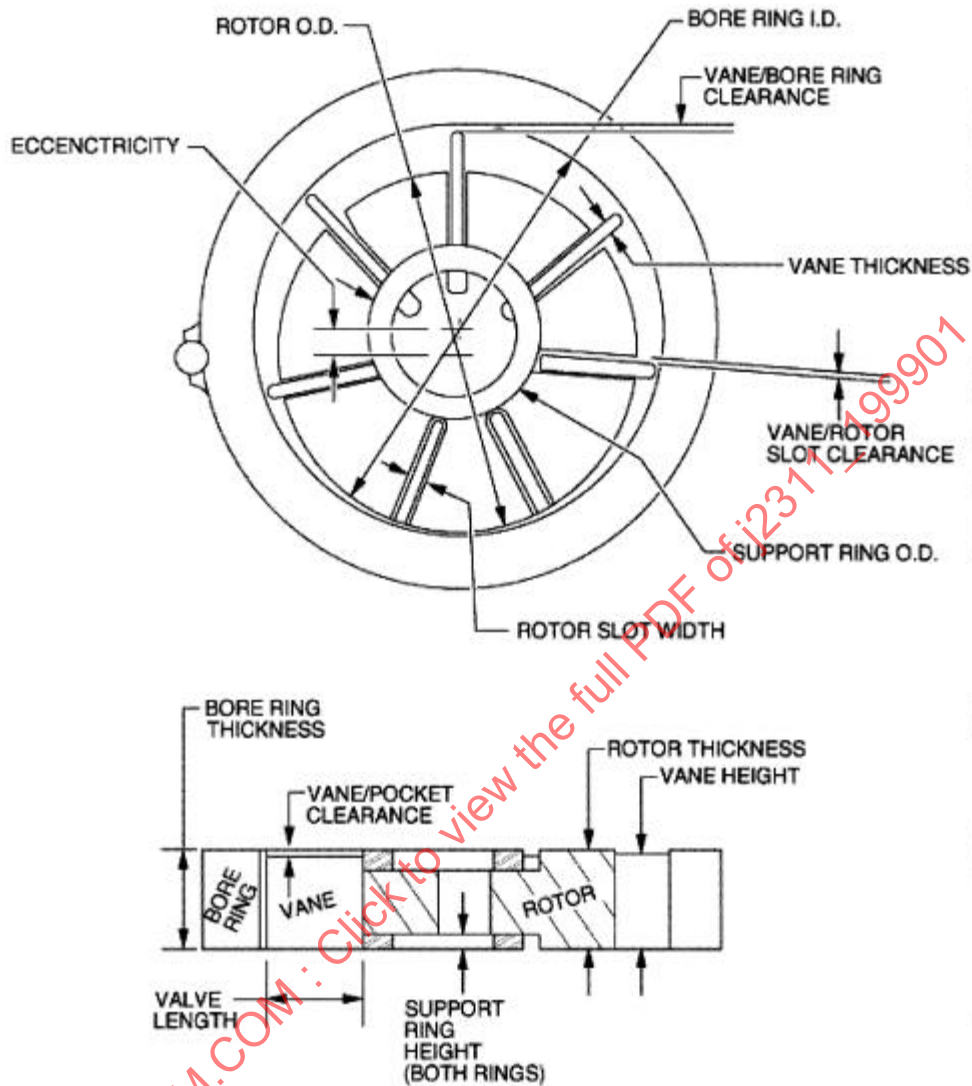


FIGURE 6—VARIABLE VANE BUILD PARAMETERS

- 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, “Test Circuit” 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 - 0- 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 light petroleum grease. 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 7.

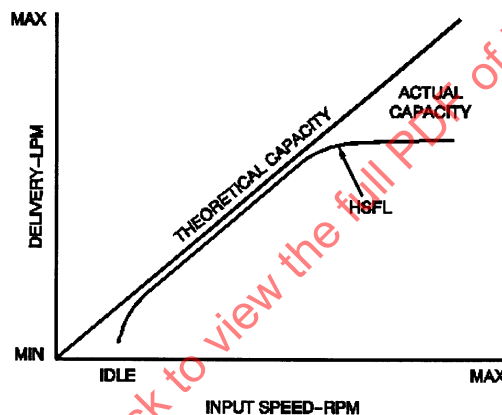


FIGURE 7—TYPICAL HSFL CURVE FIXED DISPLACEMENT PUMP

- 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 8.

TABLE 5—CRITICAL INLET AND AUTO PRIME TEST CONDITIONS

Speed	Discharge Pressure	Inlet Temperature	Pump Delivery
Idle (or 1000 rpm, whichever is lower)	350, 1200, and 1900 kPa	35, 90, and 135 °C	Full Delivery (Fixed units)
at 750 to 500 rpm/s			
1500 and 2500 rpm			25%, 50%, and Max (Variable units)
at 1500 to 1000rpm/s			

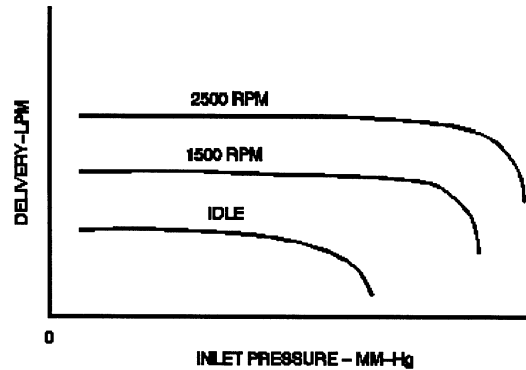


FIGURE 8—TYPICAL CRITICAL INLET CURVE FIXED DISPLACEMENT PUMP

- 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. 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 h

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 Section 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.

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)
500 to maximum rpm in 500 rpm increments	350, 850, 1200, 1550, and 1900	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 Theoretical Capacity (see Figure 1). Refer to 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 9A.
- 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 PRESSURE")**—Calculate the Theoretical Capacity at 750 rpm (see 3.38); this flow rate shall be known as "Min Line Flow." Operate the pump at 50% of Maximum Rated Speed, adjust, 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 9B.

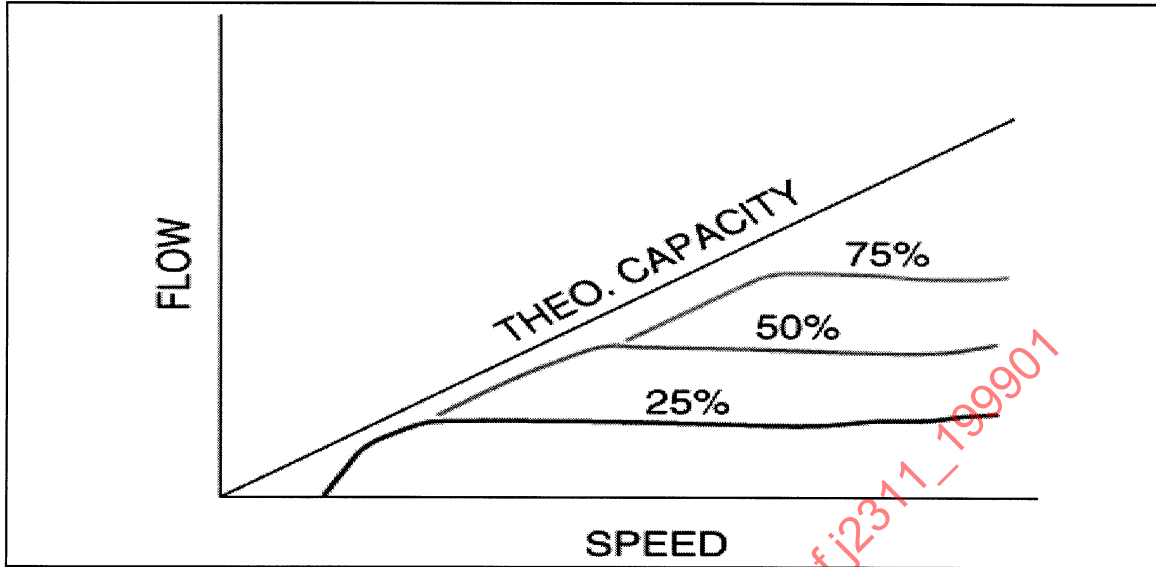


FIGURE 9A—TYPICAL PARTIAL DELIVERY CURVES

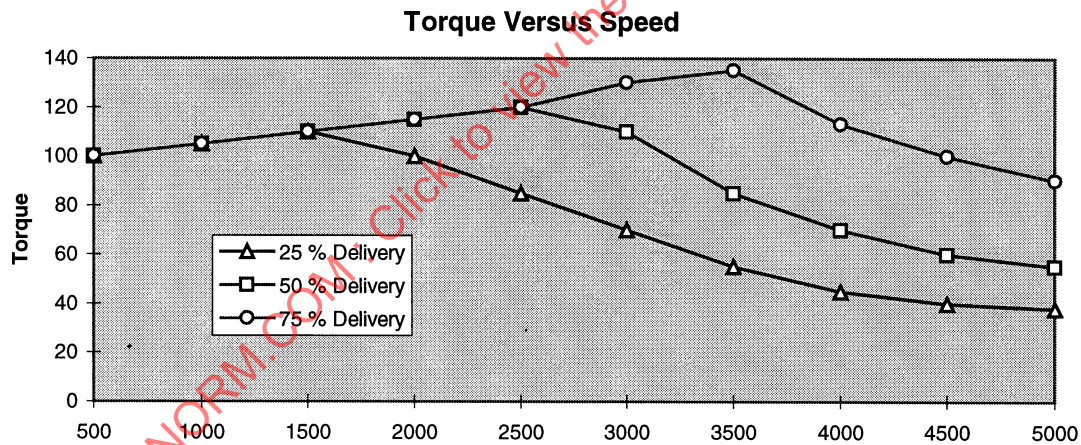


FIGURE 9B—TYPICAL TORQUE CURVES, AT PARTIAL DELIVERY

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 to Maximum Rated speed in 500 rpm increments	350, 850, 1200, 1550, and 1900	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.

6.7 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 min or until evidence of seizure is noted.

6.8 Fluid Borne Noise—See Figure 10—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

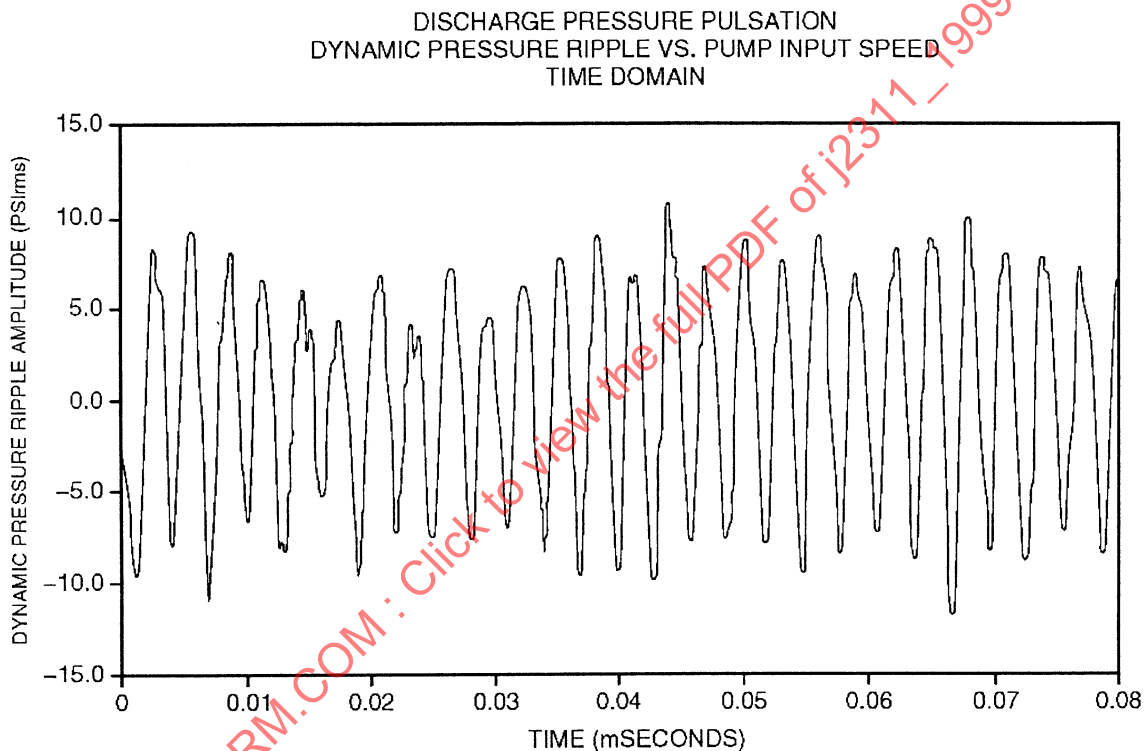


FIGURE 10—DISCHARGE PRESSURE PULSATION DYNAMIC PRESSURE RIPPLE VERSUS PUMP INPUT SPEED TIME DOMAIN

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 11.

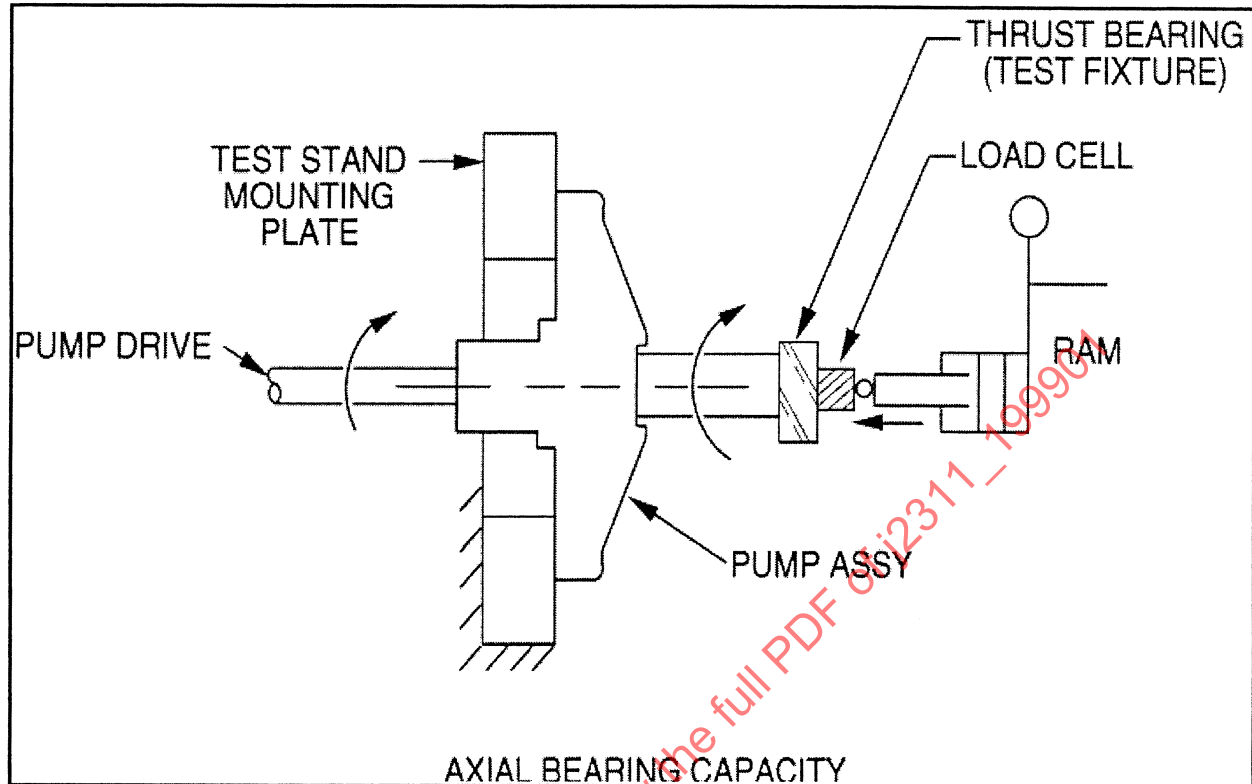


FIGURE 11—AXIAL BEARING CAPACITY

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 12.

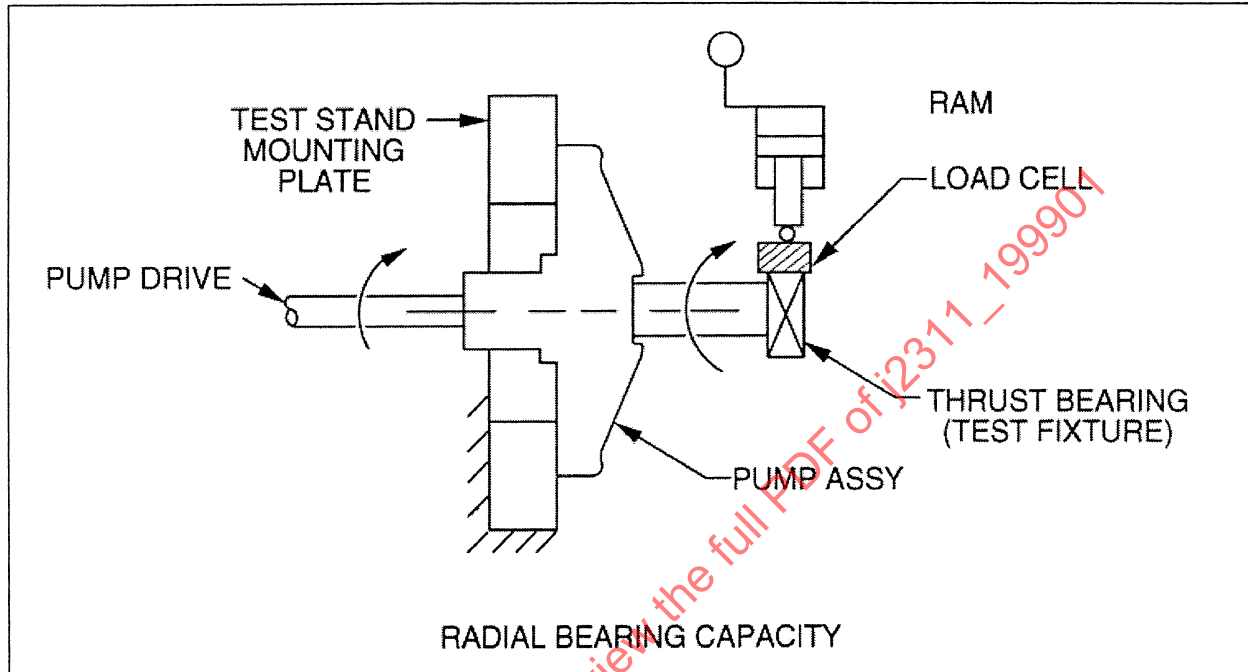


FIGURE 12—RADIAL BEARING CAPACITY

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 max 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 max rated	Static - Series 10A-12A Unbalance - Series 10B-12B	0%, 50%, 100%, 150%, 200%, 250%

6.11 Rated Fatigue Pressue (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
idel (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—Insure that the Safety Relife 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 overpressurization 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 13 and 14.

6.13.1 RESPONSE TIME—Cycle the shutoff valve to direct pump discharge to TV2 while recording instantaneous pressure against time. From this recording, determine the rate of pressure rise in kPa/s, overshoot in kPa and pressure control resonse time in milliseconds. See Figure 13.

- 6.13.2 **RECOVERY TIME**—Cycle the shutoff valve to direct pump discharge to TV1 while recording instantaneous pressure against time. From this recording, determine the rate of pressure drop in kPa/s, pressure drop in kPa and pressure control recovery time in milliseconds. See Figure 13.
- 6.13.3 **STABILITY**—While performing 6.13.1, the “Response” cycle, wait for pressure stabilization to occur before proceeding to 6.13.2. Count the number of cycles displayed from $t=0$ until the discharge pressure has settled at the low-flow load pressure. Any peak-to-peak pressure oscillation equal to or less than steady-state pump ripple shall be considered stable. See Figure 14. Repeat this procedure for the “Recovery” cycle.

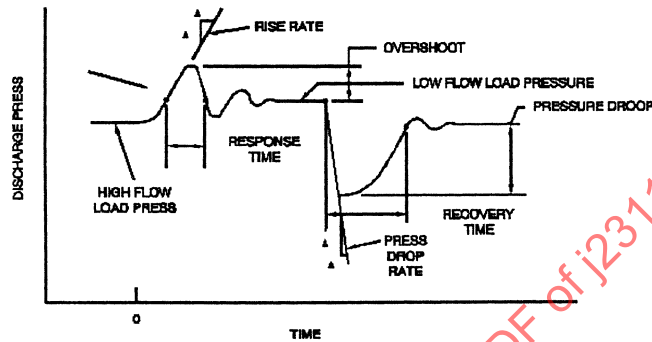


FIGURE 13—RESPONSE AND RECOVERY

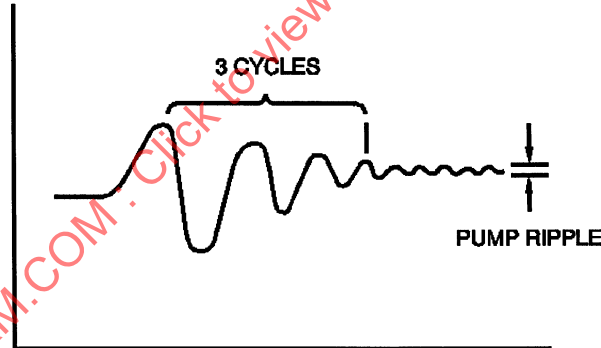


FIGURE 14—STABILITY

- 6.14 **Cold Auto Prime (Cold Start)**—Perform this test in a manner similar to that described in 6.3. Operate the pump to assure a functional unit and set load controls to provide 350 kPa discharge pressure, at Maximum Rated Inlet Temperature, and continue operating the pump until all external components have stabilized to within 10 °C of inlet fluid temperature. Stop the pump and drain all displacement element cavities and the complete inlet path. 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. Cool the system until the entire circuit including reservoir and all external pump components have stabilized at the Minimum Inlet Temperature. Maintain this “Cold Soak” for an additional 4 h minimum. Accelerate the drive to the schedule listed in Table 12, and 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.

TABLE 12—COLD AUTO PRIME TEST CONDITIONS

Test Point	1	2	3	4	5
Speed (rpm)	0 to 300	300 steady	300 to 750	750 steady	2000 steady
Time, "t = x" s	0 to 5	5+ to 10	10+ to 12	12+ to 17	19+ to 30

6.15 Scavenge Pumps—Scavenge pumps are most often special applications of simple fixed displacement pumps, usually gear units. Since their purpose is simplified, the evaluations needed to assess their performance are also simplified.

6.15.1 **SCAVENGE PUMP PERFORMANCE**—Operate the pump at the conditions shown in Table 13, record speed, inlet temperature, inlet pressure, discharge pressure, torque, and flow.

TABLE 13—SCAVENGE PUMP PERFORMANCE TEST CONDITIONS

Speed (rpm)	Discharge Pressure (kPa)	Inlet Temperature (°C)
500 to maximum rpm in 500 rpm increments	17, 35, and 70	35, 90, and 135

6.15.2 **SCAVENGE PUMP AUTO PRIME**—The Auto Prime test is similar to that defined in 6.3. Operate the pump to assure a functional unit, and set load controls to provide discharge pressure and temperature listed in Table 14. Stop the pump and drain all displacement element cavities and the complete inlet path. 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 min rated speed, ("idle" or 1000 rpm, whichever is less) and 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.

TABLE 14—SCAVENGE PUMP AUTO PRIME TEST CONDITIONS

Speed (rpm)	Discharge Pressure kPa	Inlet Temperature (°C)
Idle (or 1000 rpm) 1500 and 2500 rpm	17, 35, and 70	35, 90, and 135

6.15.3 **SCAVENGE PUMP COLD START**—The Scavenge Pump Cold start test is similar to that defined in 6.14. Operate the pump to assure a functional unit and set load controls to provide 17 kPa discharge pressure. Heat the test circuit to Maximum Rated Inlet Temperature, and continue operating the pump until all external components have stabilized to within 10 °C of inlet fluid temperature. Stop the pump and drain all displacement element cavities and the complete inlet path. 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. Cool the system until the entire circuit including reservoir and all external pump components have stabilized at the Minimum Inlet Temperature. Maintain this "Cold Soak" for an additional 4 h minimum. Accelerate the drive to the schedule listed in Table 15 and 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.

TABLE 15—SCAVENGE PUMP COLD AUTO PRIME TEST CONDITIONS

Test Point	1	2	3	4	5	6
Speed (rpm)	0 to 300	300 steady	300 to 750	750 steady	750 to 2000	2000 steady
Time, "t=x" s	0 to 5	5+ to 10	10+ to 12	12+ to 17	17+ to 19	19+ to 30