AEROSPACE STANDARD

AS595™	REV. D

Issued 1959-02
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Reaffirmed 2015-10

Superseding AS595C

(R) Aerospace – Civil Type Variable Delivery, Pressure Compensated, Hydraulic Pump

RATIONALE

AS595D has been reaffirmed to comply with the SAE five-year review policy.

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1. SCOPE

This SAE Aerospace Standard (AS) establishes the general requirements for the design, construction, acceptance and qualification testing of flat cut-off pressure compensated, variable delivery hydraulic pumps, used in civil aircraft hydraulic systems. It also provides parameters for a Procurement Specification to be used in conjunction with this AS for each pump.

NOTE: Hydraulic pumps may incorporate features such as a clutch in the input drive, which will not be covered by this standard.

1.1 Field of Application

This AS is primarily for hydraulic pumps driven by an engine; however, it also can be applied to pumps driven by other power sources such as electric motors, ram air turbines and engine bleed air turbines. These pumps may be soft cut-off pressure compensated, variable delivery type due to input power limitations.

Pumps conforming to this standard are intended mainly for use in commercial aircraft hydraulic systems conforming to the general requirements of ARP4752, and to the regulations of 14 CFR Part 25 and/or CS-25/JAR 25. However, pumps conforming to this AS can also be used in:

- Civil aircraft hydraulic systems conforming to the regulations of 14 CFR Part 23 and/or CS-23/JAR 23. For these applications, the equivalent 14 CFR Part 23/CS-23/JAR 23 requirements should be used in place of the 14 CFR Part 25/CS-25/JAR 25 requirements.

- Helicopter hydraulic systems conforming to the regulations of 14 CFR Part 27 and/or CS-27/JAR 27. For these applications, the equivalent 14 CFR Part 27/CS-27/JAR 27 requirements should be used in place of the 14 CFR Part 25/CS-25/JAR 25 requirements.

- Helicopter hydraulic systems conforming to the general requirements of ARP4925, and to the regulations of 14 CFR Part 29 and/or CS-29/JAR 29. For these applications, the equivalent 14 CFR Part 29/CS-29/JAR 29 requirements should be used in place of the 14 CFR Part 25/CS-25/JAR 25 requirements.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this standard to the extent specified herein. The latest issue of the SAE documents shall apply. The applicable issue of the other documents shall be the issue in effect at the date of the purchase order. In the event of conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

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 724-776-4970 (outside USA), www.sae.org.

AS1241 Fire Resistant Phosphate Ester Hydraulic Fluid for Aircraft

ARP1288 Placarding of Aircraft Hydraulic Equipment to Identify Phosphate-Ester Fluid Compatibility

AS1300 Boss, Ring Locked Fluid Connection Type, Standard Dimensions for

AIR1922 System Integration Factors That Affect Hydraulic Pump Life

AS4273 Fire Testing of Fluid Handling Components for Aircraft Engines and Aircraft Fluid Systems

ARP4386 Terminology and Definitions for Aerospace Fluid Power, Actuation and Control Technologies

ARP4752 Design and Installation of Commercial Transport Aircraft Hydraulic Systems

ARP4925 Aerospace Design and Installation of Commercial Transport Helicopter Hydraulic Systems

AS4941 General Requirements for Commercial Aircraft Hydraulic Components

AS33649 Bosses, Fluid Connection, Internal Straight Thread

2.1.2 European Aviation Regulations

Available from European Aviation Safety Agency, Otto Platz 1, Postfach 101253, D-50452 Cologne, Germany, Tel: +49-221-8999-000, www.easa.eu.int.

CS-23 Certification Specifications for Normal, Utility, Aerobatic and Commuter Aeroplanes

CS-25 Certification Specifications for Large Aeroplanes

CS-27 Certification Specifications for Small Rotorcraft

CS-29 Certification Specifications for Large Rotorcraft

2.1.3 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

14 CFR Part 23 Code of Federal Regulations, Part 23 Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes

14 CFR Part 25 Code of Federal Regulations, Part 25 Airworthiness Standards, Transport Category Airplanes

14 CFR Part 27 Code of Federal Regulations, Part 27 Airworthiness Standards, Normal Category Rotorcraft

14 CFR Part 29 Code of Federal Regulations, Part 29 Airworthiness Standards, Transport Category Rotorcraft

2.1.4 ISO Publications

Available from American National Standards Institute, 25 West 43rd Street, New York, NY 10036-8002, Tel: 212-642-4900, www.ansi.org, or International Organization for Standardization, 1 rue de Varembe, Case Postale 56, CH-1211, Geneva 20, Switzerland, Tel: +41-22-749-01-11, www.iso.org.

ISO2685 Environmental Test Conditions for Airborne Equipment - Resistance to Fire in Designated Fire Zones

2.1.5 Joint Aviation Authorities Committee Documents

Available from Global Engineering Documents, 15 Inverness Way, East Englewood, Colorado, 80112-5776, Tel: 800-854-7179, www. global.ihs.com.

JAR-23 Joint Airworthiness Requirements, Normal, Utility, Aerobatic and Commuter Category Aeroplanes

JAR-25 Joint Airworthiness Requirements, Large Aeroplanes

JAR-27 Joint Airworthiness Requirements, Small Rotorcraft

JAR-29 Joint Airworthiness Requirements, Large Rotorcraft

2.1.6 RTCA Publications

Available from Radio Technical Commission for Aeronautics Inc., 1828 L Street, NW, Suite 805, Washington, DC 20036, Tel: 202-833-9339, www.rtca.gov.

RTCA/DO-160 Environmental Conditions and Test Procedures for Airborne Equipment

2.1.7 U.S. Government Documents

Available from the Document Automation and Production Service (DAPS), Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6257, http://assist.daps.dia.mil/quicksearch.

MIL-PRF-5606 Hydraulic Fluid, Petroleum Base; Aircraft, Missile and Ordnance

MIL-F-8815 Filter and Filter Elements, Fluid Pressure, Hydraulic Line, 15 Micron Absolute and 5 Micron Absolute, Type II Systems, General Specification For

MIL-PRF-83282 Hydraulic Fluid, Fire Resistant Synthetic Hydrocarbon Base, Aircraft

MIL-PRF-87257 Hydraulic Fluid, Fire Resistant Synthetic Hydrocarbon Base, Aircraft

2.2 Related Publications

The following publication is provided for information purposes only, and is not a required part of this SAE Aerospace document.

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 724-776-4970 (outside USA), www.sae.org.

AS19692 Pumps, Military, Variable Flow, General Specification For

2.3 Definitions

Refer to ARP4386 for general hydraulic system terms that are used in this Aerospace Standard.

DESIGN OPERATING PRESSURE: The Design Operating Pressure is the normal maximum steady pressure. Excluded are reasonable tolerances, transient pressure effects such as may arise from pressure ripple, reactions to system functioning or demands that may affect fatigue.

NOTES:

1. This term is used in the 14 CFR Part 25/CS-25/JAR 25.1435 (a)(1) airworthiness regulation that is concerned with the strength of each hydraulic system element, including hydraulic components.

2. This definition is too general to be used in pump design; instead "rated discharge pressure" is considered to adequately encompass its implied meaning.

DISCHARGE PRESSURE PULSATIONS: Discharge pressure pulsations are the oscillations of the discharge pressure, occurring during nominally steady operating conditions, at a frequency equal to the number of pistons times the drive shaft speed, or a multiple thereof. The amplitude of the oscillations is the difference between the average minimum and the average maximum oscillations recorded during a one-second trace.

NOTE: This is a characteristic of the pump and the system operating together.

FLAT CUT-OFF PRESSURE COMPENSATED, VARIABLE DELIVERY HYDRAULIC PUMP: This is a pump that provides a nearly constant pressure at the pump output at all flows lower than the maximum flow capacity of the pump (Refer to Figure 1 for the pressure-flow characteristics of this type of pump).

MAXIMUM CASE DRAIN PRESSURE: The maximum case drain pressure is the pressure developed by the pump when the pump case drain port is blocked and the pump is operating at rated discharge pressure.

MAXIMUM FULL-FLOW PRESSURE: The maximum full-flow pressure is the maximum discharge pressure at which the pump control will not be acting to reduce pump delivery at rated temperature, speed, inlet and case drain pressure.

MAXIMUM INLET PRESSURE: The maximum inlet pressure is the maximum steady state inlet pressure at which the pump may be required to operate.

MAXIMUM TRANSIENT DISCHARGE PRESSURE: The maximum transient discharge pressure is defined as the peak value of the discharge pressure recorded during a discrete transient event (normally found when cycling from full flow pressure to rated pressure (zero flow)).

MINIMUM INLET PRESSURE: The minimum inlet pressure is the lowest inlet pressure at which the pump may be required to operate during a system failure or during a system high flow transient condition.

PUMP EFFICIENCY: The pump overall efficiency (including volumetric efficiency) is obtained from the equation:

$$\text{Pump Overall Efficiency (\%)} = (\text{Output Fluid Power/Input Shaft Power}) \times 100 \qquad \text{(Equ.1)}$$

where:

$$\text{Input Shaft Power} = \text{Shaft Torque} \times \text{RPM}$$

$$\text{Output Fluid Power} = (\text{Full - Flow Pressure - Inlet Pressure}) \times \text{Rated Flow}$$

This equation ignores compressibility effects. If this equation is to be used, the flow rate measurement should be made on the compressed flow stream.

To include the effects of expanded flow or compressed flow for output fluid power, the following equations should be used:

$$\text{Output Fluid Power} = \text{Pressure Differential} \times \text{Expanded Flow Rate} \times \left(1 - \frac{\Delta P}{2B}\right) \qquad \text{(Equ. 2)}$$

or

$$\text{Output Fluid Power} = \text{Pressure Differential} \times \text{Compressed Output Flow Rate} \times \frac{(2B - \Delta P)}{2 \times (B - \Delta P)} \qquad \text{(Equ. 3)}$$

where:

ΔP=Pump Pressure Rise

B=Adiabatic Bulk Modulus, determined with the pressure equal to the average of the pump inlet and outlet pressures

PUMP CASE DRAIN PORT (also called the PUMP COOLING PORT): The pump case drain port is the location where the pump case leakage flow is directed out of the pump and returned to the hydraulic system reservoir.

PUMP INLET PORT (also called the PUMP SUCTION PORT): The pump inlet port is the location where the fluid is supplied to the pump by the hydraulic system reservoir.

PUMP OUTLET PORT (also called the PRESSURE PORT or the DELIVERY PORT or the DISCHARGE PORT: The pump outlet port is the location where the pump discharges pressurized flow to the hydraulic system.

PUMP SHAFT DRAIN PORT (also called the DRAIN PORT or the SHAFT SEAL PORT): The pump shaft drain port is the location where any shaft seal leakage flow is collected for external drainage.

PURCHASER: The Purchaser is the organization that has the engineering responsibility for the hydraulic system that includes the pump. Typically, the Purchaser is an aircraft manufacturer, a system supplier or a modification center. The Purchaser is responsible for the compilation of the Procurement Specification.

PROCUREMENT SPECIFICATION: The Procurement Specification is the document that includes the following:

a. Technical requirements

b. Acceptance and qualification test requirements

c. Reliability requirements

d. Quality requirements

e. Packaging requirements

RATED CASE DRAIN PRESSURE: The rated case drain pressure is the nominal pressure at the pump case port at which the pump is required to operate continuously in the system.

RATED DISCHARGE PRESSURE: The rated discharge pressure is the nominal pressure that the pump is required to maintain at rated temperature, rated speed, rated inlet pressure, rated case drain pressure and at zero flow.

RATED ENDURANCE: The rated endurance of a pump is the total number of hours and cycles of operation to be included in the endurance phase of its qualification testing.

RATED FLOW: The rated flow of a pump is the measured volumetric fluid output of the pump under conditions of:

- Rated temperature
- Rated speed
- Rated inlet pressure
- Rated case drain pressure
- Maximum full-flow pressure
- Using the hydraulic fluid specified in the Procurement Specification

NOTE: The flow is measured in the compressed state.

RATED INLET PRESSURE: The rated inlet pressure is the minimum pressure at the inlet port of the pump when it is operating at rated speed, maximum full-flow pressure and rated temperature.

RATED SPEED: The rated speed is the maximum speed at which the pump is designed to operate continuously at rated temperature.

RATED TEMPERATURE: The rated temperature is the maximum continuous temperature of the fluid to be supplied at the inlet port of the pump.

RESPONSE TIME: The response time is the rate of change of displacement of the pump when subjected to a specific discharge circuit transient. On most pump models it is not possible to measure the pump displacement. Instead, a test can be carefully designed wherein it is possible to deduce the change in displacement of the pump by the inspection of the pump discharge pressure. This measurement is called “Response Time” as it is a dynamic characteristic of a pump operating in a specified discharge circuit. It is not strictly an attribute of the pump. For this reason, the term “Response Time” is used throughout this document instead of “Pump Response Time”. In such a test, the response time is the time interval between the instant when an increase (or decrease) in discharge pressure change initiates; and the subsequent instant when the discharge pressure reaches its first maximum (or minimum) value.

SCATTER FACTOR: The scatter factor is the multiplication factor to be applied for hydraulic impulse fatigue testing when pressure impulse testing is conducted on 1 or more test specimen, for example:

No of Test specimens	Factor to be applied for one component life
1	6
2	5.2
3	4.5
4	4.1
5	3.75
6	3.45

STABILITY: The stability of the pump is the freedom from persistent or quasi-persistent oscillation or "hunting" of the delivery control mechanism at any frequency that can be traced to the pump delivery control means, within stated limits in the Procurement Specification.

SOFT CUT-OFF PRESSURE COMPENSATED, VARIABLE DELIVERY HYDRAULIC PUMP: This is a pump that incorporates a control means to reduce the slope of the pressure/flow curve to achieve two objectives:

- Keep the maximum flow at the lower pressure
- Develop full pressure at reduced flow

SUPPLIER: The Supplier is the organization that has the responsibility for the design, production and qualification of the pump. Normally, the Purchaser would approve the Supplier for the design, development and manufacture of these pumps.

3. REQUIREMENTS

The Purchaser shall prepare a Procurement Specification for each pump for which design approval is desired.

3.1 General

The requirements of AS4941 apply with the exceptions and additions specified herein. The Procurement Specification shall take precedence in the case of a conflict between the requirements of this standard and the Procurement Specification.

3.1.1 System Specification

The pump shall be designed for installation in hydraulic systems as defined in ARP4752, and as defined in the Procurement Specification.

3.1.2 System Characteristics

The Procurement Specification shall include the characteristics of the hydraulic system in which the pump is to be used.

3.1.3 Airworthiness Requirements

The hydraulic pump shall comply with Title 14 of the Code of Federal Regulations (14 CFR), Part 25 (for US certified aircraft) or to EASA Certification Specifications (CS)/Joint Airworthiness Requirements (JAR), Part 25 (for European certified aircraft).

The sections in these regulations that are applicable to hydraulic pumps are as follows:

a. 25.581 - Lightning protection

b. 25.1163 - Powerplant accessories

c. 25.1183 - Flammable fluid-carrying components

d. 25.1435 - Hydraulic systems

The impact of these requirements on the design, manufacture and qualification of civil type hydraulic pumps will be referred to in this document.

AS4941 covers the following airworthiness regulations, which also affect the design of civil hydraulic pumps:

a. 25.603 - Materials

b. 25.613 - Material strength properties and design values

c. 25.621 - Casting factors

3.2 Qualification

Pumps furnished under this standard shall be products that have passed the qualification tests specified in the Procurement Specification.

3.3 Functional Requirements

3.3.1 Hydraulic Fluid

The Procurement Specification shall state the applicable hydraulic fluid.

3.3.2 Rated Discharge Pressure

The Procurement Specification shall state the value of the rated discharge pressure.

The following nominal values of rated discharge pressure are commonly used:

a. 1500 psi (10 345 kPa)

b. 3000 psi (20 690 kPa)

c. 4000 psi (27 586 kPa)

d. 5000 psi (34 482 kPa)

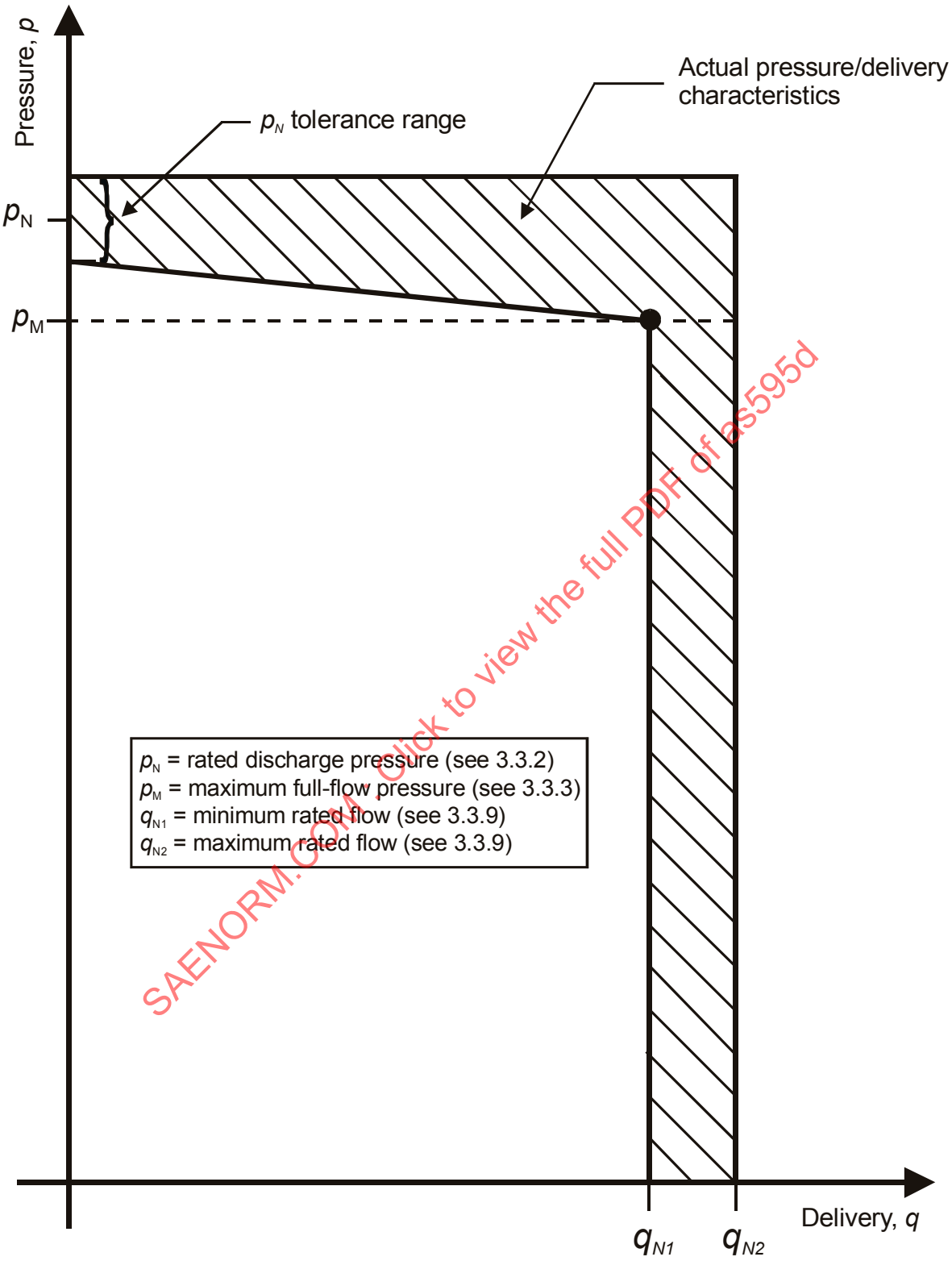
The permissible tolerance range for the rated discharge pressure shall be ±50 psi (±345 kPa), unless otherwise specified in the Procurement Specification. This tolerance range shall be doubled for fluid temperatures below 100 °F (38 °C) or for pump speeds from 25 to 50 percent of rated speed.

The pump shall be able to maintain the rated discharge pressure, using the hydraulic fluid specified in the Procurement Specification, at the following range of conditions:

- From 20 °F (-7 °C) to rated temperature
- From 50 to 100 percent of rated speed
- At rated inlet pressure

3.3.3 Maximum Full-Flow Pressure

The maximum full-flow pressure shall be between 0 to 200 psi (0 to 1380 kPa) less than the rated discharge pressure (see Figure 1), unless otherwise specified in the Procurement Specification.



NOTES:
1. This diagram is given as an indication. It may be presented in a different way, for example, the axes may be reversed.
2. The Procurement Specification may specify the maximum zero-pressure flow.

FIGURE 1 - PRESSURE/DELIVERY CHARACTERISTICS OF A FLAT CUT-OFF PRESSURE COMPENSATED, VARIABLE DELIVERY HYDRAULIC PUMP

3.3.4 Inlet Pressures

3.3.4.1 General: The inlet pressure shall be measured at the inlet port of the pump in a manner that indicates the static head.

3.3.4.2 Rated inlet pressure: The Procurement Specification shall state the value of the rated inlet pressure, which shall be in psia or kPa absolute.

3.3.4.3 Minimum Inlet Pressure: The Procurement Specification shall state the value of the minimum inlet pressure, which shall be in psia or kPa absolute, and if it applies during a short term high flow condition or during a steady state failure condition. When specifying the minimum inlet pressure, the system designer should consider the inertial effects of the fluid in combination with the fastest permissible pump response rate (refer to AIR1922). Any allowable performance degradation when the pump operating at the minimum inlet pressure shall be stated in the Procurement Specification.

The Procurement Specification shall include the circuit impedance for the pump inlet and outlet piping system and/or a complete physical description of the circuit. This is to enable the Purchaser to conduct a dynamic flow analysis to determine the pump operation at the minimum inlet pressure.

3.3.4.4 Maximum inlet pressure: The Procurement Specification shall state the value of the maximum steady state inlet pressure, which shall be in psia or kPa absolute.

3.3.5 Case Drain Pressures

3.3.5.1 Rated case drain pressure: The Procurement Specification shall state the value of the rated case drain pressure.

3.3.5.2 Maximum transient case pressure: The Procurement Specification shall state the value, duration and frequency of occurrence of the maximum transient case pressure.

3.3.5.3 Maximum case drain pressure: The Procurement Specification shall state the value of the maximum case drain pressure.

3.3.6 Case Drain Flow

The Procurement Specification shall state that the pump shall be capable of producing at least a minimum case drain flow to limit the differential temperature between the inlet port and the case drain port to a stated maximum value.

This shall be under the following conditions:

a. Rated discharge pressure (zero delivery flow)

b. Rated temperature

c. Any speed between 50 to 100 percent of rated speed

d. A given maximum differential pressure between case pressure and inlet pressure

The minimum and maximum case drain flow shall be stated at conditions specified in the Procurement Specification.

The Procurement Specification shall state the minimum case flow if the case drain flow is routed to a system heat exchanger.

3.3.7 Rated Fluid Temperature

The Procurement Specification shall state the value of the rated fluid temperature.

3.3.8 Minimum Continuous Fluid Temperature

The Procurement Specification may state the value of the minimum continuous fluid temperature at the pump inlet port.

3.3.9 Rated Output Flow

The Procurement Specification shall state the rated output flow of the pump, at the rated case drain pressure. The rated flow shall be expressed in gallons per minute (gpm) or liters per minute (l/min). The minimum and maximum rated flow (see Figure 1) shall be specified.

3.3.10 Rated Speed

The Procurement Specification shall state the rated speed of the pump. The rated speed shall be stated as revolutions per minute (rpm) of the pump drive shaft.

NOTE: As an indication, the maximum recommended values are given in the Nomographs in Figures 2A and 2B. If speeds are kept well below those indicated by the curves, the operating life may be improved; exceeding the recommended speeds may impact the reliability and life of the pump. However, several system factors such as fluid, temperature, duty cycle, contamination, expected life, etc. will also influence the values. AIR1922 lists some of these influencing factors and their effects.

3.3.10.1 Overspeed: The pump shall be capable of operation at 115 percent of rated speed for the durations and at the conditions of Table 1, unless otherwise specified in the Procurement Specification.

3.3.11 Rated Endurance

The pump shall complete the endurance test without the replacement of functional components including the shaft seal.

3.3.12 Torque and Heat Rejection

The Procurement Specification shall state:

a. The maximum value of input torque or power for rated flow and temperature conditions for the pump

b. The maximum value of heat rejection, or input torque, when the pump is operated at zero flow, at rated temperature and rated speed

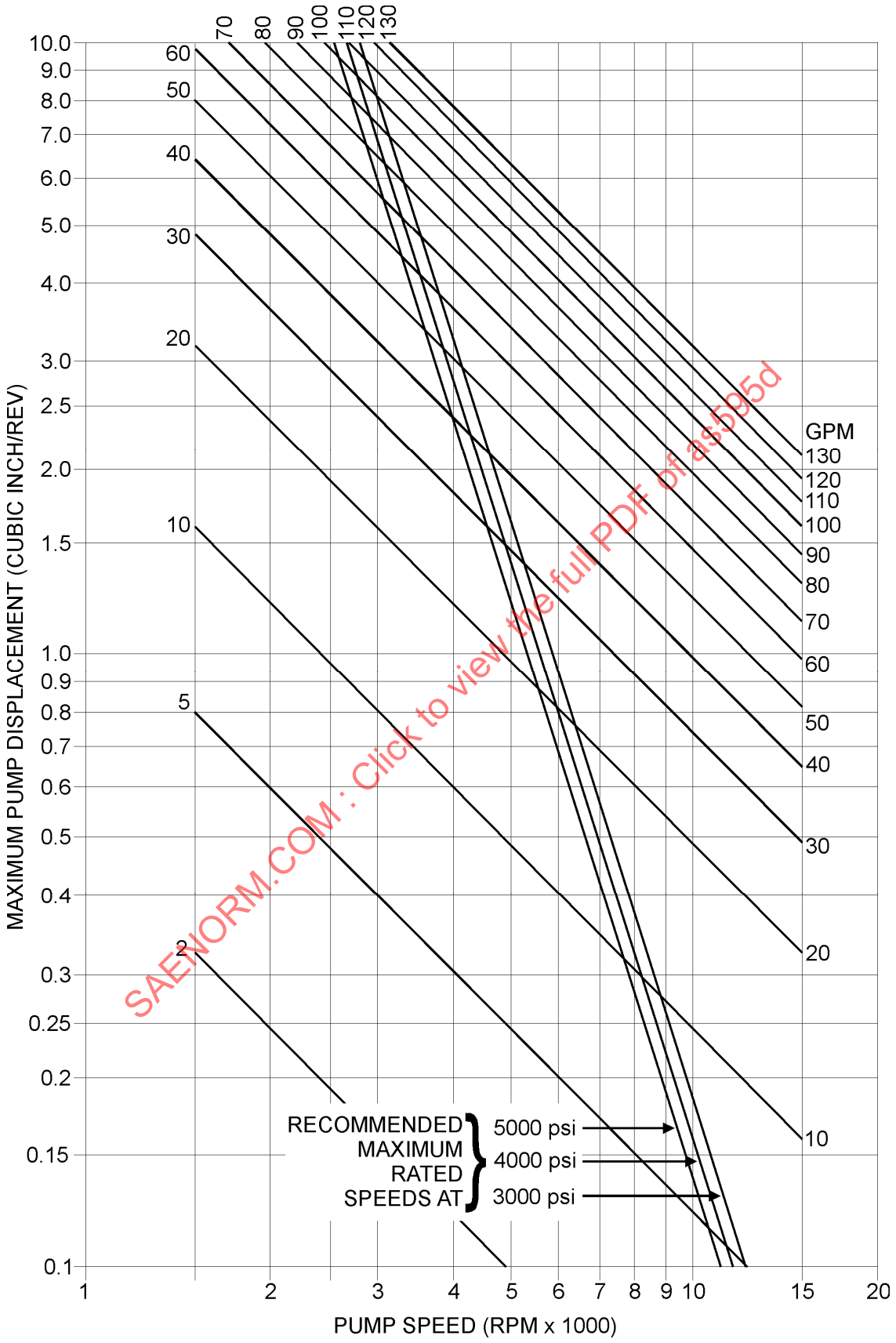


FIGURE 2A - NOMOGRAPH OF MAXIMUM RECOMMENDED VALUES FOR RATED SPEEDS AGAINST PUMP DISPLACEMENT (AMERICAN UNITS)

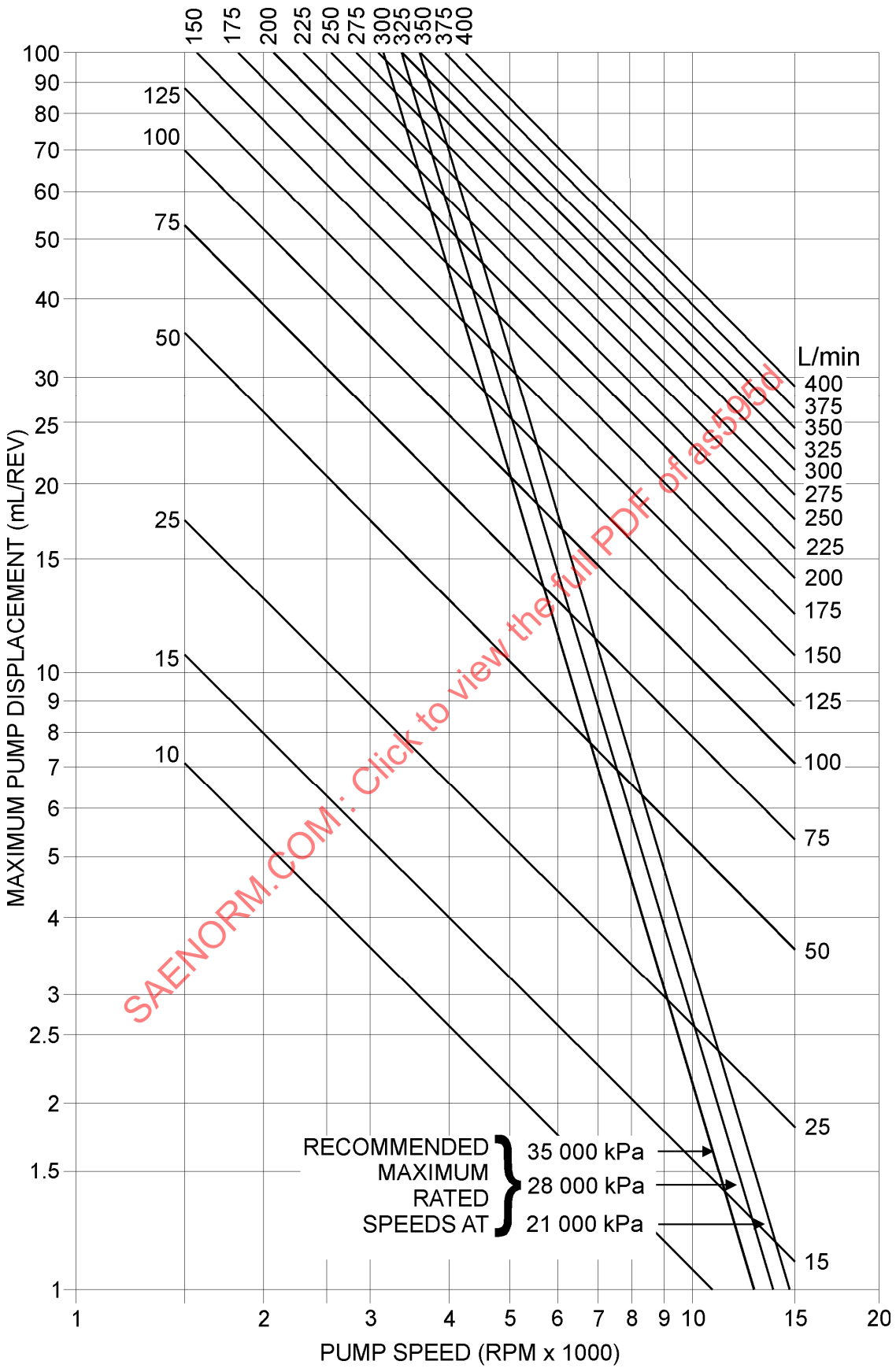


FIGURE 2B - NOMOGRAPH OF MAXIMUM RECOMMENDED VALUES FOR RATED SPEEDS AGAINST PUMP DISPLACEMENT (METRIC UNITS)

3.3.12.1 Overspeed: The pump shall be capable of operation at 115 percent of rated speed for the durations and at the conditions of Table 1, unless otherwise specified in the Procurement Specification.

3.3.13 Rated Endurance

The pump shall complete the endurance test without the replacement of functional components including the shaft seal.

3.3.14 Torque and Heat Rejection

The Procurement Specification shall state:

a. The maximum value of input torque or power for rated flow and temperature conditions for the pump

b. The maximum value of heat rejection, or input torque, when the pump is operated at zero flow, at rated temperature and rated speed

3.3.15 Efficiency

The Procurement Specification may require a target efficiency for a new pump about to be delivered to the Purchaser and a degradation limit in efficiency as an objective after the qualification endurance test.

3.3.16 Discharge Pressure Pulsations

The Procurement Specification shall state the maximum permitted amplitude of the discharge pressure pulsations.

The amplitude of pressure pulsations shall be determined by the test procedure of 6.6.4.

3.3.17 Variable Delivery Control

The delivery control means shall act to increase the delivery of the pump from zero to its maximum full-flow pressure value. This shall be for any given operating speed as the discharge pressure is reduced from rated discharge pressure to maximum full-flow pressure and vice versa.

3.3.18 Response Time

The Procurement Specification should specify the appropriate response time that best meets the overall hydraulic system needs. However, if the response time is not defined, then a maximum response time of 50 ms is recommended.

NOTE: An arbitrary selection of response time, without performing the appropriate system analysis, can result in less than optimum performance and life of both the hydraulic pump and the hydraulic system.

The real-time plot of discharge pressure against time shall be used as the criterion of movement of the delivery control mechanism. All pump models shall have a maximum response time when:

a. Operating at rated inlet temperature

b. At rated speed

c. In a circuit, with the system impedance defined in 6.6.1

In Figures 3 and 4, the time intervals t_1 and t_2 are the response times of the pump as a function of the system impedance.

NOTES:

1. Refer to AIR1922 for inlet pressure requirements and response time

2. The Procurement Specification may state the minimum and maximum response time for the pump to decrease the flow from full-flow to zero (t_1), and a separate minimum and maximum response time for the pump increase the flow from zero to full-flow (t_2)

3.3.19 Stability

The real-time plot of discharge pressure against time shall be used as the criterion of stability.

All pump models shall recover steady-state operation (other than permissible pressure pulsations as specified in 3.3.14) within not more than 1.0 s after the initial response to a change in flow demand. This shall occur for:

a. Any operating condition within the limits stated in the Procurement Specification

b. Any speed greater than 50 percent of the rated speed

When required by the Procurement Specification, the pump manufacturer shall provide an adequate description of the pump dynamic performance to permit the system designer to integrate pump dynamic performance into his complete pump/system analysis.

3.3.20 Maximum Transient Discharge Pressure

The value of the maximum transient discharge pressure shall not exceed:

a. 1000 psi (6897 kPa), as determined in the maximum pressure test specified in 6.6.2, or

b. 125% of the rated discharge pressure, or

c. The maximum pressure specified in the Procurement Specification

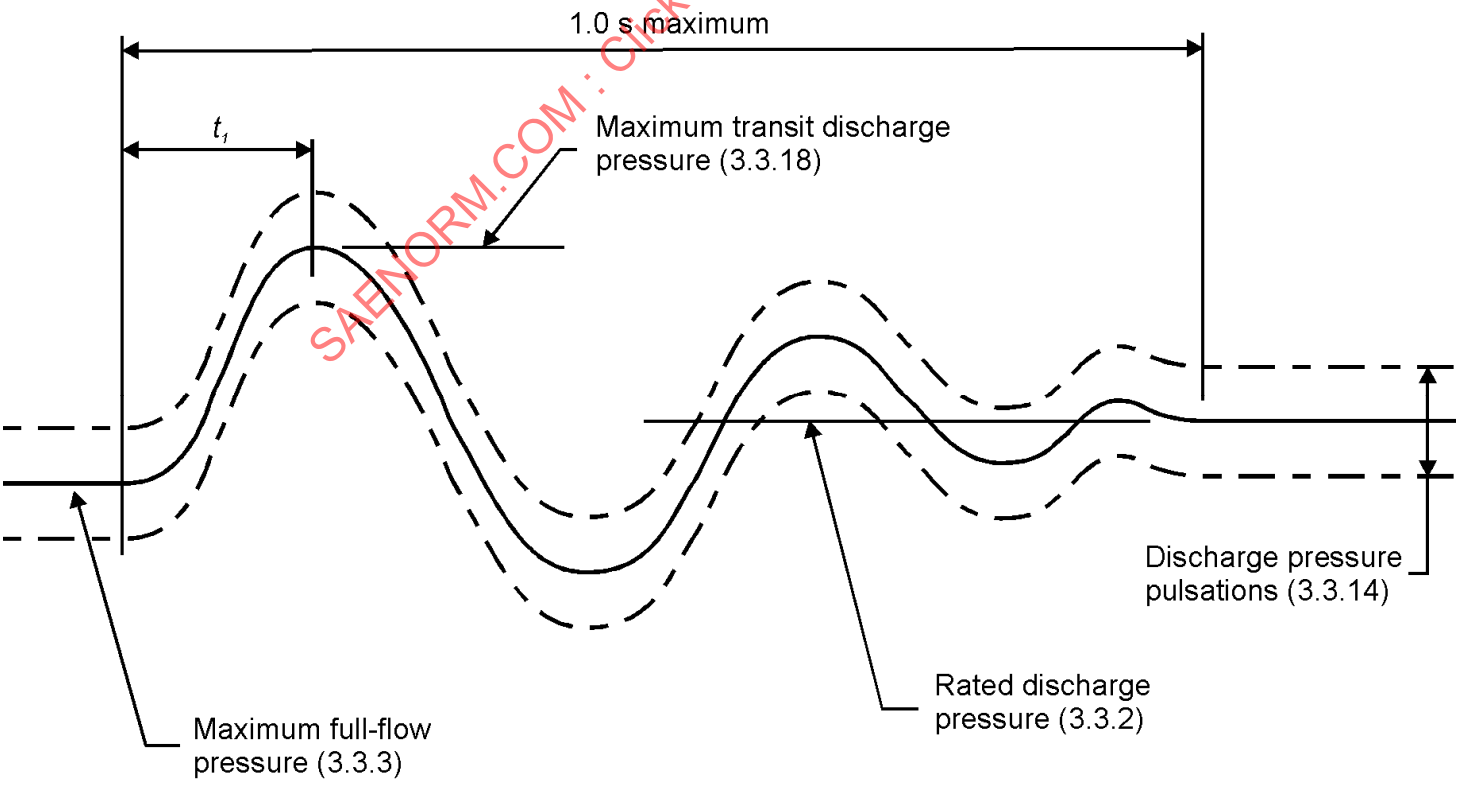


FIGURE 3 - TYPICAL VARIATION OF PRESSURE AGAINST TIME - TRANSIENT FROM MAXIMUM FULL-FLOW PRESSURE TO RATED DISCHARGE PRESSURE (ZERO-FLOW)

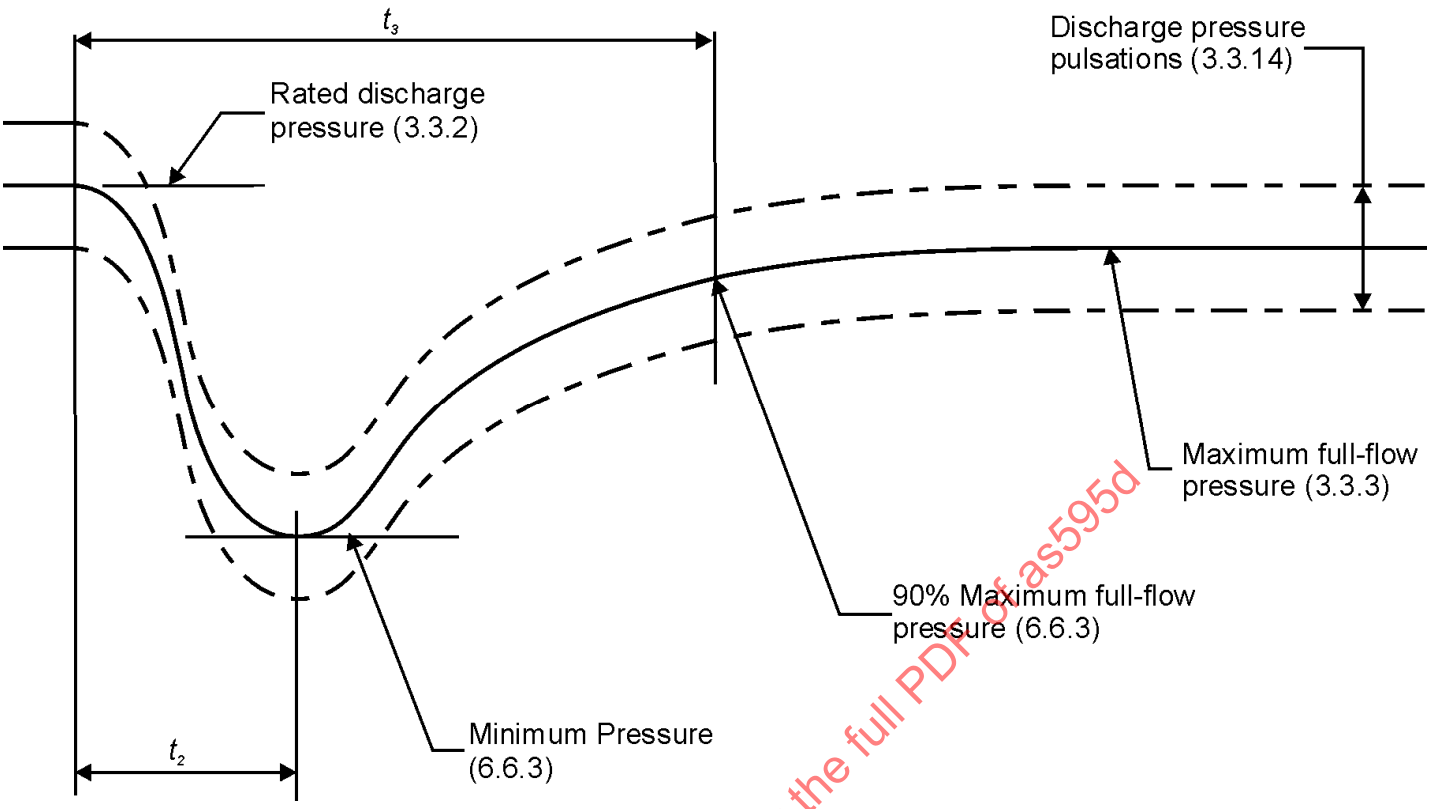


FIGURE 4 - TYPICAL VARIATION OF PRESSURE AGAINST TIME - TRANSIENT FROM RATED DISCHARGE PRESSURE (ZERO-FLOW) TO MAXIMUM FULL-FLOW PRESSURE

3.3.21 Depressurization

If it is required by the Procurement Specification that the pump be depressurized either automatically or remotely, (for example, by means of an electrical signal) the depressurization control shall not, when de-energized, interfere with the normal operation of the variable delivery control.

The Procurement Specification shall state:

a. If a blocking valve is also to be fitted in the pump discharge port to isolate the pump from the system when the pump is depressurized

b. The performance requirements for the pump when it is depressurized, for example:

- Low output pressure
- Low input torque
- Low output pressure and low torque

c. The acceptance and qualification tests for the depressurization control

d. The maximum and minimum operating pressure when full-flow depressurization is required

e. The duty cycle of the depressurizing device including:

- The number of applications
- The percentage of the flight time when the pump is depressurized

3.3.22 Balance

The moving parts of the hydraulic pump shall be inherently balanced and the pump shall not vibrate in such a manner as to cause failure of any part in the pump or drive mechanism at speeds up to the overspeed value specified in 3.3.10.1.

3.3.23 Adjustment

Means shall be provided to adjust the delivery control mechanism to cause zero flow to occur at rated discharge pressure. This adjustment shall, preferably, be continuous or it is acceptable for it to be in steps of less than 1 percent of the rated discharge pressure over a minimum range from 95 to 105 percent of the rated pressure.

The adjustment device shall be capable of being securely locked and it shall be possible to carry out adjustment and locking using only standard hand tools. Where practicable, the adjustment device shall be fitted in such a way that adjustments can be made while operating under full system pressure with negligible loss of fluid.

3.3.24 Safety Wire Sealing

Lead type safety wire sealing shall not be used.

3.3.25 Directionally Critical Components

Wherever practical, internal parts that are subject to malfunction or failure due to reverse installation or out of true position shall have mechanical provisions to ensure that they cannot be installed or assembled incorrectly.

3.3.26 Pump Dry Running

If the supply of liquid to the pump is zero, or less than the volume the pump displaces, for any duration up to the maximum flight time, no elements of the pump shall exit the envelope of the pump. The Procurement Specification shall state the time period and the running speed when the pump will be running under these conditions.

3.4 Environmental Requirements

All pumps shall be designed to operate under the environmental conditions specified below for the design life of the pump without any impairment of function or change in adjustment.

Except as specifically directed herein, testing to demonstrate compliance with these requirements shall not be mandatory.

3.4.1 Altitude

Provided that the inlet and case drain pressures are maintained in accordance with 3.3.4 and 3.3.5 respectively, pump performance shall not be affected by change of altitude from sea level to the maximum specified altitude or vice versa.

3.4.2 Ambient and Pad Temperatures

It shall be assumed that the ambient temperature surrounding the pump shall be such that no heat is transferred to or from the pump, except by normal circulation of the working fluid, unless otherwise specified in the Procurement Specification.

3.4.3 Vibration

Pumps shall be capable of withstanding vibrations excited by the driving means. All pumps shall be designed to withstand the applicable vibration levels as stated in RTCA/DO-160, unless otherwise specified in the Procurement Specification.

For design and test purposes, torsional vibration excited by the driving means shall be considered negligible. As part of the qualification tests, all pump models shall be subjected to the vibration tests specified in 6.14.

3.4.4 Operational Shocks and Crash Safety

All pumps shall be designed to withstand sustained accelerations in accordance with RTCA/DO-160 requirements, unless otherwise specified in the Procurement Specification.

3.4.5 Other Environmental Conditions

The pump shall be designed to comply with the following sections of RTCA/DO-160, unless otherwise specified in the Procurement Specification:

a. Fluids susceptibility. The Procurement Specification shall state the relevant fluids that have to be considered

b. Salt spray. This requirement only applies if the pump is mounted in an unpressurized part of the aircraft and is defined as Category S

c. Water resistance. The Procurement Specification shall state the applicable Category for the pump

d. Sand and dust

Tests shall be carried out to show compliance with the salt spray and sand and dust requirements. Compliance with the other requirements can be demonstrated by design analysis.

If a solenoid depressurization valve is used to control the pump, then compliance with electro-magnetic interference (EMI) requirements, as specified in the Procurement Specification, shall also apply.

3.4.6 Fire Resistance

The hydraulic pump must be fire resistant if it is installed in an area that is subjected to engine fire conditions (that is, an engine driven pump). This is in order to obtain compliance with the 14 CFR Part 25/CS-25/JAR 25.1183 requirement.

The Procurement Specification shall state the running speed of the pump, and the flow through the pump that will occur during engine fire conditions. This is to enable the necessary precautions to be incorporated into the pump design in order for the pump to be shown to fully comply with this requirement.

3.4.7 Sonic Fatigue

The pump shall not be adversely affected or prematurely failed due to external noises, as stated in the Procurement Specification.

3.4.8 Acoustic Noise

The pump shall not generate acoustic noise greater than that stated in the Procurement Specification.

3.5 Installation Requirements

3.5.1 Dimensions

Dimensions pertinent to the installation of pumps in aircraft shall be specified on the Supplier's installation drawing and in the Procurement Specification.

3.5.2 Weight

The dry weight of the completely assembled pump shall be stated on the Supplier's installation drawing.

The Supplier should also provide an estimate of the weight of fluid in a completely filled pump so that the weight of the pump as installed in the aircraft can be determined.

3.5.3 Mounting

The Procurement Specification shall state the flange design.

3.5.3.1 Orientation: The case drain port of the pump should be located at or near the top of the pump as it is installed on its drive pad. The shaft drain port should be located at or near the base of the pump as it is installed on its drive pad. The reorientation of the pump due to aircraft attitude shall not affect pump operation.

3.5.3.2 Direction of rotation: The direction of rotation of the pump shall be clearly and permanently marked on an exposed surface of the pump housing.

3.5.4 Drive Coupling

The drive coupling shall be a replaceable part of the pump assembly and shall incorporate a shear section as a means to comply with 14 CFR Part 25 /CS-25/JAR 25.1163(c) regulation. The drive coupling shall only fail at its shear section. The drive coupling shall be held in place in the pump by a positive retainer.

The Procurement Specification shall state the interface between the coupling and the driver, including the coupling spline lubrication at the engine accessory gearbox end or the non-metallic insert in the gearbox.

3.5.4.1 Drive Coupling Materials: The material chosen for the drive coupling, and the parts of the pump that interface with the drive coupling, shall have excellent wear resistance properties.

Consideration shall be given to the use of non-metallic spline inserts in the pump and at the pump/gearbox interface (if the gearbox does not already incorporate a non-metallic insert) in order to achieve the required wear resistance requirements. However, care must be taken in the design and installation of the non-metallic inserts so as to prevent their premature failure.

3.5.5 Ports

3.5.5.1 Pump Outlet Port: Unless otherwise specified in the Procurement Specification, the pump outlet port shall be as follows:

- For pumps with rated discharge pressure up to 3000 psi (20 690 kPa), they shall be in accordance with AS1300 or AS33649
- For pumps with rated discharge pressure greater than 3000 psi (20 690 kPa), they shall be in accordance with AS1300

3.5.5.2 Pump Inlet and Case Drain Ports: Unless otherwise specified in the Procurement Specification, the pump inlet and case port shall be in accordance with AS1300 or AS33649.

3.5.5.3 Pump Shaft Seal Ports: Unless otherwise specified in Procurement Specification, the pump shaft seal port shall be in accordance with AS33649.

3.5.5.4 Structural Strength: The structural design of the ports and of the affected sections of the pump housing shall be such as to withstand the application of 250 percent of the maximum wrenching torque required for making the tubing connection, without permanent distortion or impairment of function.

3.5.5.5 Port Markings: The inlet, outlet, case drain and shaft drain ports shall be identified on each pump by clear and permanent markings.

3.6 Detail Requirements

3.6.1 Materials

In accordance with AS4941 requirements.

3.6.1.1 Metals: In accordance with AS4941 requirements.

3.6.2 Corrosion Protection

In accordance with AS4941 requirements.

3.6.3 Castings

In accordance with AS4941 requirements.

3.6.4 Reclaimed Materials

In accordance with AS4941 requirements.

3.6.5 Seals

In accordance with AS4941 requirements, except that the external seals shall have a minimum cross-section of 0.103 inch (nominal) or larger.

3.6.6 Standard Parts

In accordance with AS4941 requirements.

3.6.7 Marking

3.6.7.1 Identification of the product: The pump must be marked for identification in accordance with standard practices (refer to ARP1288) and the Purchaser's requirements, as a means of compliance with the 14 CFR Part 25/CS-25/JAR 25.1301 requirement.

3.6.7.2 Nameplate: Unless otherwise specified in Procurement Specification, a nameplate containing the following information (see Figure 5) legibly filled in shall be securely attached to the pump. The information shall be marked in the spaces provided.

PUMP, HYDRAULIC, VARIABLE DELIVERY, AIRCRAFT
Procurement Specification No._____ Mfrs. part No.*_____ Mfrs. name or trademark_____ Serial number_____ Fluid_____

* (or identification)

FIGURE 5 - NAMEPLATE DATA

The following in Figure 6 is to be provided, if required by the Procurement Specification:

Rating:		
Delivery	_____	gpm*
Pressure	_____	psi+
Speed	_____	rpm

*(or l/min; +(or kPa)

FIGURE 6 - ADDITIONAL NAMEPLATE DATA

The Procurement Specification shall state any other additional required nameplate data.

The color of the nameplate shall be purple and aluminum for pumps designed for AS1241 hydraulic fluids. The color of the nameplate shall be black and aluminum for pumps designed for MIL-PRF-5606, MIL-PRF-83282 or MIL-PRF-87257 fluids.

3.6.8 Electro-Conductive Bonding

14 CFR Part 25/CS-25/JAR 25.581 requirement requires that the aircraft must be protected against the catastrophic effects of lightning. In order to comply with this regulation, the hydraulic pump must have a facility to enable it to be effectively bonded to the airframe. The Procurement Specification shall state the bonding requirements.

3.7 Strength Requirements

The Procurement Specification for the pump shall state the design operating pressure for the inlet, delivery and case pressure parts of the pump.

3.7.1 Proof and Ultimate Pressure Requirements

3.7.1.1 Proof pressure requirements: The pump shall withstand the proof pressure (the design operating pressure multiplied by 1.5) without permanent deformation that would prevent it from performing its intended functions. This is in order to comply with 14 CFR Part 25/CS-25/JAR 25.1435(a)(1) requirements.

3.7.1.2 Ultimate pressure requirements: The pump shall withstand the ultimate pressure (the design operating pressure multiplied by 2.0) without rupture. This is in order to comply with 14 CFR Part 25/CS-25/JAR 25.1435(a)(1) requirements.

3.7.2 Impulse (Fatigue) Requirements

The pump shall withstand the fatigue effects of all cyclic pressures, including transients and externally induced loads, taking into consequence the effect of pump failure. This is in order to comply with 14 CFR Part 25/CS-25/JAR 25.1435(a)(4) requirements.

The Procurement Specification shall state:

- The overall predicted duty cycle for the outlet, inlet and case parts of the pump, throughout the lifetime of its application
- The scatter factor that is to be applied for analysis or fatigue (pressure impulse) testing
- Any externally induced loads (for example, structural or thermal)

In addition, when defining the duty cycle for the impulse testing, the following should be considered:

a. The pressure variations due to the pump pulsation levels

b. The peak transient pressure generated by the pump as it reacts to changes in flow demands

NOTE: The test pressure cycles to be used are:

a. Basic Pressure Cycles:

- Case port – 0 to rated case drain pressure – 0 psi (kPa)
- Outlet port – 0 to rated discharge pressure – 0 psi (kPa)
- Inlet port – 0 to maximum inlet pressure – 0 psi (kPa)

b. Transient Pressure Cycles*: Nominal pressure** - peak transient pressure spike - nominal pressure

*To be applied at the inlet and outlet ports

** Nominal pressure for the outlet port is the rated discharge pressure; nominal pressure for the inlet port is the hydraulic reservoir pressure (i.e. no flow being supplied by the pump)

3.7.3 Combined Pressure and Structural Load Requirements

If the pump is subjected to externally applied loads as it is being operated, then it has to be designed to meet the following strength requirements as mandated by the airworthiness regulations:

- The design operating pressure in combination with limit structural loads that are imposed on the pump. No permanent or temporary deformation of the pump is permitted under these conditions that would prevent it from performing its intended function. This is in order to comply with 14 CFR Part 25/CS-25/JAR 25.1435(a)(2) requirements.

- The design operating pressure multiplied by 1.5 in combination with ultimate structural loads that are imposed on the pump. The pump shall not rupture. This is in order to comply with 14 CFR Part 25/CS-25/JAR 25.1435(a)(3) requirements.

The Procurement Specification shall state the limit and ultimate structural loads.

3.8 Design and Construction

In accordance with AS4941 requirements.

3.9 Maintainability

In accordance with AS4941 requirements.

3.10 Reliability Requirements

In accordance with AS4941 requirements.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection

In accordance with AS4941 requirements.

4.2 Classification of Tests

In accordance with AS4941 requirements.

4.3 Test Stand Requirements

The following tolerance limits are set for the required steady state operating conditions for the test stands that are employed for the acceptance tests and the qualification tests, unless otherwise agreed to between the Supplier and the Purchaser:

a. Inlet pressure: ±2 percent of rated inlet pressure, but not less than ±5 psi (34 kPa)

b. Case pressure: ±2 percent of rated case pressure, but not less than ±15 psi (103 kPa)

c. Delivery pressure: ±2 percent of rated delivery pressure, but not less than ±30 psi (207 kPa)

d. Inlet temperature: -70 to +110 °F, within ±5 °F (-57 to +43 °C, within ±3 °C); +110 to +225 °F, within ±10 °F (+43 to +107 °C, within ±6 °C)

e. Pump shaft speed: within ±100 rpm

f. Flow: within ±2 percent of rated flow

g. Torque: ±2 percent of pump maximum input torque

The accuracy of the instrumentation shall be consistent with the measurement tolerances required.

Filtration Requirements: In accordance with AS4941 requirements, except for the qualification endurance testing (see 6.9).

5. ACCEPTANCE TESTS

Each hydraulic pump submitted for delivery under a procurement contract shall be subjected to the acceptance test requirements specified below. These shall consist of:

a. Visual and dimensional examinations

b. A test program to determine product conformance to the dimensional, workmanship, functional and performance requirements of this Standard and the Procurement Specification. The test program is specified in 5.2.

5.1 Examination of the Product

The pump shall be examined to determine conformance with the applicable standards and all requirements of this standard and of the Procurement Specification, for which there are no specific tests.

5.2 Test Program and Inspection Methods

Throughout the test program, there shall be no external leakage sufficient to form a drop except that the shaft seal may leak at a rate not to exceed 12 drops per hour, or as stipulated in the Procurement Specification.

Starting with 5.2.3 (Load Cycles), the hydraulic fluid in the test circuit shall be as specified in the Procurement Specification. Filter elements qualified to MIL-F-8815, or as specified in the Procurement Specification, shall be installed in the pump inlet, outlet and case drain port lines of the test set-up. The rating of the filter elements shall be agreed between the Purchaser and the Supplier.

The Supplier shall repeat the applicable parts of the conformance test procedure if, at any phase of testing, working parts require replacement. The break-in run portion may be omitted if the rotating group assembly was not affected.

5.2.1 Proof Pressure Tests

These tests may be conducted at normal operating temperature, either statically or with the pump in operation. There shall be no evidence of permanent deformation following the tests.

The outlet port shall be pressurized for at least one minute to the proof pressure stipulated in the Procurement Specification. With the outlet port at rated pressure, the case drain and inlet ports shall be pressurized for at least one minute to the proof pressures stipulated in the Procurement Specification.

NOTE: During this test, the shaft seal leakage may exceed the maximum allowable leakage for normal operation. If this does occur, it shall not be considered as a test failure.

5.2.2 Break-in Run

The break-in run may be conducted at any desired operating conditions as deemed optimal by the Supplier, but must include at least 15 minutes of operation at rated speed and temperature while at maximum full-flow pressure.

5.2.3 Load Cycles

A step-function load shall be imposed causing the pump to cycle from rated discharge pressure (no flow) to maximum full-flow pressure at 6 cycles per minute for at least 15 minutes, or as specified in the Procurement Specification, with equal dwells at each load condition.

5.2.4 Tear Down Inspection

A tear down inspection shall be conducted after completion of the proof, break-in and cycling tests on a minimum of 3 pumps of a given model of an initial production run or as specified in the Procurement Specification. The pumps shall be disassembled and inspected; if all parts are in acceptable condition, the pump shall be reassembled and the test program continued. The requirements of this paragraph may be omitted after the last pump has successfully passed the inspection.

The tear down inspection shall be reinstated whenever the following changes in a production program occur:

a. Continuity of manufacturing is interrupted. Permissible periods of production interruption shall be designated in the Procurement Specification

b. Alternate tooling and production facilities are designated

The tear down inspection shall also be reinstated if a failure occurs during conformance testing, which:

- Upon inspection reveals visible damage to the pump, and
- May not, in all cases, be detected by measurable test parameters

5.2.5 Fluid Contamination Test

5.2.5.1 General: This test shall be conducted to prevent shipment of a functionally acceptable but materially deteriorating pump. The fluid from the pump case drain shall be checked for contamination as agreed to between the Supplier and the Purchaser.

5.2.5.2 Use of Inline Particle Counters: Ideally, inline particle counters should be used to check for an incipient pump failure by continuously monitoring the particle sizes. If there is a noticeable increase in the number of particles in the case drain line after the break-in run has been completed, then the pump should be stopped and removed for a tear down inspection.

5.2.5.3 Filter Patch Test: If inline particle counters are not available, then the use of filter patches check for an incipient pump failure is an acceptable alternative means.

The operating time and duty shall be chosen such as to yield the most significant patch information for the particular pump model, and shall be a permanent part of the acceptance test procedure along with the filter membrane specifics.

The Procurement Specification shall make provisions for the establishment of a preliminary patch standard before the start of the quality conformance tests of the first pump to be delivered under the contract. This preliminary patch standard may be modified by agreement of the contracting parties until the completion of the functional test of the 25th pump to be delivered under the contract, or as agreed between the Purchaser and the Supplier. Thereafter, the standard in effect for that test will become the standard for the remainder of the contract.

5.2.5.3.1 Filter Sampling Method: Check the fluid in the pump case drain filter bowl for contamination accumulated during the functional test performed in accordance with 5.2.2 and 5.2.3.

5.2.5.3.2 Patch Preparation: Collect the fluid in the filter bowl in a clean container. Rinse both the filter bowl and element with the appropriate volume of a suitable fluid solvent and add to the applicable container.

The total resulting fluid shall be passed through a membrane having a diameter of approximately 1.85 inch (47 mm), which will trap contaminant in each filter bowl. The Procurement Specification shall state the membrane material. Wash the membrane free of fluid with the appropriate volume of fluid solvent. After drying, the resultant filter patch shall be coated with clear lacquer and permanently attached to the log sheet of the test.

All fluid solvent shall be filtered through a 0.45 µm pore size membrane prior to use in all stages of the patch preparation procedure.

5.2.5.3.3 Patch comparison: Each filter patch specified in the acceptance test procedure shall be compared with the standard patch then in effect and any discrepancy noted in the test log.

If the contamination level exceeds that of the standard, the filter patch test may be repeated. The second patch shall show equal or less contaminant than the standard patch to be acceptable. If it does not, up to 2 additional patch tests may be run to establish the trend. If the patches remain unacceptable, the pump should be disassembled to determine the source of the contamination and corrective action taken.

5.2.6 Calibration

During the calibration tests, the test conditions shall be as specified in the Procurement Specification. Typically, these are:

- Rated inlet and case pressures
- Rated inlet fluid temperature or typical system fluid temperature
- Normal room ambient conditions

The pump shall be tested for at least the following characteristics and the results shall conform to the limits of the Procurement Specification:

a. Rated discharge pressure variation as the pump speed is varied from 50 to 100 percent of rated speed

b. There shall be no indication of pressure control instability as the pump speed is varied from 50 to 100 percent of rated speed through the flow range. The Procurement Specification shall define specific system conditions, if any are required

c. The flow of the pump at maximum full-flow pressure and at rated speed shall be measured and recorded. The flow may be measured in the low-pressure side of the discharge line provided adequate compensation is made for fluid compressibility when stating the value

d. The case drain flow at rated discharge pressure and at rated speed shall be measured and recorded

e. The input torque at maximum full-flow pressure and/or at rated discharge pressure shall be measured if required by the Procurement Specification. This test need not be conducted if pump torque is not especially critical in the application

5.2.7 Electro-Conductive Bonding

Measure the electrical resistance between any point on the mounting flange face and specified points on the pump (for example, the pump inlet, case, delivery and shaft seal connections). It shall not be greater than the value specified in the Procurement Specification.

5.3 Preparation for Shipment

In accordance with AS4941 requirements.

5.4 Storage and Packing

In accordance with AS4941 requirements.

6. QUALIFICATION TESTS

Qualification tests, for the purposes of checking whether the pump design conforms to the requirements of this Standard and the Procurement Specification, shall consist of the tests specified herein.

6.1 Qualification Procedure

6.1.1 Qualification by Similarity

In accordance with AS4941 requirements.

6.1.2 Pump Qualification Test Report

In accordance with AS4941 requirements.

6.2 Range of Qualification Tests

The qualification tests shall be conducted on pumps that are fully representative of the pumps to be manufactured.

The number of pumps to be used during the qualification testing shall be agreed between the Supplier and the Purchaser.

The qualification tests to be carried out are as follows:

a. Expanded envelope acceptance tests (see 6.3)

b. Fluid immersion test (see 6.4)

c. Calibration (see 6.5)

d. Heat rejection test (see 6.5.3)

e. Maximum pressure test (see 6.6.2)

f. Determination of response time test (see 6.6.3)

g. Pressure pulsation test (see 6.6.4)

h. Minimum inlet pressure test (see 6.7)

i. Solenoid tests (see 6.8)

j. Endurance test (see 6.9)

k. Low temperature and thermal shock tests (see 6.10)

l. Other environmental tests (see 6.11)

m. Fire resistance test (see 6.12)

n. Proof pressure test (see 6.13.1)

o. Ultimate pressure test (see 6.13.2)

p. Combined pressure and structural test (see 6.13.3)

q. Vibration test (see 6.14)

r. Drive coupling shear test (see 6.15)

s. Any additional tests required by the Procurement Specification

6.3 Expanded Envelope Acceptance Tests

Those acceptance tests that are also part of the qualification test program shall be performed exactly as specified in 5.2, except that:

a. The pressure control test of 5.2.6 shall be extended to check the discharge pressure at cut-off, as well as the pump stability, throughout the complete fluid temperature and speed range, as specified in 3.3.2

NOTE: The low temperature test is defined in 6.10.1.

b. The shaft seal leakage is allowed to degrade to a maximum of 2 ml/hr, or as stipulated in the Procurement Specification. This shall be throughout the duration of the qualification program

6.4 Fluid Immersion Test

In accordance with AS4941 requirements.

NOTE: The mating electrical connectors are to be installed before starting the test.

6.5 Calibration

6.5.1 Pump Inlet Pressurized

Regulate the pressure at the pump inlet port to the rated inlet pressure at full-flow and rated speed conditions.

6.5.2 Flow Rate and Driving Torque Values

Determine values of flow and driving torque at 50 percent, 75 percent, 100 percent and 110 percent of rated speed. At each of these speeds, make four sets of flow and torque recordings at 25 percent, 50 percent, 75 percent and 100 percent of maximum full-flow pressure and rated discharge pressure and at five equally spaced increments of flow between zero flow and maximum full-flow pressure.

Perform calibrations at the rated inlet condition specified in 3.3.4 and 3.3.7, unless otherwise specified in the Procurement Specification. Flow measurements may be made in the line downstream of the load valve, but shall be corrected for fluid compressibility.

6.5.3 Heat Rejection Test

6.5.3.1 Principle

The principle of this test is to measure the rate of heat rejection of the pump over the expected normal range of operating conditions. The rate of heat rejection at specified conditions shall be equal to the difference between the input and output power of the pump at those conditions.

The output power may be calculated on the basis of flow measurements in the low-pressure side of the discharge line, provided that adequate compensation is made for fluid compressibility when calculating output power.