



AEROSPACE RECOMMENDED PRACTICE

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Superseding ARP4940

Application Guide for Aerospace Hydraulic Motors

RATIONALE

It was brought to the committee's attention that check valves in Figures 9 and Figure 11 had been drawn backwards. This change corrects this with a Limited Scope Ballot.

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Documents

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1. SCOPE

This SAE Aerospace Recommended Practice (ARP) is an application guide for fixed and variable displacement hydraulic motors. It provides details of the characteristics of fixed and variable displacement hydraulic motors, architectures, circuit designs, controls, and typical applications. The applications include airborne and defense vehicles with emphasis on high performance applications.

1.1 Purpose

The purpose of this document is to apprise the system designer of the available options in the control and application of hydraulic motors and it provides guidance in how to integrate them in a control system.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and 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 +1 724-776-4970 (outside USA), www.sae.org.

AIR1899	Aerospace Military Aircraft Hydraulic System Characteristics
AIR5005	Aerospace - Commercial Aircraft Hydraulic Systems
ARP1280	Aerospace - Application Guide for Hydraulic Power Transfer Units
ARP1383	Aerospace - Impulse Testing of Hydraulic Components
ARP4386	Terminology and Definitions for Aerospace Fluid Power, Actuation and Control Technologies
AS595	Aerospace - Civil Type Variable Delivery, Pressure Compensated, Hydraulic Pump
AS7997	Motors, Aircraft Hydraulic, Constant Displacement, General Specification for
AS19692	Aerospace - Military Type Variable Delivery, Pressure Compensated Hydraulic Pump

2.2 Definitions

Refer to ARP4386 for terms that are generally used in this document.

High speed applications, in the context of hydraulic motors as discussed in this document, are those where speeds are approaching or exceeding the typical rated speeds for pumps of similar displacements as defined in AS595 and AS19692.

High performance applications, in the context of hydraulic motors as discussed in this document, are those where rapid changes of speed occur in a cyclic manner during the life of the motor.

Windage is defined as the mechanical torque required to overcome the resistance of the rotating group of a hydraulic pump or motor due to the hydraulic fluid surrounding the rotating group. The torque is a function of rotational speed.

3. MOTOR DESIGNS

See Appendix A for design parameters and specification guidelines for hydraulic motors.

3.1 Fixed Displacement Motors

3.1.1 Design

Fixed displacement motors designs include diverse technologies such as piston, vane, and gear types. For high pressure applications, piston motors are generally used. The common piston motor designs are axial piston inline and bent axis types.

Inline designs are simpler, lighter, and typically are lower cost. The bent axis designs have lower mechanical and volumetric losses, and have better break-out and low speed characteristics

3.1.2 Performance Characteristics

The displacement of a fixed displacement motor is selected to provide the necessary torque required by the application, by considering that the theoretical torque is the product of displacement and differential (inlet - outlet) pressure. Once the displacement is selected, the theoretical flow required to operate the motor at the required speed is the product of displacement and speed.

Output speed is a function of input flow less volumetric losses, which are typically pressure dependent. The losses include internal leakage around the pistons and under the cylinder block/barrel and piston shoes or other piston linkages. Since the losses are pressure, not speed dependent, the volumetric efficiency increases with speed.

Output torque losses result from friction and windage, and are speed and pressure dependent. At higher speeds, windage is a dominant factor. At break-out, torque efficiency is usually lower than at moderate speeds, then decrease at higher speeds.

3.2 Variable Displacement Motors

3.2.1 Design

See Figure 1.

Variable displacement motors are controlled by a swash plate, whose angle is controlled to vary the displacement of the motor. Displacement is generally a function of the tangent of the swash plate angle.

They lend themselves most readily to variable displacement adaptation for both uni-directional and bi-directional application. For uni-directional applications, such as a generator drive, the swash angle varies from zero to maximum in one direction only. For bi-directional applications, the displacement varies from positive to negative passing through the zero displacement position. These implementations are called "overcenter" because the swash angle crosses the center on zero-displacement point. It is important to note that in overcenter motors, the Inlet (high pressure) and Return (low pressure) ports always remain unchanged regardless of direction of rotation - the direction is determined by the swash plate position on either side of center.

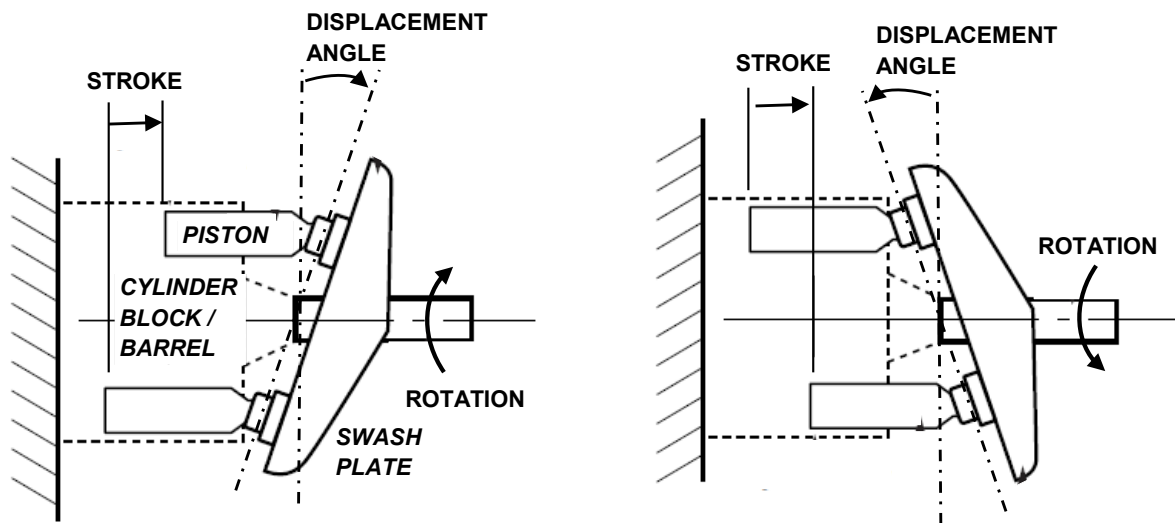


Figure 1 - Over-center variable displacement motor

3.2.2 Performance Characteristics

3.2.2.1 Torque Output - Continuous Rotation

See Figure 2 for a typical example.

When the motor is running, the torque output is directly proportional to displacement with an offset to balance losses. This offset increases with speed. The torque characteristic is continuous through null as long as the direction of rotation does not change.

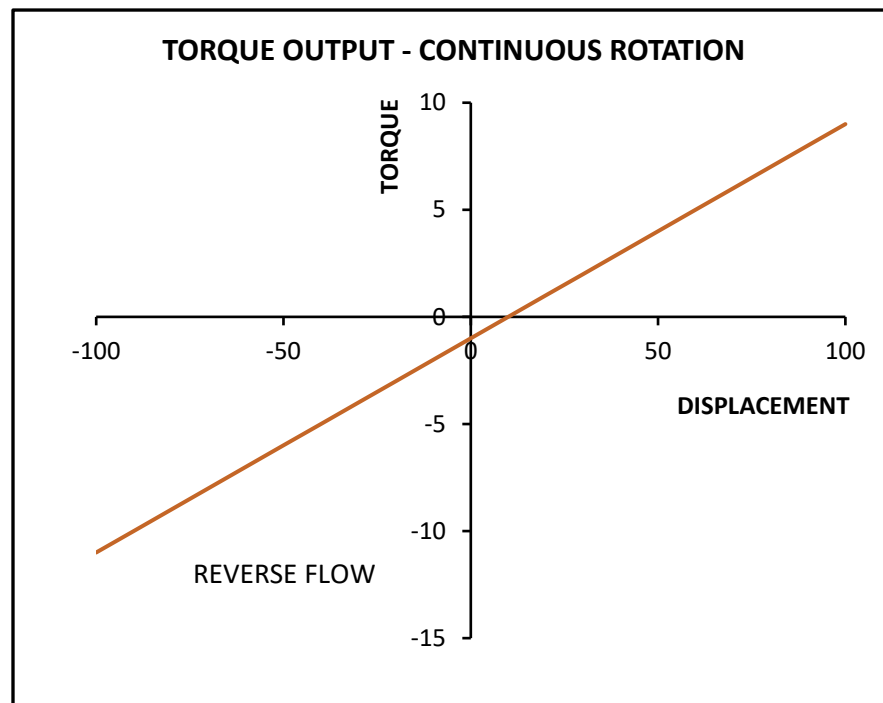


Figure 2 - Torque (example) output versus displacement, continuous rotation

3.2.2.2 Torque Output - Starting

See Figure 3 for a typical example.

When starting the motor, there is a discontinuity as the motor requires approximately 30% displacement to start even against low loads. This should be considered in the control system design.

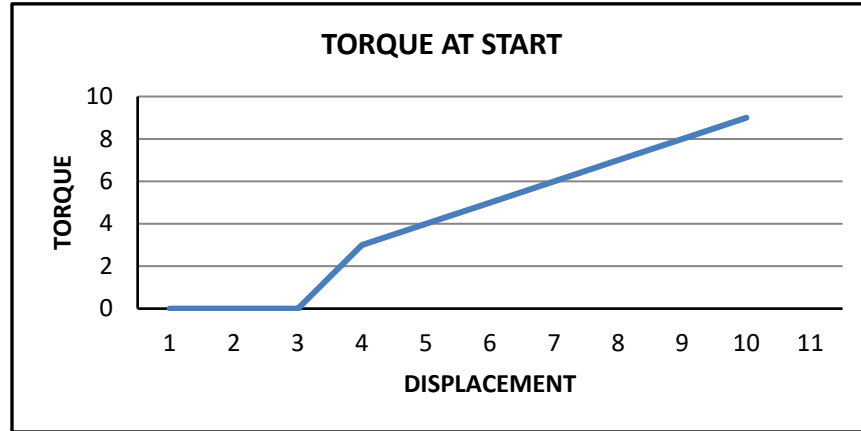


Figure 3 - Torque output versus displacement, starting (example)

3.2.2.3 Reverse Flow

When rotating in one direction and braking is required, displacement in the opposite direction is commanded. This will reverse the flow direction. This means the unit will operate as a pump drawing flow from the low pressure port and discharging it into the high pressure port, creating the braking torque. The hydraulic system should be designed to accommodate this, i.e., the main system should allow this or provisions around the motor should allow it. If the braking energy is small this can be done with cross port relief valves. In the case of a hoist, which could have longer periods of operation with negative loads, this may not be possible.

4. OPERATIONAL CHARACTERISTICS

4.1 System Architecture

See Figures 4 (i) and 4(ii).

Hydraulic motors and the loads that they drive can be integrated in either open loop or closed loop architectures. This refers to the method the motors are connected to the hydraulic sources, not the scheme that is used to control the motors and their loads.

In conventional “open loop” or “central” hydraulic systems, as shown in Figure 4 (i), one or more pumps pressurize a common hydraulic trunk line, to which multiple consumers are connected. In this manner, consumers can be linear actuators and/or motor driven actuators, with each consumer extracting power from the central system independently, but not to exceed the total power available. Such a system architecture is used for powering flight controls, landing gear, brakes, and utility systems such as winches, hoists, doors, and special mission related equipment.

An alternate architecture is the “closed loop” system, as shown in Figure 4 (ii), where a pump is directly connected to, and dedicated to a single consumer, and the pump and consumer are controlled simultaneously to achieve the desired torque and speed output. These systems are rare on aircraft applications, but may be found on afterburner exhaust nozzle controls, propeller pitch controls and remotely located doors and winches.

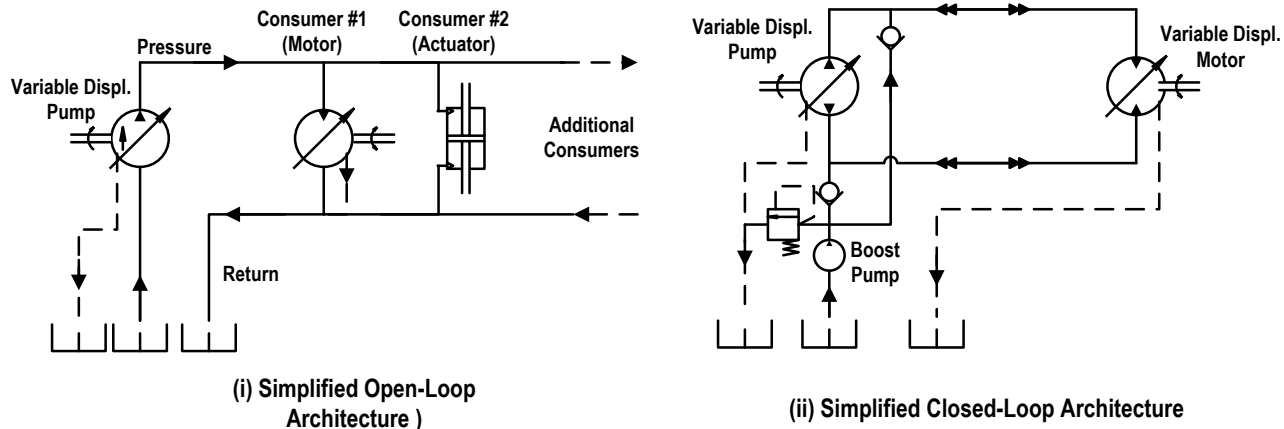


Figure 4 - Examples of closed and open loop hydraulic system architectures

4.2 System Integration Considerations

The integration of the motor into the actuation and hydraulic systems should take into account the nature of the load, the type of control desired, and the characteristics of the hydraulic system which provides power to the actuator. In particular, the following system parameters should be considered:

4.2.1 Load Inertia

The total load inertia, including that of the motor itself, and acceleration rates have a significant influence on system design.

4.2.2 Starting Conditions

The following are the important considerations during the start phase of motor operation:

- The rate of opening of the supply control valve
- The load inertia and drive train stiffness

If the control valve opens rapidly and the load inertia is high in relation to the drivetrain stiffness it is possible that an oscillation of the drivetrain will ensue. The analysis of this potential problem would normally be the responsibility of the system designer but the motor supplier should be aware of the problem as it could cause load reversals inside the motor which could be damaging to the motor.

Another effect which could be damaging is cavitation in the inlet line as a result of the preceding shut down. If the inlet line is essentially empty at the time of start valve opening the resulting rush of fluid to fill the void could cause a “water hammer” effect potentially causing damage to the motor or drivetrain.

4.2.3 Stopping Conditions

Stopping a motor requires careful consideration. Due to the inertia of the motor (and load), closing a valve while the motor is running may impose high pressure requiring installation of cross port relief valves or special anti-cavitation valves. This is to prevent water hammer effects occurring due to a rapid stop, which could cause a pressure spike in either the supply line, the motor outlet port or both.

When the motor decelerates over a relief valve, a bypass is required to provide inlet to the motor from a low pressure source. If a high inertia load is controlled, recirculating the fluid in a relief/inlet loop will cause local heating of the fluid, with the possibility of damage to the motor and fluid; in this case, a replenishing system is required to provide fresh oil to the motor inlet during deceleration.