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Aerospace Hydraulic Pump Controls

RATIONALE

The document has been revised to incorporate a new section describing an anti-stall speed control system, and clarifications to other sections.

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1. SCOPE

This SAE Aerospace Information Report (AIR) presents an overview of the application and control of fixed and variable displacement pumps with the emphasis on the controls most commonly used on variable displacement pumps. It describes various options to control the operation of hydraulic pumps in terms of controlling the pump output pressure and/or flow and assisting in the selection of the pump.

1.1 Purpose

The information contained herein is intended to provide application information to assist system integrators in selecting the most appropriate pump controls for a given application. It can also be used as an introduction to pump designers.

1.2 Field of Application

The controls described are applicable to hydraulic pumps installed on commercial and military aerospace applications.

Additional details relating to design and performance characteristics of pumps in various aerospace applications are provided in the following documents:

- a. AS595 provides additional information on civilian aircraft pumps
- b. ISO8278 provides additional information on civilian and military aircraft pumps
- c. AS19692 and AIR560 provide additional information oriented toward general military and missile pumps, respectively
- d. ISO22089 and ARP1280 provide additional information for controlling power transfer units
- e. AS5994 provides additional information on electric motor driven pumps

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.

AIR560	Missile Hydraulic Pumps
ARP1280	Aerospace - Application Guide for Hydraulic Power Transfer Units
AS595	Aerospace – Civil Type Variable Delivery, Pressure Compensated, Hydraulic Pump
AS5994	Pump Units, Hydraulic, Electric Motor Driven, Variable Delivery
AS19692	Aerospace – Military Type Variable Delivery, Pressure Compensated Hydraulic Pump

2.1.2 ISO Publications

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

ISO8278 Hydraulic pressure compensated, variable delivery pumps-General requirements

ISO22089 Aerospace - Hydraulic power transfer units - General specifications

3. OVERVIEW OF PUMP CONTROLS

3.1 Definition

Hydraulic pump controls are devices used to dynamically control the displacement of variable displacement pumps in a predictable and repeatable way. Typically, the intent is to control parameters such as pressure, flow, input starting or running torque and any combination thereof, since in some cases the system requirements may be fulfilled by combining two or more of these control schemes.

3.1.1 Aerospace Type Controls

These controls differ from Industrial and Mobile controls due to the particularities of aerospace applications that demand fast response and light weight. They are usually integrated within the pump body to increase reliability and reduce weight and external leakage. Aerospace hydraulic systems differ from industrial and mobile systems in that they are more compact, have less volume and utilize smaller line sizes thereby experiencing greater pressure drops and surges, and have smaller reservoir volumes making heat rejection more challenging. These factors make aerospace type controls somewhat different in implementation from their industrial and mobile counterparts, although in principle they are similar.

3.1.2 Classifications

Generally, aerospace pump controls can be classified into the following categories, although there are many overlapping combinations possible to fit more demanding applications:

- Pressure limiting controls
- Torque (power) limiting, unloading and blocking controls
- Thermal controls
- Adaptive controls
- Multi-function controls

The control types listed above include both hydromechanical and electrical technology, and also touch on industrial controls that may, in some instances, find application in an aerospace environment.

4. DESCRIPTION OF CONTROLS

4.1 Fixed Versus Variable Displacement Pumps

4.1.1 Introduction

Fixed displacement pumps provide flow that is directly proportional to its speed of rotation, the ratio being the displacement of the pump expressed as a volume per revolution. Variable displacement pumps are capable of varying their displacements in response to some control mechanism. Applying various control schemes to this variable displacement mechanism to achieve different control characteristics is the subject of this report. A brief introduction to fixed displacement pumps is offered to illustrate some factors that may make a fixed displacement pump more suited to a particular application as opposed to a variable displacement model.

4.1.2 Concept Description

4.1.2.1 Fixed Displacement Pump

For a given input speed, a fixed displacement pump delivers a fixed flow, as depicted by the Pump Flow line in Figure 1. As long as the system loads can use this amount of pump flow, then the operating point lies on this line, at a point corresponding to the pressure demanded by the loads.

In many instances, however, the loads attached to the pump are controlled by valving that limit their flow demand to a value less than the pump flow, as depicted by the Load Flow line. Point 1 on the chart corresponds to such a condition, where the Required Pressure includes the pressure demanded by the load plus the total pressure drop in the pressure and return lines between the pump to the load control valve. Because the load is not demanding all of the available pump flow, the pump is constrained to operate at point 2, passing the Relief Valve Flow across the relief valve at the pressure determined by the Relief Valve Setting. Consequently, area B represents the power loss in the load control valve to maintain the required flow and pressure in the load and area C represents the power loss in the relief valve to bypass the flow not needed by the load but supplied by the pump. The sum of areas B and C represent the total power loss in the system that is converted to heat, as depicted by the shaded area in Figure 1. The schematic at the right of Figure 1 illustrates the flow path described above.

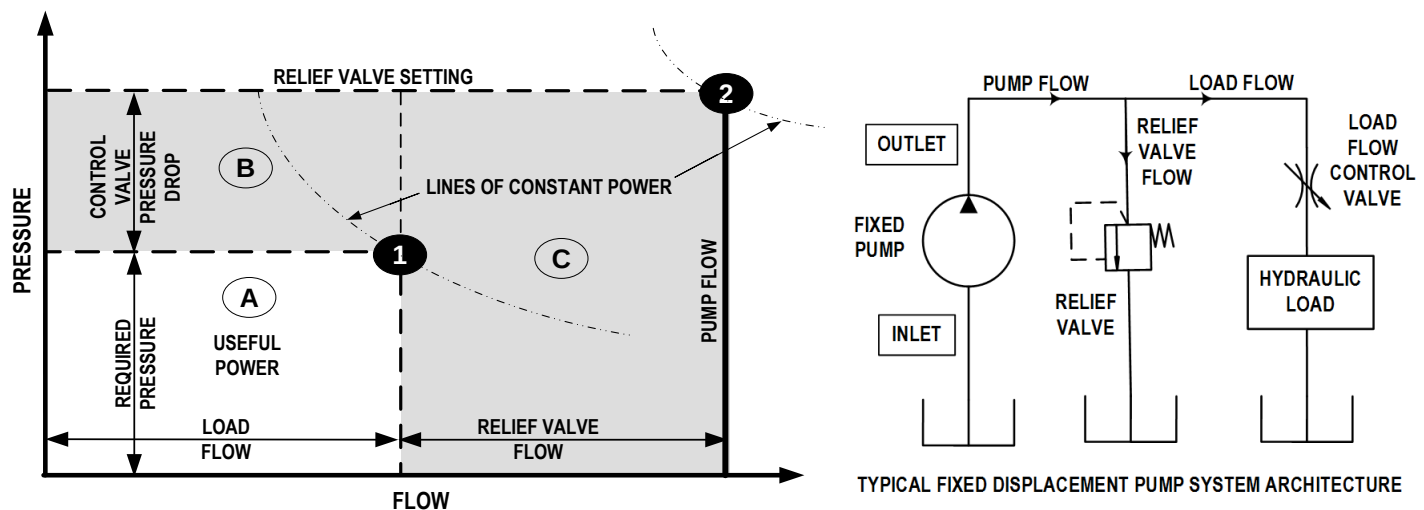


Figure 1 - Fixed displacement pump characteristics below rated flow

Fixed displacement pumps were used years before variable pumps were invented and were used successfully in specific applications. It is still possible to take advantage of the simple design of fixed displacement pumps by using them in applications where they can operate on the Pump Flow line below point 2, thereby not wasting power as described above.

In such a case, the operating point 1 is located on the Pump Flow line as depicted in Figure 2 and the required pressure in the load is less than the relief setting, depicted as point 2. Note that as long as the operating point 1 is below point 2 on the Pump Flow line, all of the pump flow is passing through the load at the required load pressure and none of the flow is passing through the relief valve; consequently, the power loss described in Figure 1 is not present.

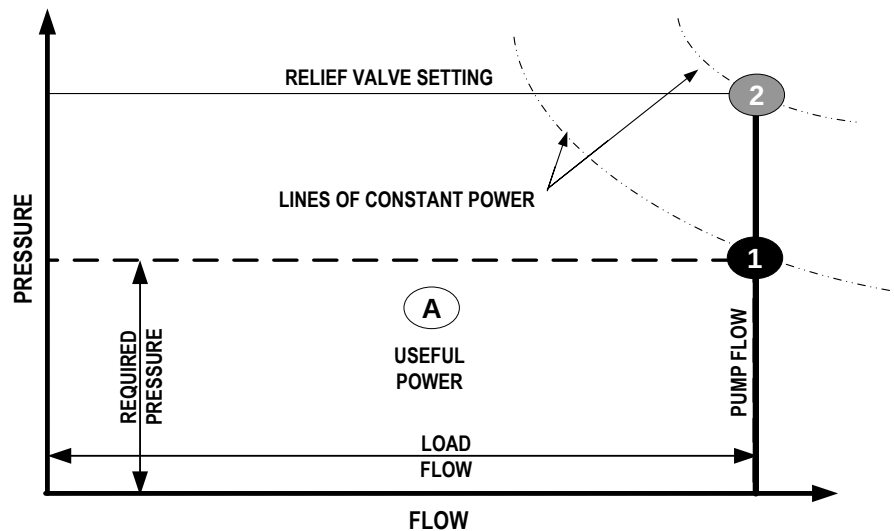


Figure 2 - Fixed displacement pump characteristics below relief pressure

The scenario described above is illustrated by the following application examples:

- a. For systems that only require moving an actuator intermittently at maximum speed, the pump can be coupled to an electric motor which can be started and stopped as required. In this case, the operating point is on the Pump Flow line below point 2, and may jump to point 2 momentarily if the load actuator bottoms, at which time an external pressure signal stops the motor.
- b. For systems where the function of the pump is to charge an accumulator and hence the accumulator provides flow as needed to the system, an unloading valve (also known as a “cut-in cut-out” valve) can be provided downstream of the pump. This valve allows the pump to fill the accumulator at the pump’s full flow until the preset pressure is reached, at which time the valve shifts to a bypass position where the full pump flow is directed at low pressure back to the reservoir. A check valve integral with the unloading valve maintains pressure in the accumulator and the system downstream. As the system consumes the high pressure fluid from the accumulator, the low pressure preset is reached and the unloading valve shifts back to the accumulator charging position and the accumulator charging cycle repeats.

In this type of application, the operating point is near the bottom of the Pump Flow line (near zero pressure) when the valve is bypassing, and higher up the line when the accumulator is charging, but is designed to remain below point 2 at all times.

The unloading valve can be actuated either hydraulically by pilot pressure from the system or electrically by a signal from a pressure switch. This implementation is common in systems where precise regulation of system pressure is not needed, but is allowed to vary from maximum to a lower preset minimum level.

- c. For electric motor driven pumps where an electric motor with sufficient dynamic bandwidth is used to vary pump speed using digital controls so as to achieve the desired pressure / flow characteristic. These types of electric motor pumps are used in the control of Electro Hydrostatic Actuators (EHA) and in system back up pump applications (for example, A380 braking and steering systems). The variable speed motor controls used in these applications are not covered in this report.

In this type of application, the operating point moves up and down the Pump Flow line dynamically, but is designed to always remain below point 2 so as not to allow flow through the relief valve.

Fixed displacement pumps are very compact, have in fact no internal control, since all controls for the system are done outside the pump. They can achieve very high power density, power to weight ratio. They can also be integrated at higher sub-assembly level by the next level integrator; they can be located at the point of usage when driven by electric motors at variable speed.

4.1.2.2 Variable Displacement Pump

The advantage of the variable displacement pump is that it can operate at any flow, from zero to its maximum capacity. Assuming the conditions from the fixed pump example of Figure 1, the operating point 1 is again shown in Figure 3. Since the variable pump can match its output flow to the Load Flow, area C is not a power loss as it was in the fixed pump example. The only power loss in a variable displacement pump is area B, resulting from the pressure drop through the control valve. In applications involving a central hydraulic system with multiple loads operating at varying flows simultaneously, the variable displacement pump is always able to match the combined load flow demand.

Although a relief valve is also used in a variable displacement pump circuit, it is only required as a safety feature and is not normally passing fluid. The absence of flow through the relief valve reduces the heat generated in a system with a variable pump.

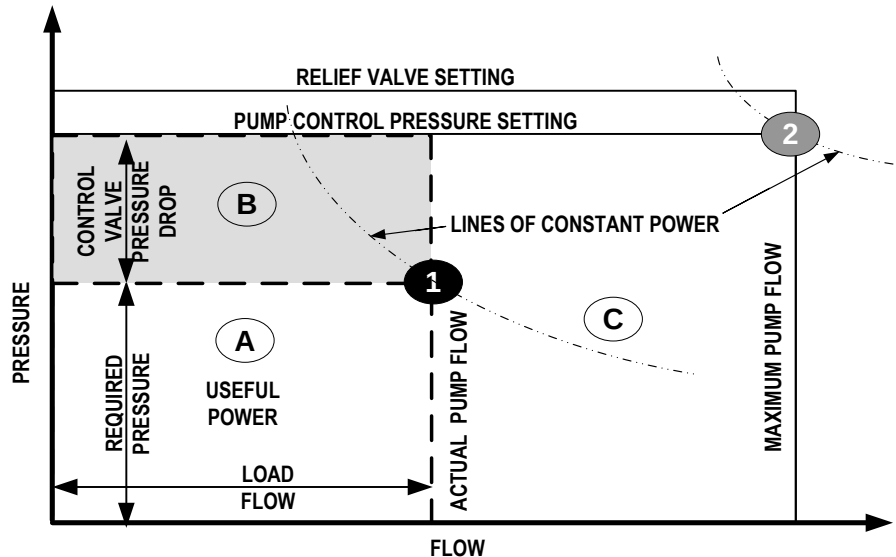


Figure 3 - Characteristics of a variable displacement pump

The control schemes described in this document are limited to those that are utilized with variable displacement pumps and illustrate ways that the pump design can be optimized and tailored to the system for which it is intended.

4.1.3 Examples and Limitations of Usage

4.1.3.1 Variable Displacement Pumps

Variable displacement pumps are typically used in central hydraulic systems characterized by multiple consumers where pump output is controlled by means other than the pump's speed. Examples of the use of variable displacement pumps include:

- Engine driven pumps, attached to engine gearboxes or to airframe mounted accessory drives (AMAD) that are constrained to run at a speed proportional to the engine speed and provide power at near constant pressure matching the demand of the consumers.
- Electric motor pumps where the motor speed is fixed, as a function of the electric motor power supply and the inherent design of the motor. These pumps are generally used to power the same consumers as engine driven pumps for operating on the ground (without the need to run the engines) or during taxi and flight to augment the power from engine driven pumps.
- Air driven pumps, either driven by air turbines powered by the aircraft pneumatic system or by an air turbine deployed in the airstream (Ram Air Turbine), both types used for emergency power generation.
- Other turbine driven pumps, such as a gas turbine (for example, APU) or solid propellant gas generator or monofuel for emergency power.

- e. Pumping elements for Power Transfer Units (PTUs), although fixed displacement pumps are more commonly used. In such cases, the pump displacement range is between two finite (non-zero) limits. See ARP1280 for examples.
- f. Systems where near-constant pressure is required throughout the flow range and digital control is not desired.

4.1.3.2 Fixed Displacement Pumps

Examples where fixed displacement pumps can be used include:

- a. EHA systems where the power can be in the neighborhood of 20 kW input to the pump with speeds demonstrated in excess of 20000 rpm.
- b. For starters on small jet engines as found on helicopters, the power at hand may be hydraulic power, which is usually stored in hydraulic accumulators. To recharge the accumulator, either hand pumps for very small jet engines, or electrically driven pumps, (usually DC) are used. These pumps are usually of the fixed displacement type for small systems. The only control being a pressure switch and a check valve located at the exit of the pump.
- c. For cargo doors and landing gears, which operate infrequently for short durations, the same type of control is weight effective with either a DC or AC motor driving a fixed displacement pump, a micro switch is used to stop the pump at either end of travel. The rest of the circuit is comprised of cylinder(s) and a relief valve.
- d. As pumping elements of Power Transfer Units (PTUs) where the pump speed is dynamically controlled by the hydraulic motor side of the PTU in response to system pressures. See ARP1280 for examples.

4.2 Pressure Controls for Variable Displacement Pumps

4.2.1 Overview of Pressure Controls

Pressure controls are dynamic elements installed in variable displacement pumps to control displacement by maintaining a prescribed outlet pressure. These controls are characterized by high bandwidth (natural frequency $f_n > 300$ Hz) and low damping (critical damping ratio $\zeta < 0.7$) in order that they can maintain tight pressure control. This may lead to stability issues in the application of these pumps to aircraft hydraulic systems. It is of utmost importance that system stability be analyzed carefully by considering pump piston ripple, transient start/stop cycles and cavitation effects during rapid increases in flow demand.

Because of the dynamic nature of pressure controls, the interdependence of the pump controls and system design have significant impact upon the fatigue life of the system components. High impulse pressure cycles are a consequence of pressure transients due to flow transients, while pressure ripple generated by the pump and transmitted throughout the system give rise to high cycle but lower amplitude impulse. Typically, pressure transients are 35% of rated pressure, while pump generated ripple is $\pm 5\%$ of rated. The pump pressure ripple can be as low as $\pm 1\%$ in some well-designed systems and as high as $\pm 10\%$ as allowed in older systems.

A useful parameter for analyzing transient effects is system stiffness, or impedance, which is a function of system volume, fluid bulk modulus and compliance of the system tubing and hoses. This is based on an equivalent bulk modulus, B_e , which incorporates the effects of the compliance of the tubing and hoses containing the hydraulic fluid.

According to AS19692, the standard system impedance for testing pump control response time is to be established such that the rate of pressure rise upon a step input of rated flow to zero flow is 50000 psi/s (344738 kPa/s).