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APPLICATION GUIDE FOR FIXED DISPLACEMENT AIRCRAFT POWER TRANSFER UNITS

1. PURPOSE - The purpose of this document is to apprise the system designer of the characteristics, applications, limitations, and variations of power transfer units using standard fixed displacement hydraulic pump and motor combinations.

2. SCOPE - This document will be limited in scope to power transfer units made up of two fixed displacement pumps/motors.

3. DEFINITION

3.1 The power transfer unit is a device for utilizing the hydraulic energy in one hydraulic system to supplement the hydraulic power in a second system without interchange of fluid between the systems. The power transfer unit must be so designed that there is no possibility of intermixing the fluids of the two independent systems. The power transfer unit must be so constructed that a catastrophic failure in one system of the power transfer unit will not affect the operation of the second system.

3.2 Depending upon the system requirements, power transfer units can be designed with both units having the same displacement or with the displacement of the two units different. Power transfer units can be used as pressure reducers or as pressure intensifiers, or to maintain the same pressure in both systems.

Power transfer units can be used to transfer power from one system to a second system in one direction only (uni-directional), or they can be used to transfer power in either direction between two systems (bi-directional).

4. CHARACTERISTICS

4.1 The power transfer unit is a power balanced or torque balanced device. A pressure unbalance between the motor and pump systems will cause the power transfer unit to supply power to the pump system and increase the pump system pressure. An overspeed condition, as a result of the Delta pressure or single failure in the power transfer unit, may be prevented by use of a flow control in the motor supply port. During steady state operation, the torque output of the motor will always equal the torque input to the pump. Any torque unbalance greater than the unit hysteresis between the motor and the pump will cause a change in flow.

4.2 During starting, the change from static friction to running friction has a significant effect on unit operation. At breakaway, there is a significant pressure unbalance between the motor and the pump.

4.2.1 Acceleration of a power transfer unit without adequate flow control is uncontrolled and can be damaging to the unit. The rate of acceleration is a function of the pressure unbalance at breakaway and the flow available to the power transfer unit motor for the first 200 or 300 milliseconds.

4.3 There may be a slight variation in efficiency with respect to unit displacement. The higher displacement unit usually has a slightly higher operating efficiency (full flow).

4.4 Because of system compliance in large hydraulic circuits and the difference between static and running friction, non-controlled bi-directional power transfer units will cycle off and on under certain operating conditions; i.e., one circuit pressurized from primary source and the other circuit pressurized by the power transfer unit. The rate of cycling will be determined by the size of the pump side circuit, the quiescent leakage of the pump side circuit, and the difference in stiction and friction.

5. DESIGN

5.1 In a majority of applications, the power transfer units are made up of two standard pump/motor units mounted back to back. In applications where weight is critical, the two units can be mounted in a special housing that is lighter weight but keeps the systems separated. For uni-directional power transfer units, optimum performance can be obtained by using both pump and motor design. For bi-directional power transfer units, each unit must be designed to operate as both a pump and a motor.

5.2 The power transfer unit and using systems must be so designed that no single failure in one system component will cause a loss of fluid in the other system. Some guidelines and recommendations that one should keep in mind when designing systems using power transfer units are as follows:

5.2.1 Specify large pump inlet lines with a positive head of supply fluid or a pressurized reservoir to assure self-priming and minimum cavitation.

5.2.2 Provide a shutoff valve in each motor pressure line to enable shutdown of the motor in the event of a broken drive shaft or loss of fluid in the pumping (driven) system. This not only prevents a useless drain of power on the good system and provides maintenance with a means of pressurizing one system at a time, but also minimizes the exposure of the good driving system to a potentially hazardous situation.

5.2.3 Provide a flow control valve in each motor pressure line to prevent a catastrophic overspeed of the motor in the event of a broken drive shaft or loss of fluid in the pumping (driven) system with a possible subsequent failure of the good system. This also controls normal flow to permit sizing the suction line to prevent cavitation.

5.2.4 A jumper check valve around the motor pump shutoff valve will prevent damage to drive shaft and/or driven pump due to the inertial wind-up of motor mechanism in the event one shutoff valve closes abruptly before the other.

5.3 The power transfer unit must be so constructed as to prevent the interchange of fluid between the two systems.

5.4 The power transfer unit can be designed to transmit power in one direction (uni-directional), or it can be designed to transmit power in both directions (bi-directional).

6. POWER TRANSFER UNIT (PTU) OPERATION

6.1 Uni-Directional PTU

6.1.1 Uni-directional power transfer units can be designed to deliver flow to the pump system above, below, or equal to the motor system. This is accomplished by selecting the displacement of the pump smaller than, or larger than, the displacement of the motor.

6.1.2 The starting, running, and stopping problems with the uni-directional power transfer unit are quite simple and can be minimized in several different ways. Because flow is in only one direction in both the pump and the motor, the components can be specifically designed for their respective functions. These differences are slight, but they do improve the efficiency of the power transfer unit. Since the pump is always a pump, its displacement does not have to be the same as that of the motor. It is possible and practical to select a pump displacement that will permit the power transfer unit to supply fluid at or near the nominal pressure of the pump circuit.

6.1.3 Sizing the pump smaller than the motor will reduce the difference between the pump circuit pressure and the motor circuit pressure for starting.

6.1.4 A simple method to prevent the power transfer unit from stalling during periods of zero demand is to install a low pressure check valve or an auxiliary bleed orifice in the pump outlet. See Figure I. All hydraulic units have a certain amount of internal leakage when they are pressurized, even if a unit is stalled. The check valve will prevent pump circuit pressure from stalling the power transfer pump. The check valve will force the power transfer unit pump to make up its own leakage; to do this, it must rotate, even if it is at a very low speed. As long as the unit rotates, it will not have to break static friction to start supplying fluid to the pump system.

6.1.5 The uni-directional power transfer unit with a pump outlet check valve will come on line with a minimum pressure decay in the pump system. It permits the optimization of pump and motor design, and can operate at or near the nominal system pressure of the pump system.

6.2 <u>Bi-Directional PTU</u>

6.2.1 In the bi-directional power transfer unit, both units must perform as pumps and both units must perform as motors. The high pressure ports of the power transfer unit always remain high pressure, but the direction of flow changes as the unit changes from a pump to a motor. See Figure II.

6.2.2 The starting characteristics of the bi-directional PTU are not as good as the uni-directional PTU. Because the unit must operate in both directions, it becomes more difficult to prevent the PTU from stalling. The bi-directional PTU usually has both elements sized the same because the system pressure in both systems is the same. It is not possible to use a simple check valve in the high pressure line as it is in the uni-directional PTU because the flow in the high pressure line must go in both directions. It is possible to use a shuttle valve arrangement that will accomplish the same thing, but this configuration makes the PTU much more complicated.

The starting problem occurs when high pressure is applied to both high pressure ports. When this happens, the unit stalls hydraulically. To restart the unit, it is necessary to overcome the static friction of both the pump and the motor. It is difficult to predict the breakaway characteristics of static friction, especially on small displacement units. Units that are designed and assembled to the same specification will respond differently from unit to unit, assembly to assembly, and start to start, because of the variability of static friction.

6.2.3 The bi-directional power transfer unit is much more versatile than the uni-directional power transfer unit. It will transfer power in both directions, it can be used to top off either system in periods of high demand, it can be used to provide power to ground check hydraulic systems, and it can power either system from the other in case of emergency.

7. POWER TRANSFER UNIT PERFORMANCE

7.1 The torque efficiency of a PTU is of much more importance to the design than is the overall efficiency. Torque efficiency is a measure of the Delta P across the motor to the Delta P across the pump. Since PTU's are very seldom used in continuous duty applications, the overall efficiency, which is a measure of heat rejection, is of secondary importance. Reference Table II.

7.2 Torque Efficiency

The torque efficiency of a PTU must be considered at two points. The first is the stall torque efficiency. This will determine the Delta P at which the unit will come on line. The second point is at maximum flow. The torque efficiency at this point will determine the minimum running Delta P between the two systems. The torque efficiency of PTU's at these two operating points varies with size and component design. Figure III shows a typical circuit for checking running torque efficiency. It should be noted that the pressure gages are located as close to the ports as possible to prevent false Delta P readings at full flow.

7.2.1 Breakaway

Static friction is very unpredictable and varies from unit to unit and start to start. It also has a size effect. For uni-directional applications, a simple check valve in the pump outlet will prevent the PTU from stalling and allow the unit to rotate fast enough to make up the pump leakage. In these applications, static friction is of very little importance. For bi-directional PTU's, static friction becomes very important. Static friction losses in large (1.5 in.^{3}/rev.) PTU's will result in a torque efficiency of 70% to 75%. For small PTU's (.095 in.^{3}/rev.), the breakaway torque efficiency will be between 65% and 75%. The wider variation in torque efficiency of the small unit is a greater percentage of the available torque. Figure III shows a test circuit for checking breakaway and a brief description of how it is used. Because the effect of static friction on the PTU breakaway characteristics is so unpredictable, a minimum of ten stops and starts should be run in each direction of operation. The test results, because they are run under very closely controlled conditions with a slow bleed-off of pump pressure, will give the designer a very conservative indication of the minimum Delta P at which the PTU will start.

7.2.2 Maximum Flow

The torque efficiency or pressure ratio is a function of speed and, to some extent, size. Small PTU's will have a torque efficiency at rated speed of 80%-85%, while the large units will range from 80%-90%.

7.3 Volumetric Efficiency

Volumetric efficiency is the ratio of motor input flow to pump outlet flow. For heat rejection calculation, it is of little value because it involves two separate systems. Volumetric efficiency of the PTU ranges from 80% at low flow to 95% at high flows. This is based on a volumetric efficiency of 90% per unit for low flows, to 95% at maximum flows.

8. GENERAL COMMENTS

8.1 This ARP covers only the fixed displacement PTU. See Table I. There are several instances where variable units have been used in a PTU application. No attempt was made to discuss their design or operation because of the special problems resulting from variable torque operation. Because of the difference in operation, a separate ARP on variable units would be in order.

8.2 There are several operational items that should be mentioned for proposed users of PTU's.

8.2.1 The starting characteristics of bi-directional PTU's seem to present the system designer with the most problems. The acceleration rate of a bi-directional PTU, unless adequately protected by flow control devices, can cause serious damage to the motor side of the unit. This not only causes damage to the PTU, but also generates an unusual amount of noise. Care must be taken to limit the rate of acceleration to the ability of the hydraulic system to provide fluid to the pump inlet and prevent cavitation during and for some period after start-up. The start-up phase of the PTU duty cycle is probably the most damaging part of the cycle.

8.2.2 Noise is one of the environmental problems. High speed, high pressure hydraulic equipment makes a considerable amount of noise, and with a PTU there are two such units back to back. Couple this with cavitation during start-up, and noise becomes a consideration in the mounting location, type of mounting, and the shield necessary to reduce the noise level.

8.2.3 On a uni-directional PTU, where it is possible to install a check valve in the pump outlet, the start-up problem will be reduced. So far as it is known, there are no problems in operating a PTU in this manner, provided the pump case drain line is not ported back to the pump inlet. This could cause heat generation in the PTU.

8.2.4 There must be some positive protection to any PTU against overspeed. Usually, there is a good possibility that there is considerable excess flow at a relatively constant pressure in the motor system. Unless the unit is protected by flow limiting devices, the speed of the unit could become dangerously high because of the torque unbalance between the motor and the pump.

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SAE COMMITTEE A-6, AEROSPACE FLUID POWER & CONTROL TECHNOLOGIES

FIXED UNI-DIRECTIONAL POWER TRANSFER UNITS

AIRCRAFT APPLICATION	UNITS PER A/C	HYDRAULIC FLUID	MOTOR DISPL CIR	PUMP DISPL CIR	RATED PUMP FLOW GPM	RATED PRESSURE PUMP PSID	RATED PRESSURE MOTOR PSID
727	1	Phosphate Ester Base	.095	.080	1.27	3000	3000
747	1	"	.095	.080	1.27	3000	3000
DC-10	2	"	.52	.43	8.0	2600	2900
Gulfstream II	1	"	.66	.60	10.0	2900	3000
L-1011	2	"	1.519	1.519	35.0	2500	3000
B-52	2	MIL-H-5606	.23	.23	2.0	2200	3000

FIXED BI-DIRECTIONAL POWER TRANSFER UNITS

			UNIT DISPL			
C-5	3	MIL-H-5606	1.519	35.0	2600	3000
F-14	1	"	1.55	30.0	2250	2850
DC-9	1	Phosphate Ester Base	.095	2.0	2500	3000

Table I

EQUATIONS

Equal Displacement Power Transfer Unit

Torque Efficiency % $\dfrac{\text{Delta PSI Pump}}{\text{Delta PSI Motor}} \times 100$

Pressure Ratio $\dfrac{\text{Delta PSI Pump}}{\text{Delta PSI Motor}}$

Volumetric Efficiency % $\dfrac{\text{GPM Pump (out)}}{\text{GPM Motor (in)}} \times 100$

Overall Efficiency % $\dfrac{\text{Delta PSI x GPM Pump (out)}}{\text{Delta PSI x GPM Motor (in)}} \times 100$

Unequal Displacement Power Transfer Unit

Torque Efficiency % $\dfrac{\text{Delta PSI x in.}^3\text{/rev. Pump}}{\text{Delta PSI x in.}^3\text{/rev. Motor}} \times 100$

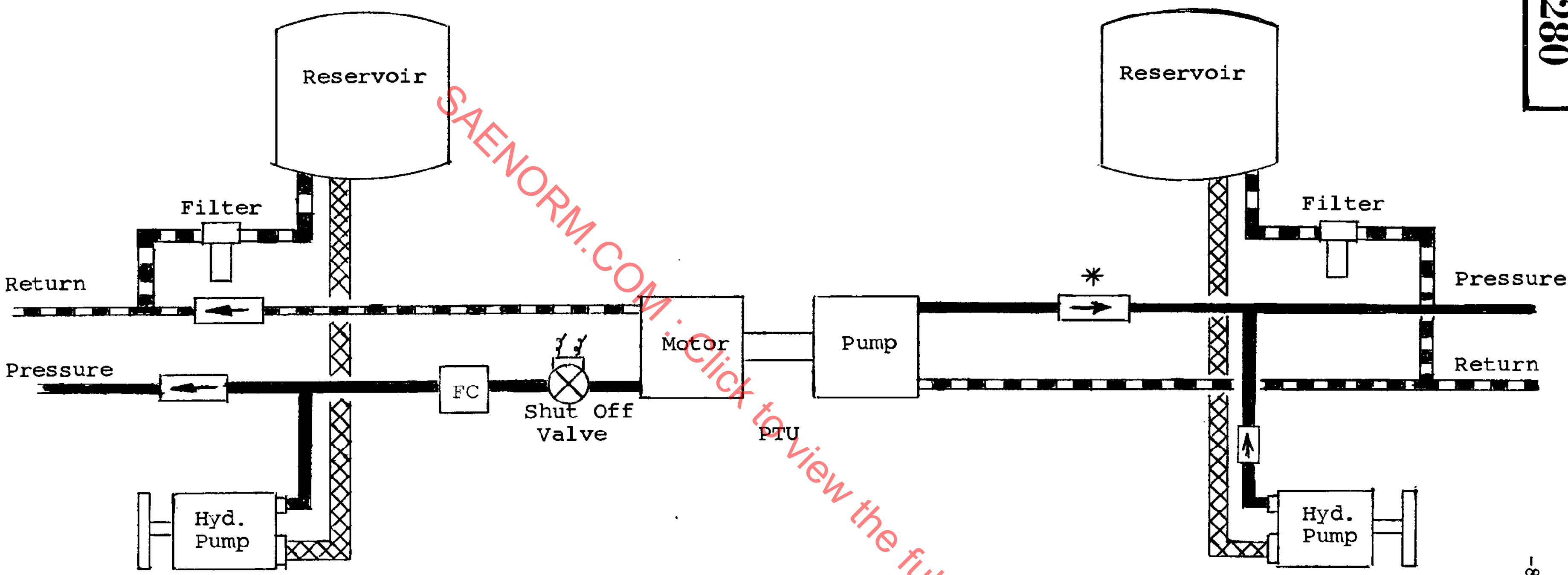
Pressure Ratio $\dfrac{\text{Delta PSI Pump}}{\text{Delta PSI Motor}}$

Volumetric Efficiency % $\dfrac{\text{Pump GPM (out)}}{\text{Pump GPM (in)}} \times \dfrac{\text{Motor GPM (out)}}{\text{Motor GPM (in)}}$

Overall Efficiency % Volumetric Eff. x Torque Eff.

Table II

TYPICAL CIRCUIT
FOR
UNI-DIRECTIONAL P.T.U.



* Check valve installed in pump discharge line to prevent PTU from stalling when system pressure exceeds max. PTU discharge pressure.

Figure I.