AEROSPACE RECOMMENDED PRACTICE

ARP1280	REV. B
Issued 1976-03 Revised 2009-12 Reaffirmed 2014-11 Superseding ARP1280A	

(R) Aerospace - Application Guide for Hydraulic Power Transfer Units

RATIONALE

ARP1280B has been reaffirmed to comply with the SAE five-year review policy.

1. SCOPE

This SAE Aerospace Recommended Practice (ARP) is an application guide for hydraulic power transfer units and describes:

- The various types
- Typical design approaches
- Their operational characteristics and limitations
- Circuit recommendations
- Typical applications

The scope of this ARP is limited to devices that transfer power between hydraulic systems and do so by means of rotary subassemblies such as hydraulic motors and pumps.

1.1 Purpose

The purpose of this document is to apprise the system designer of the available options in power transfer units, configuration tradeoffs, and system design precautions in their application.

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

ARP24	Determination of Hydraulic Pressure Drop
AIR737	Aerospace Hydraulic and Pneumatic Specifications, Standards, Recommended Practices, and Information Reports
ARP819	Fluid System Characteristics Affecting Hydraulic Pump Operation
ARP994	Recommended Practice for the Design of Tubing Installations for Aerospace Fluid Power Systems
AIR1899	Aerospace Military Aircraft Hydraulic System Characteristics
AIR1922	System Integration Factors That Affect Hydraulic Pump Life
AS1241	Fire Resistant Phosphate Ester Hydraulic Fluid for Aircraft

2.1.2 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.dla.mil/quicksearch/.

MIL-PRF-5606	Hydraulic Fluid, Petroleum Base; Aircraft, Missile and Ordnance
MIL-PRF-83282	Hydraulic Fluid, Fire Resistant Synthetic Hydrocarbon Base, Aircraft

2.1.3 ISO Publications

Available from American National Standards Institute, 25 West 43rd Street, New York, NY 10036-8002, Tel: 212-642-4900, www.ansi.org.

ISO22089	Aerospace – Hydraulic Power Transfer Units – General Specifications

2.2 Definitions

The power transfer unit (PTU) is a device which uses some of the hydraulic power in one hydraulic system to supplement the hydraulic power in a second system without the interchange of fluid between the systems. PTUs can be designed to transfer power from one system to a second system in one direction only (unidirectional), or they can be designed to transfer power in either direction between two systems (bidirectional).

3. PTU CONCEPT

The basic concept of a PTU is a hydraulic motor driving a pump, mounted back-to-back. The displacement of each of these may be the same or different. Accordingly, PTUs can be used as pressure reducers, as pressure intensifiers, or to maintain the same pressure in both systems. Occasionally they are used as flow dividers.

If bidirectional operation is required, both the pump and the motor reverse their functions; that is, that which previously operated as a pump now functions as a motor and vice versa. The fact that the shaft between the two subassemblies reverses direction of rotation is, conceptually, incidental.

If the pressure relationship between the two systems must remain the same in both directions of operation (rather than reverse also), one or both of the subassemblies that make up the PTU must be of a variable displacement design.

The PTU is a torque balanced device. A change in the pressure ratio between the motor side (primary system) and the pump side (secondary system) will result in a torque imbalance between the motor and pump sides of the PTU. This will then cause the PTU to start turning (driven by the motor side) and thereby supply power to the pump side and increase the secondary system pressure until a torque balance is re-established. At this point the PTU will maintain a speed proportional to the flow demand of the secondary system, and will stop again if there is no flow demand. During steady state operation, the torque output of the motor side will always equal the torque input to the pump side. Any torque unbalance between the motor and the pump will cause a change in speed and thus flow.

4. GENERAL DESIGN AND QUALIFICATION REQUIREMENTS

ISO22089 provides design, production acceptance testing and qualification requirements for PTU's.

5. OPERATIONAL CHARACTERISTICS

Friction, pump and motor efficiencies, and the inherently very high torque-to-inertia ratio result in several characteristics that are unique to the PTU. These must be thoroughly understood to prevent damaging operation such as overspeed, excessive acceleration, instability, cogging, etc.

5.1 PTU Efficiency

From a system performance standpoint, the torque efficiency of a PTU is much more important than its overall efficiency. Torque efficiency is a measure of the differential pressure across the motor in relation to that across the pump. Since a PTU is very seldom used in continuous duty applications, the overall efficiency, which is a measure of heat rejection, is of secondary importance. Equations that quantify these relationships are shown below in Equations 1 to 7.

$$\text{Theoretical Pump Input Torque} = \frac{\Delta P \text{ across pump x D of pump}}{2\,\pi} \qquad \text{(Eq. 1)}$$

$$\text{Theoretical Motor Output Torque} = \frac{\Delta P \text{ across motor x D of motor}}{2\,\pi} \qquad \text{(Eq. 2)}$$

$$\text{Pump Torque Efficiency (\%)} = \frac{\text{Useful pump output torque x 100}}{\text{Actual pump inlet torque}} \qquad \text{(Eq. 3)}$$

$$\text{Motor Torque Efficiency (\%)} = \frac{\text{Actual motor torque output x 100}}{\text{Input motor torque}} \qquad \text{(Eq. 4)}$$

NOTE: The actual pump input torque is assumed to be equal to the actual motor torque output. This is because the motor directly drives the pump by a shaft.

$$\text{PTU Torque Efficiency} = \text{Pump torque efficiency x Motor torque efficiency}$$

$$\text{PTU Torque Efficiency (\%)} = \frac{\Delta P_{pump} \text{ x } D_{pump} \text{ x } 100}{\Delta P_{motor} \text{ x } D_{motor}} \qquad \text{(Eq. 5)}$$

$$\text{PTU Volumetric Efficiency (\%)} = \frac{Q_{pump(out)} \times Q_{motor(out)} \times 100}{Q_{pump(in)} \times Q_{motor(in)}}$$

$$= \frac{Q_{pump(out)} \times D_{motor} \times 100}{Q_{motor(in)} \times D_{pump}} \qquad \text{(Eq.6)}$$

$$\text{PTU Overall Efficiency (\%)} = \frac{\Delta P_{pump} \times Q_{pump(out)} \times 100}{\Delta P_{motor} \times Q_{motor(in)}} \qquad \text{(Eq. 7)}$$

where:

ΔP = Differential pressure, psi (kPa)
D = Displacement, in^3/rev (ml/rev)
Q = Flow, gpm (l/min)

The torque efficiency should be considered at the following two points:

- Stall torque efficiency, as it affects the differential pressure at which the unit will come on line. It is strongly influenced by static friction which is very unpredictable and varies from unit to unit and start to start. Stall torque efficiencies are generally slightly higher for relatively larger displacement units than for the smaller ones.

- Full flow torque efficiency, as it affects the operating differential pressure between the two systems. It is driven primarily by mechanical and viscous losses.

5.2 Frictional Effects

During startup, the change from static friction to running friction has a significant effect on operation. At breakaway, there is a significant torque unbalance between the motor side and pump side which diminishes substantially as soon as the PTU rotates. Depending on the magnitudes of the friction and flow demand, this can cause continuous start-stop action (instability) or low speed cogging.

5.3 PTU Acceleration

Acceleration of the PTU is primarily a function of the magnitude of the torque unbalance at breakaway and the hydraulic power available to the motor side. PTU inertia and dynamic friction are negligible factors. Zero to rated flow acceleration times of 15 to 20 ms are common if the flow rate to the motor is not controlled. Such acceleration times are substantially faster than those for typical pump installations and will usually create damaging inlet cavitation problems because the system cannot accelerate the column of inlet fluid fast enough to keep up with the demand of the pump side of the PTU.

5.4 Overspeed

Overspeeding of the PTU, which would cause significant damage to the unit, can occur if the flow to the motor side is not properly limited. The speeds reached during transients are an important consideration and warrant careful analysis.

5.5 Acoustic Noise

For a number of reasons, hydraulic pumps and motors tend to produce relatively high acoustic noise levels. The compromises required in the design of the PTU impacts not only the efficiency but also effects pressure pulsations and acoustic noise. In addition, a PTU is often installed in closer proximity to crew or passenger locations than is typically the case for pumps or motors. Depending on size and speeds, noise levels can easily reach 110 to 115 dB levels and may in such cases warrant some environmental design and installation precautions. With proper isolation and if speeds are kept low, noise levels as low as 80 to 90 dB may be obtained.

5.6 PTU Control Valves

The various PTU control valve options discussed throughout this ARP can be part of the system, potentially integrated with other functions, or they can be integrated into the PTU. The choice is generally influenced by weight, space, and cost tradeoffs.

5.7 PTU System Failure Cases

The PTU should be designed such that there is no possibility of intermixing the fluids of the two independent systems.

Not only must the PTU and the hydraulic system it is installed in itself be so designed such that no single failure will disable both systems, but also each system must be so designed that a component failure in one system will not cause a loss of power in the other system.

Similarly, the systems that interface with the PTU should be designed so as to minimize the possibility of a failure in either one having an effect on the other.

5.8 Control and Indication

5.8.1 Control and Operation Strategy

Typically a PTU can be used at specific periods such as:

- During a flight that are considered to be high-risk times, for example during take-off, initial climb and approach/landing
- Aircraft pre-flight checks
- During ground maintenance

The decision on whether to control a PTU manually or automatically is generally dictated by their application, as a PTU can be operated with or without any pilot intervention. For example:

a) If the PTU is used as a back up pump for an entire hydraulic system, then the control could be both automatic and manual. During a flight, the control of the PTU could be automatic, such that it is selected to run under specific flight conditions and/or the detection of a failure of the secondary system. Alternatively, the PTU control could be a manual operation with the pilot either selecting it on at specific periods during the flight, or selecting it on following the loss of the main system power source(s).

   NOTE: It is not recommended to leave a PTU running continuously throughout each flight. This is because there will be a reduction in the potential reliability primarily due prolonged running at low speed which results in excessive bearing wear.

   Additionally, there should be a means of manually selecting the PTU on for ground checks, either for pre-flight or for ground maintenance purposes.

b) If the PTU is for a specific sub-system or sub-systems then it should be linked into the operation of the sub-system(s) so that it is automatically available to supply hydraulic power only when that sub-system is operated, without any pilot intervention. For example, if a PTU is used to provide additional hydraulic power for the landing gear extension/retraction system (LGERS), then the selection of the PTU could be linked into the LGERS control system such that it operates only during the extension/retraction sequences.

If the PTU is automatically controlled, there should be a means provided to enable the PTU to be selected off, without any pilot intervention, following:

- A failure or loss of fluid in the secondary system, or
- The loss of pressure or prime in the primary system

This not only minimizes the potential of losing the primary system in a case of a failure in the secondary system, but also prevents unnecessary cycling and/or power drain on the primary system.

NOTE: If the manual cockpit control is provided with no automatic override, pilot failure to follow appropriate procedures for shutting the PTU off if it is not producing pressure may put the aircraft in a Hazardous situation due to loss of two systems.

5.8.2 Hydromechanical Control

NOTE: In bidirectional applications, control valves must be equipped with a reverse flow bypass capability.

Two control means should be considered for the control of the PTU:

a) Selecting the PTU on/off

b) Limiting the PTU flow and/or PTU input supply pressure

5.8.2.1 PTU Selection

A shutoff valve in the motor side pressure line should be provided to enable the PTU to operate or be shut down. The shutoff valve should have a controlled opening rate to control the acceleration during initial start-up of the PTU and thereby allow for a much better pump inlet pressure condition.

In addition, a Shut-off Valve can be installed in the high-pressure line on both sides of the PTU to provide additional system isolation protection in case of a primary system failure or a PTU failure. Providing a check valve around the shutoff valves will prevent any potential damage to the PTU rotating groups due to the inertial wind-up of the mechanism in the event one shutoff valve closes abruptly before the other.

5.8.2.2 PTU Flow and/or Motor Supply Pressure Control

NOTE: Dependant upon the application, it may be necessary to limit both the PTU input flow and pressure.

5.8.2.2.1 PTU Input Flow Control

A flow control valve can be provided in the motor side pressure line to limit the PTU speed. This will permit better sizing of the inlet line to the pump side and prevent cavitation. Also, in the event of improper inlet pressurization or fluid loss in the pump side system, or in case of a broken drive shaft, such a valve would prevent a catastrophic overspeed of the PTU as well as limit the power drain in the motor side. Flow control protection to guard against improper maintenance actions using ground power should also be considered.

5.8.2.2.2 PTU Input Pressure Control

A priority valve can be provided in the motor side pressure line to limit the PTU input pressure. This will ensure that if the PTU is required to provide a large power demand, then it will not result in a significant reduction in the primary system pressure.

In addition, if the flow available in the primary system is less than the rated flow of the PTU, then it would be possible to use the priority valve as the means of regulating the maximum flow to the PTU.

5.8.3 Monitoring

The monitoring of the PTU operation can be by a variety of means including:

a) The use of a pressure switch in the PTU output supply line that will confirm whether the PTU is delivering pressure or not.

b) The use of a pressure transmitter in the PTU pump output line that has the same function as a pressure switch, as the control system can provide indication of PTU output pressure at a defined level. In addition, a pressure transducer has the potential advantage of troubleshooting the PTU performance if the aircraft maintenance system enables this facility by:

- Monitoring the pump output pressure levels.
- Checking the pump output pressure rise, etc

c) The use of a pressure switch in the PTU motor input line that will confirm whether the PTU motor has been supplied with pressure or not.

d) If an electrical motor operates the shut-off valve, then it is possible to have an indication of whether the valve is opened/shut within the motor control system by, for example, using independent end of travel contacts.

6. FIXED DISPLACEMENT PTU DESIGN AND OPERATION

6.1 General

In the majority of applications, PTUs are made up of two standard fixed displacement pump/motor units mounted back to back. In applications where weight and/or envelope is especially critical, the two units can be mounted in a single housing designed such that the systems remain hydraulically separated, including in cases of failure. For example, the design must be such as to preclude loss of two hydraulic systems due to a single crack propagation.

With system pressure applied, the static friction of the bent axis design concept motor or pump is, in general, lower than that of an inline design. Consequently, stall torque and breakout characteristics are correspondingly superior, and even more so for bidirectional applications. Low speed characteristics are also superior to that of the inline design thereby allowing a wider dynamic range of operation (i.e., a wider spread between the lowest and highest practical speed).

In systems where these characteristics are of particular importance it may be advantageous to have extensive coordination between the manufacturers and the system designer and do a thorough tradeoff against all other product parameters, and then plan for the appropriate design concept or for a combination of the two.
Figures 1 and 2 show typical cross sections of inline and bent-axis PTU's.

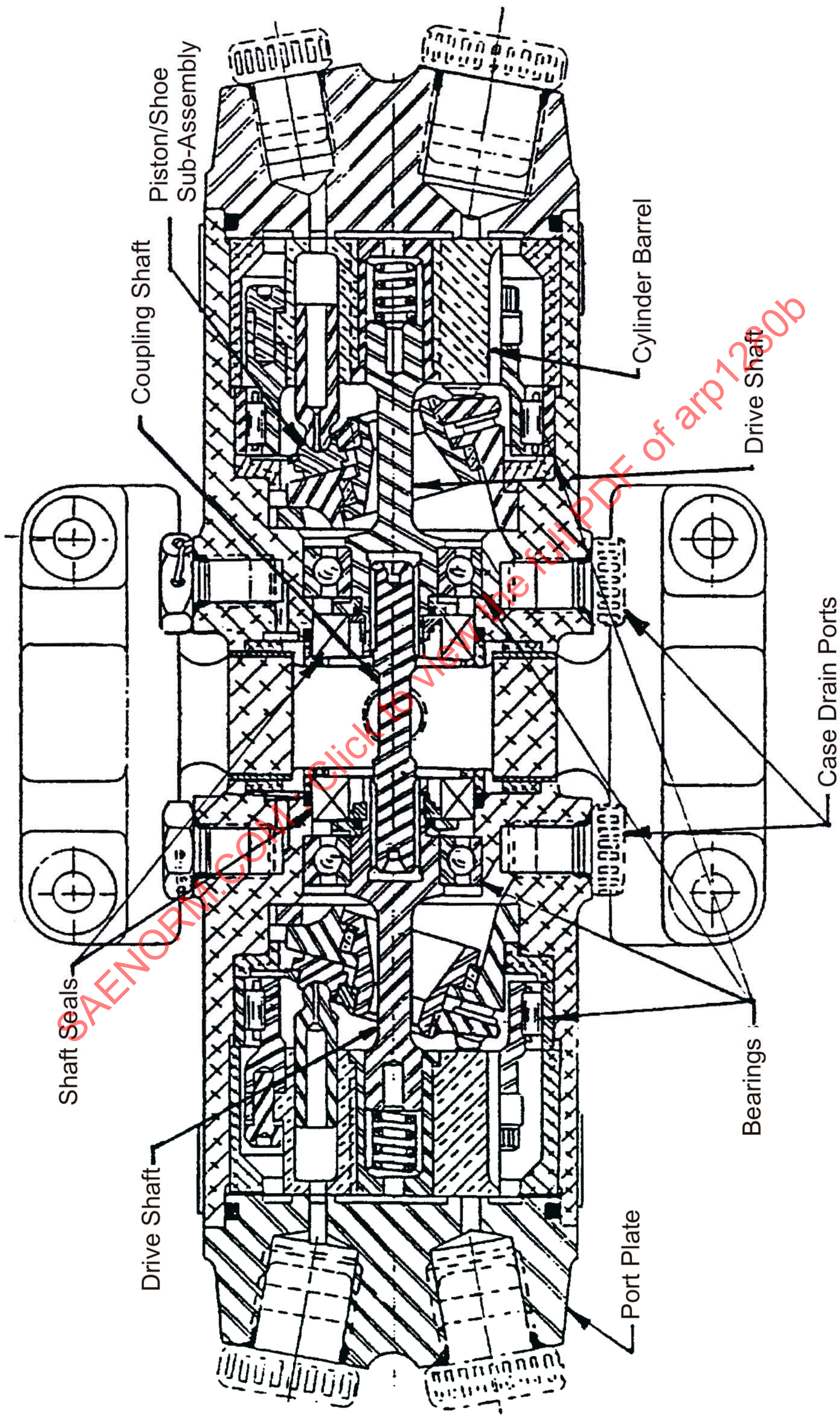

FIGURE 1 - CROSS SECTION OF A TYPICAL INLINE DESIGN PTU

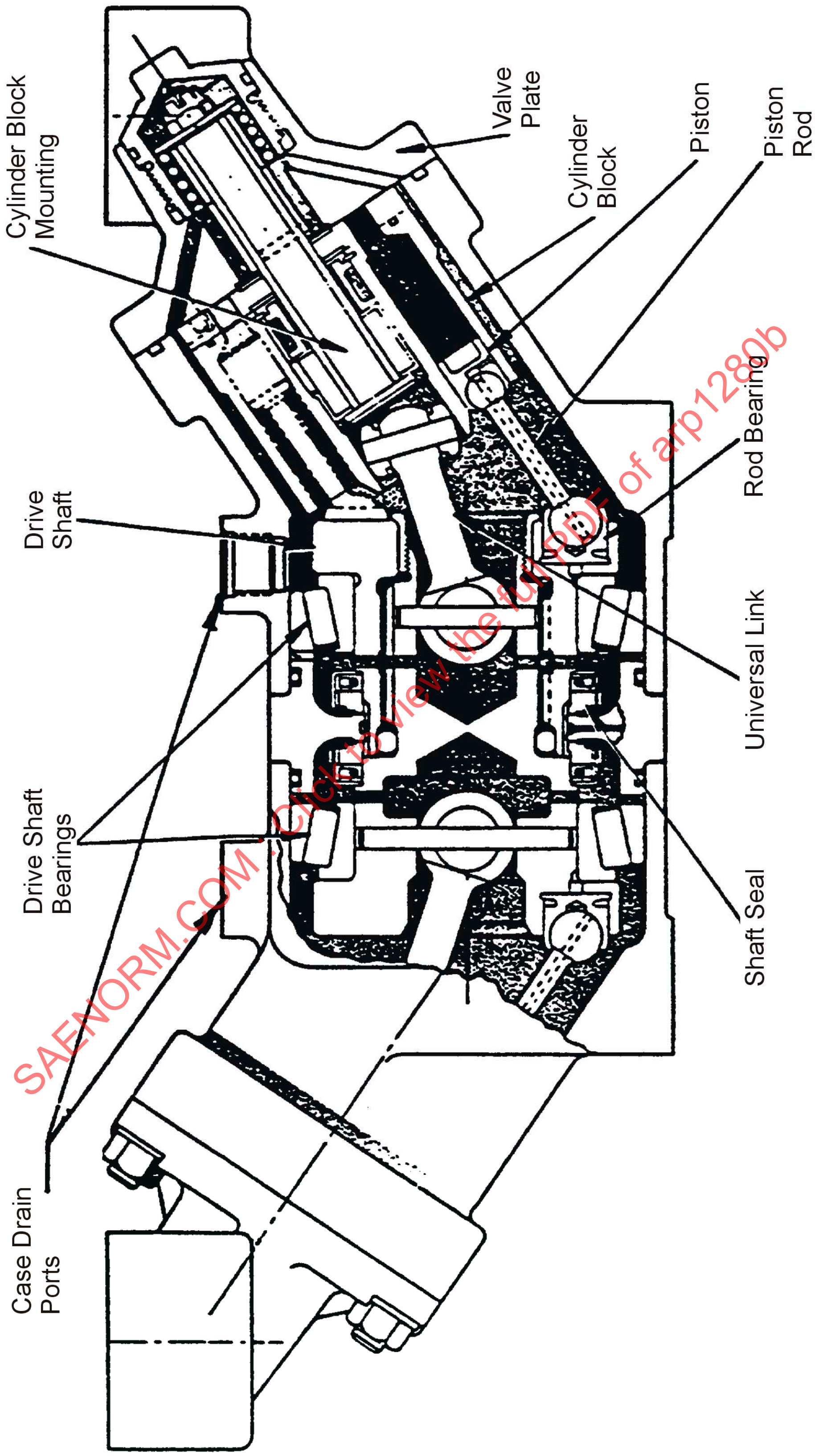

FIGURE 2 - CROSS SECTION OF A TYPICAL INTEGRATED BENT AXIS DESIGN PTU

6.2 Unidirectional PTU's

In a unidirectional PTU, performance characteristics can be optimized by tailoring the design of the pump and motor sides to specific requirements, for example, low breakout pressures or high short-term speeds or peak efficiency, etc.

6.2.1 Breakout Characteristics

If breakout characteristics are critical to satisfactory system performance, they can be improved substantially by the introduction of a low pressure check valve in the outlet line of the pump side in combination with a small orifice that bypasses flow from outlet to case, as shown in Figure 3. This will prevent the PTU from coming to a complete stop and, consequently, it will not have to break the static friction that otherwise causes the classic initial differential pressure peak during startup. The disadvantage of this feature is the continuous loss of some power from the primary system and a commensurate amount of heat added to the secondary system.

6.2.2 Pump Inlet Line

Provide a large inlet line on the pump side with a positive head of supply fluid or a close coupled, pressurized reservoir or accumulator to assure self-priming and minimum cavitation during rapid acceleration. Note that to specify a very low pump inlet pressure capability to the manufacturer forces the introduction of a boost section that adds considerable complexity and weight to the PTU. AIR1922 provides extensive system design details to optimize pump inlet lines.

6.2.3 PTU Hydraulic Circuit for Unidirectional PTU's

A typical example of a hydraulic circuit incorporating a unidirectional PTU is shown in Figure 3.

The following features are incorporated in this circuit:

- The PTU is designed to transfer hydraulic power from System 1 to System 2
- The PTU is selected on/off by a electric motor operated shut-off valve that controls the supply of hydraulic fluid to the PTU motor
- A flow control valve is incorporated in the PTU motor supply line
- A bleed orifice is located in the PTU pump outlet line

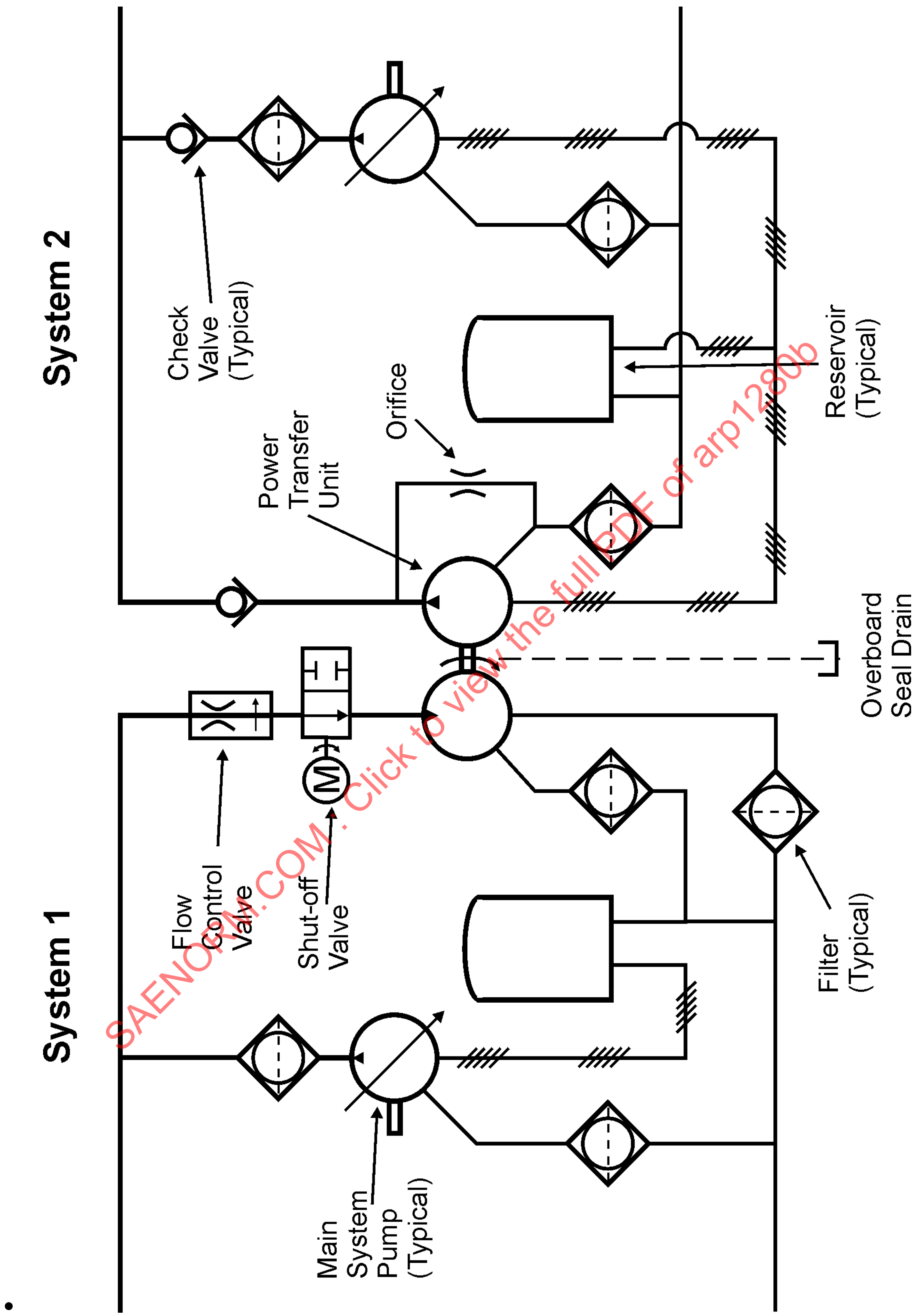

FIGURE 3 - TYPICAL CIRCUIT FOR UNIDIRECTIONAL PTU INSTALLATION

6.2.4 Unidirectional PTU Applications

Sample applications of unidirectional PTU's are listed below in Table 1.

TABLE 1 - TYPICAL APPLICATIONS OF FIXED DISPLACEMENT UNIDIRECTIONAL POWER TRANSFER UNITS

Aircraft Application	Units per A/C	Hydraulic Fluid	Motor Displ in^3/rev (ml/rev)	Pump Displ in^3/rev (ml/rev)	Pump Flow gpm (l/min)	Rated Pressure Pump psi (MPa)	Rated Pressure Motor psi (Mpa)
Airbus A300/ Airbus A310	1	AS1241	1.52 (24.9)	1.32 (21.6)	24.0 (90.8)	3000 (20.7)	3000 (20.7)
BAe146/Avro RJ	1	AS1241	0.55 (9.0)	0.55 (9.0)	10.8 (41.0)	3000 (20.7)	3000 (20.7)
BAe146/Avro RJ (alternative PTU supplier)	1	AS1241	0.37 (0.61)	0.37 (0.61)	10.8 (41.0)	3000 (20.7)	3000 (20.7)
Boeing B-52	2	MIL-PRF-5606	0.23 (3.77)	0.23 (3.77)	2.0 (7.57)	2200 (15.2)	3000 (20.7)
Boeing CH-46	1	MIL-PRF-5606	0.12 (1.97)	0.22 (3.60)	4.0 (15.1)	1500 (10.3)	3000 (20.7)
Boeing CH-47	1	MIL-PRF-5606	0.12 (1.97)	0.22 (3.60)	5.3 (20.1)	2500 (17.2)	3000 (20.7)
Boeing 727/ Boeing 747-100/200/300	1	AS1241	0.095 (1.56)	0.080 (1.31)	0.98 (20.7)	3000 (20.7)	3000 (20.7)
Boeing 737-300/400/500	1	AS1241	0.31 (5.08)	0.244 (3.95)	8.6 (32.6)	2400 (16.6)	3000 (20.7)
Boeing 757-200/300	1	AS1241	1.52 (24.9)	1.39 (22.8)	21.8 (82.5)	2175 (15.0)	3000 (20.7)
Boeing 767-200/300/400	1	AS1241	0.095 (1.56)	0.080 (1.31)	2.7 (13.0)	1240 (8.6)	3000 (20.7)
Bombardier Challenger 300	1	AS1241	0.31 (5.08)	0.29 (4.75)	8.2 (31.0)	2200 (15.2)	3000 (20.7)
Bombardier Dash 8-100/200/300	1	AS1241	0.365 (5.98)	0.3 (4.92)	7.0 (26.5)	2600 (179.3)	3000 (20.7)
Bombardier Dash 8-400	1	AS1241	0.70 (11.47)	0.67 (10.98)	16.6 (62.8)	1900 (131.0)	3000 (20.7)
Cessna Citation X	1	AS1241	0.365 (5.98)	0.365 (5.98)	8.0 (30.3)	2114 (145.8)	3000 (20.7)
Embraer ERJ-170/175/190/195	1	AS1241	0.31 (5.08)	0.29 (4.75)	5.3 (20.1)	2200 (15.2)	3000 (20.7)
Gulfstream II	1	AS1241	0.66 (10.8)	0.60 (3.8)	10.0 (38.0)	2900 (20.0)	3000 (20.7)
Gulfstream G450/550	1	AS1241	0.70 (11.5)	0.66 (10.8)	16.6 (62.8)	2800 (19.3)	3000 (20.7)
Gulfstream V	1	AS1241	1.52 (24.9)	1.39 (22.8)	21.8 (82.5)	3000 (20.7)	3000 (20.7)
Lockheed L-1011	2	AS1241	1.52 (24.9)	1.52 (24.9)	35.0 (132)	2500 (17.2)	3000 (20.7)
McDonnell Douglas DC-10/ Boeing MD-11	1	AS1241	0.47 (7.71)	0.43 (7.305)	8.0 (30.3)	2600 (17.9)	3000 (20.7)

Figures 4, 5 and 6 show typical unidirectional PTU's.

FIGURE 4 – INLINE UNIDIRECTIONAL PTU

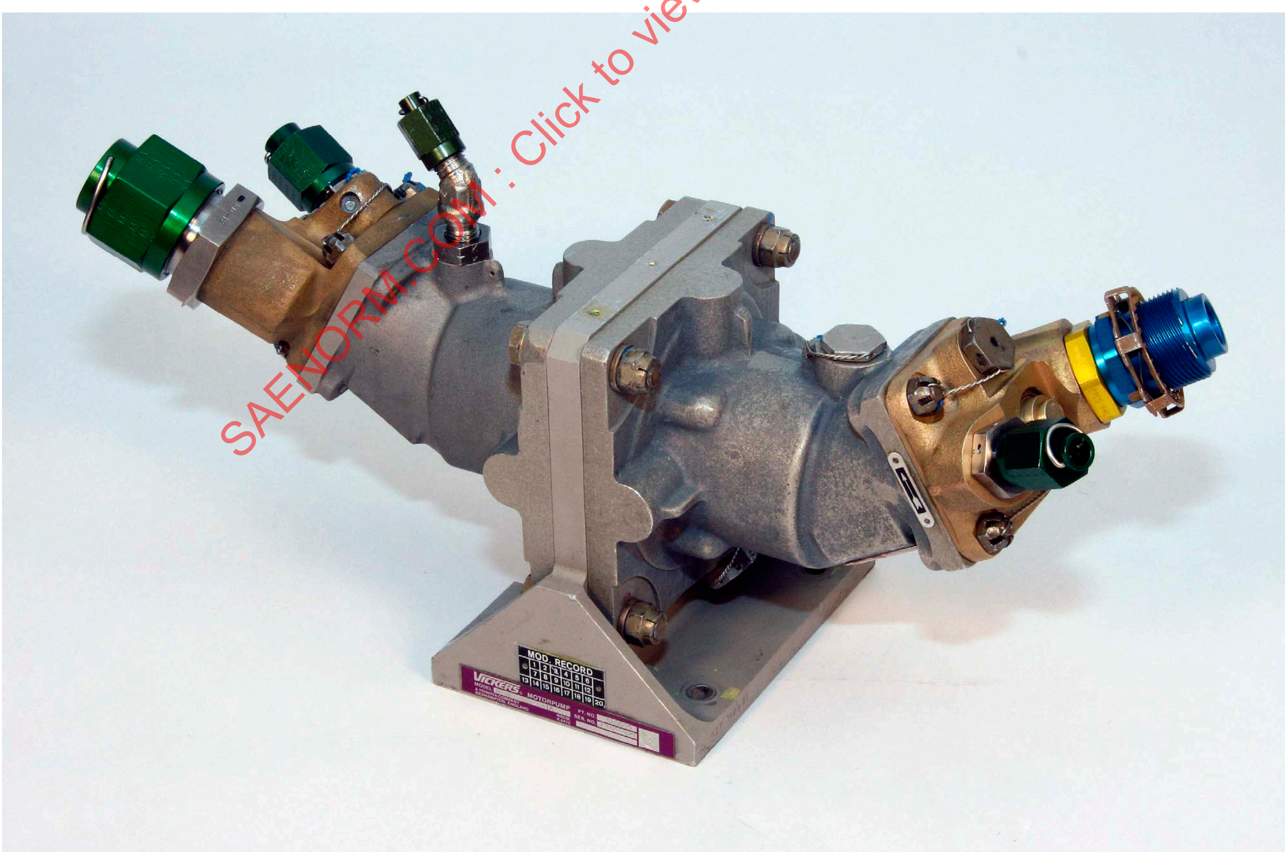

FIGURE 5 – BENT-AXIS UNIDIRECTIONAL PTU

FIGURE 6 – BENT-AXIS MOTOR/INLINE PUMP UNIDIRECTIONAL PTU

6.3 Bidirectional PTU's

The bidirectional PTU is much more versatile than the unidirectional version. Since it can transfer power in either direction, it can be used to maintain the pressure in either system during periods of high demand, or it can power either system from the other in case of an emergency. Also, it can be used to provide hydraulic power selectively for ground check out operations.

For bidirectional units, each side of the PTU must be designed to operate both as a pump and as a motor. The high pressure ports of the PTU always remain high pressure; only the direction of flow reverses.

6.3.1 Bidirectional PTU Limitations

Bidirectional units require substantial compromises in the design of the pump and motor subassemblies in such areas as cylinder block loading, port timing, and piston shoe design and retention. PTU efficiencies suffer accordingly and may typically be only in the mid-sixties percent range (overall) as compared to a mid-seventies percent range for unidirectional PTU designs. Breakout characteristics will also be less desirable and minimum smooth operating speeds much higher than for a unidirectional PTU. For example, a stalled PTU with the same displacement on both sides and 3000 psi (20 700 kPa) applied to both sides will typically not start turning (breakout) until the pressure on one of the two systems is reduced to less than half that value.

6.3.2 PTU Hydraulic Circuit for Bidirectional PTU's

A typical example of a hydraulic circuit incorporating a bidirectional PTU is shown in Figure 7.

The following features are incorporated in this circuit:

- The PTU is designed to transfer hydraulic power from System 1 to System 2, or from System 2 to System 1
- The PTU is selected on/off by two electric motor operated shut-off valves that are located in the high pressure lines of the PTU
- It is possible to have different flow rates when the PTU delivers fluid in System 1 compared to when it delivers fluid in System 2. This is achieved by having the flow control valves set to different maximum flow limits
- The low pressure lines in each side of the PTU serve as either inlet or return lines, depending upon if the PTU side is operating as a pump or motor
- There are two high pressure lines per PTU side. One line per side is the motor supply which has the flow control and shut-off valves. The other line per side is the pump output line which includes a spring loaded check valve
- The use of spring loaded check valves will limit the time when the PTU runs as it will not deliver any fluid if the main system pump is running. In addition, when the PTU is shut down, the check valves serve to protect the PTU (see 6.2.2.4)
- Bleed orifices are located in both the PTU high pressure sides

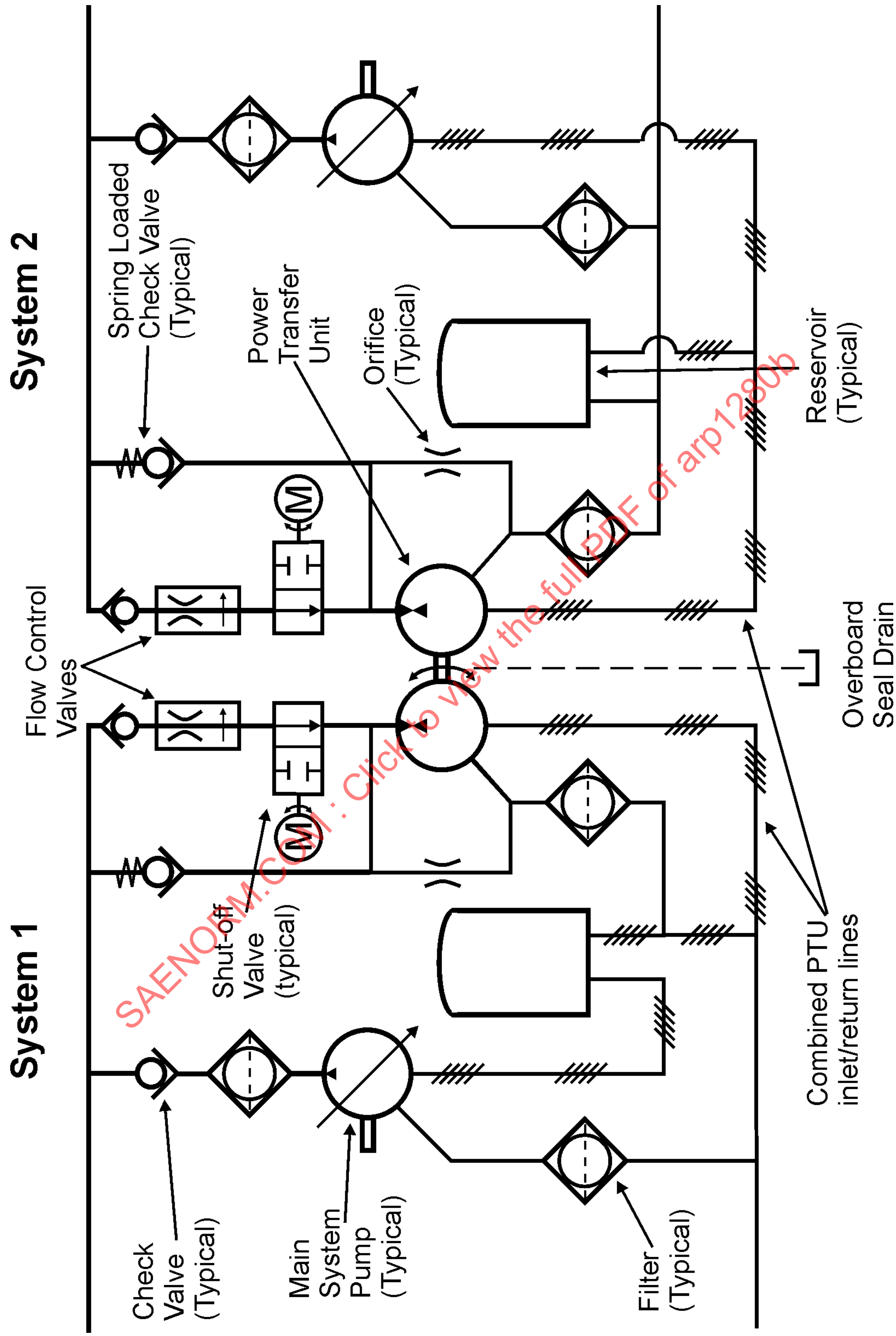

FIGURE 7 - TYPICAL CIRCUIT FOR FIXED DISPLACEMENT BIDIRECTIONAL PTU INSTALLATION