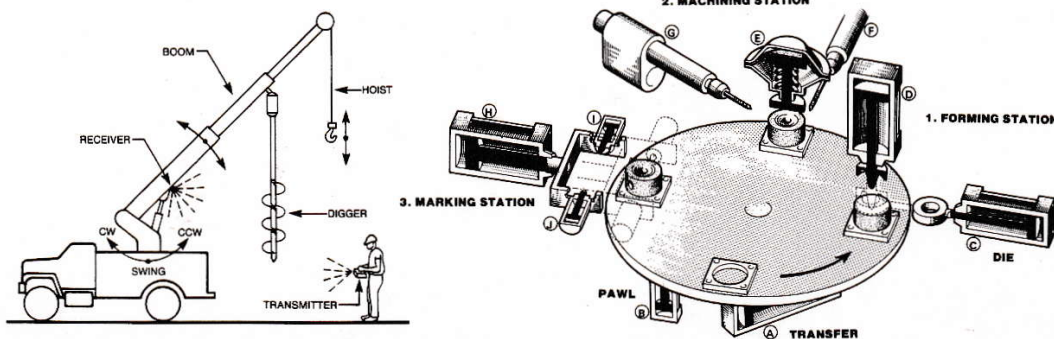


FLUID POWER DESIGN HANDBOOK

FRANK YEAPLE

Second Edition, Revised and Expanded



Fluid Power Design Handbook

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Frank Yeaple

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losses are reduced. The gear-pump drive also has some of the advantages of an eddy-current clutch, which include compact design and good shock absorption characteristics.

HYDROSTATIC DRIVES

A hydrostatic drive consists of a positive-displacement pump driving a positive-displacement fluid motor, usually in one of the basic arrangements shown in Fig. 7.11. The pumps and motors are available in many forms, including external gear, internal gear, vane, radial piston, and axial piston. Each design (Fig. 7.12) with minor modifications can be either a pump or a motor.

Any pump or motor can be varied in speed; for example, with a valving system to vary the flow to the fluid motor or with a variable-speed prime mover to drive the pump.

However, only vane and piston-type pumps and motors can have variable displacement. Gear pumps have constant displacement and must be rotated at variable speed to adjust flow.

Adjustable radial-piston and vane pumps and motors have movable pressure rings that change the eccentricity of the vanes or pistons relative to the shaft, thus changing the displacement. Adjustable axial-piston pumps and motors usually have swash plates or wobble plates that determine the effective stroke of the pistons—or the valve block itself can be tilted. But the principles are the same.

Fluid motor speed is dependent on output flow of the pump divided by the displacement per revolution of the motor. Input torque to the pump (for a constant-speed electric motor) and output torque of the hydraulic motor for a given efficiency depend on pressure and displacement. In a positive-displacement pump-motor drive, pressure rises to whatever level is required to move the load at the set displacement

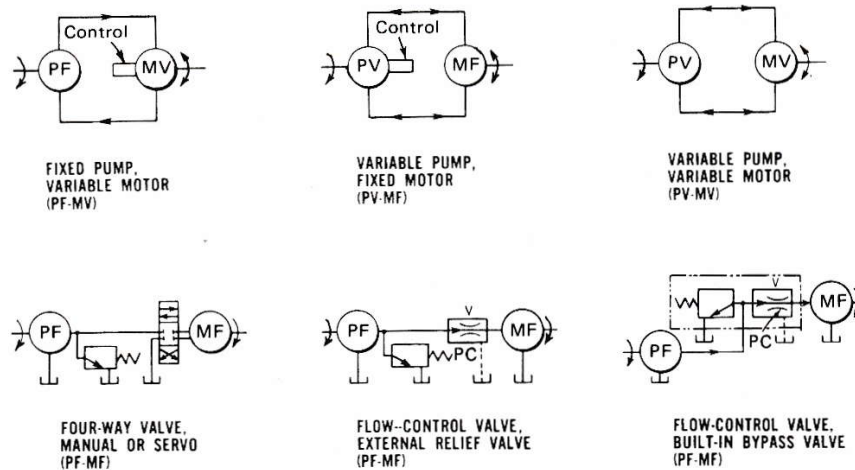


Fig. 7.11 Some typical arrangements for hydrostatic drive elements.

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Axial piston type

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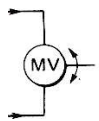
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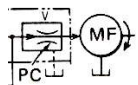
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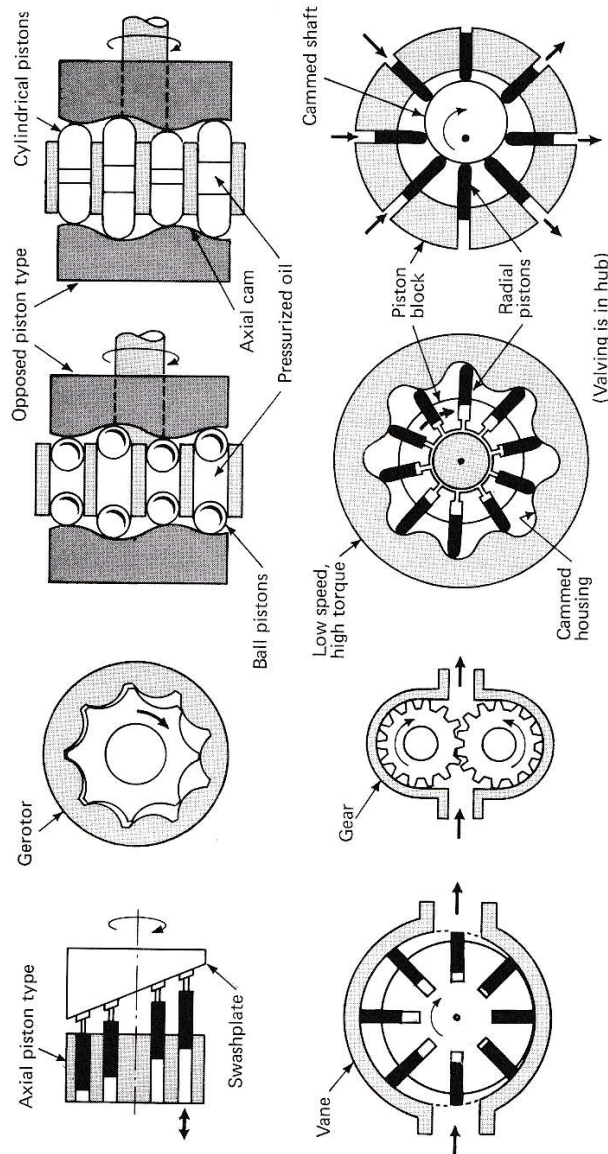


Fig. 7.12 Eight types of hydrostatic motors.

(speed) unless load torque exceeds the capacity of the fluid motor, the pump, or the prime mover. If the pressure exceeds the setting of any of the relief and safety devices, the drive slows down or stalls without damage because fluid is bypassed. As soon as the load returns to normal, the motor operates as before.

The most efficient units are the piston type; vanes are slightly less efficient.

Safe, Smooth Braking

Hydrostatic drives can be slowed down and stopped more smoothly and rapidly than most other drives. This is due in part to the overload capability of the fluid motor. There are two other important reasons: (1) The fluid motors are smaller and have considerably less inertia than equivalent electric motors, eddy-current clutches, or mechanical drives. (2) The motive fluid is easy to control or restrict at any of several flow points.

Two inherent braking systems are ideal for fluid drives: regenerative and dynamic.

With *regenerative* braking, the inertia of the driven machinery begins to drive the fluid motor as a pump, which in turn drives the pump as a motor. The kinetic energy is quickly absorbed, stopping the fluid motor and its connected equipment.

In *dynamic* braking, flow from the pump to the fluid motor is cut off by a valve. Load inertia drives the fluid motor as a pump, and the output is forced through a relief valve, creating a cushioned braking effect.

Conventional external braking with a friction clutch is often used, usually on the driven machinery. Inherent and external braking are combined in some applications. One example is a hydraulic-powered winch, in which regenerative braking action is supplemented by a friction brake to hold the load.

Adjusting the Displacement

There are many conventional ways to change the position of the yoke or stroking ring of adjustable-speed pumps and motors, including hydraulic, pneumatic, electric, and mechanical. The pressure compensator (Fig. 7.13) is of particular interest because it is a feedback system in itself.

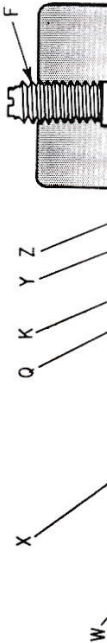
The *pressure compensator* refers to a control feedback device that senses pressure in the line to the fluid motor and uses it to adjust pump or motor displacement to correct or improve the existing operating conditions (compensate).

This pressure signal is useful for a variety of reasons. For a fixed-displacement fluid motor, you can determine torque by reading a pressure gage. And you can use the pressure as a feedback signal to reduce pump delivery, hence speed, if this has raised torque above a preset maximum.

In fig. 7.13, the compensator is attached to the pump control, A. Hydraulic pressure is applied at the upper port. If pressure—representing torque—exceeds the setting of pilot valve screw F, the pump displacement is reduced until the torque returns to normal.

Initial pressure is below the minimum setting of the compensator. Spring B extends piston A for maximum pump displacement. Hydraulic pressure at R acts through orifice X and passage V to impose a thrust on spool H. Piston A remains extended when this pressure cannot overcome spring G to shift spool H.

When the pressure reaches the setting of pilot valve screw F, spool H shifts to



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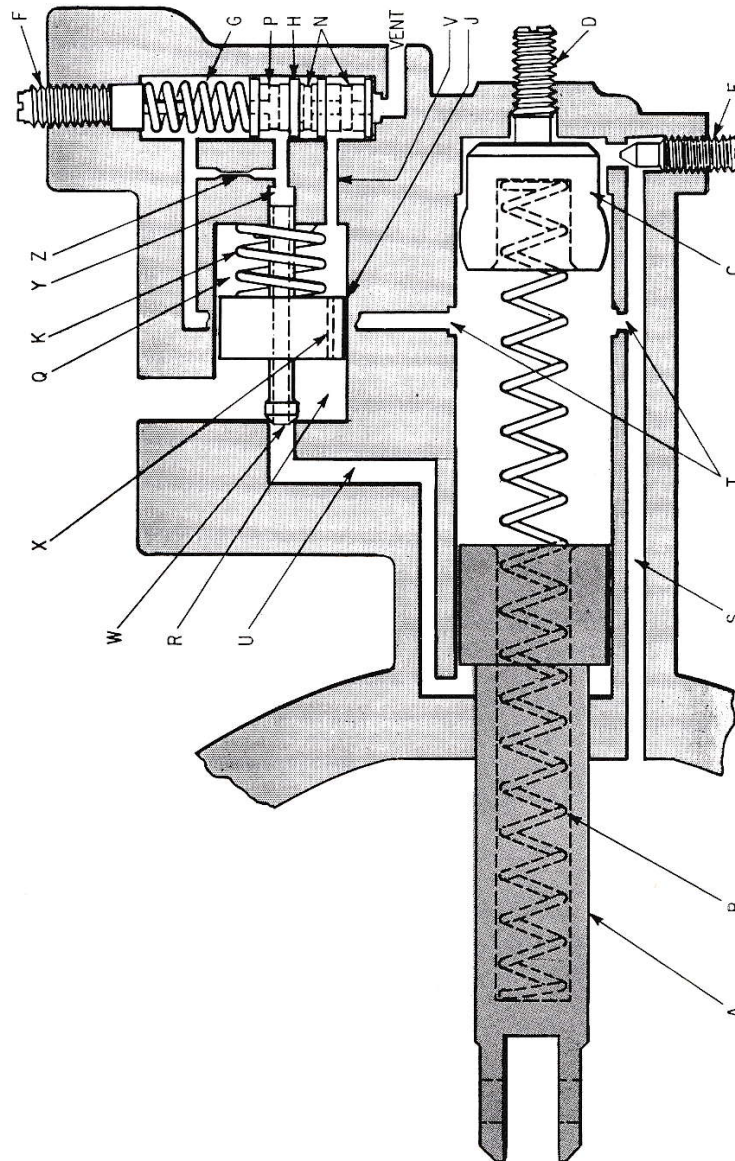


Fig. 7.13 Pressure-compensator control for pump or motor.

direct fluid from chamber Q and passage V through interconnected holes N of spool H to chamber Y. This chamber is connected to drain through orifice Z and to the annulus area of piston A through hole W of piston J and passage U. Flow through orifice X causes a pressure drop so that the pressure in chamber R becomes greater than in chamber Q. The pressure difference unseats piston J, and fluid is throttled from chamber R to passage U. Fluid in U moves piston A to decrease pump delivery until it equals system requirements.

The pressure compensator can also be mounted on a variable-displacement fluid motor. By adjusting motor displacement, you can change its speed to cope with a load change, holding the same hydraulic pressure as before. Thus speed is decreased as a function of load.

Hydrostatic-Drive Classifications

The drives shown in Fig. 7.11 can be further classified in the following five standard categories, all based on flow (Fig. 7.14).

PF-MF (variable-speed prime mover). Fixed-displacement pump, fixed-displacement motor; motor speed adjusted by varying the speed of the prime mover (electric motor or internal-combustion engine) to control pump output.

Prime mover characteristics and not pump-motor performance are involved here.

PF-MF (with flow-control valves). Fixed-displacement pump, fixed-displacement motor; motor speed adjusted with valving that controls the input or output flow of the motor.

In its simplest form the PF-MF (valved) is the lowest in cost of all hydrostatic drives. Efficiency is relatively low because control is by throttling, but there are many important uses for this basically simple drive. Several arrangements are described in detail under flow-control valves in a following section.

PF-MV. Fixed-displacement pump, variable-displacement motor; motor speed adjusted by changing the effective stroke of the pistons or vanes (gears not applicable).

This arrangement, and the PV-MF and PV-MV arrangements following, have well-defined characteristics.

In the PF-MV drive, torque decreases as speed increases, useful for driving a roll (Fig. 7.15) that winds paper or other web material. As the roll diameter increases, rotational speed must decrease to hold a constant linear velocity of the paper. At the same time, mass and resisting torque of the roll increase, matching the PF-MV performance characteristics.

Motor displacement is gradually increased by the control to reduce motor speed. The speed drops because the motor takes more fluid per revolution. Motor torque rises because the effective moment of the vanes or pistons is increased. The horsepower remains relatively constant over the entire speed range.

Using the constant torque drive described below would be uneconomical here because in such a drive the motor would have to be sized to withstand maximum torque at maximum speed—yet it would not normally run at that point.

For example, suppose the load has a torque of 40 lb-ft at 300 rpm and 10 lb-ft at 1200 rpm. A constant-torque drive would have to be sized to produce 40 lb-ft and

Hydrostatic I

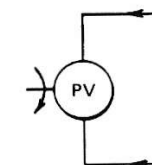
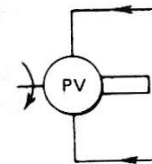
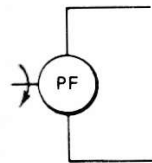
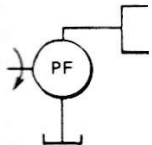
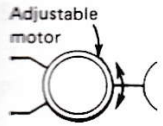


Fig. 7.14 Sc