FLUID POWER DRIVES

HYDRAULIC ADJUSTABLE-SPEED DRIVES

Hydraulic, or fluid, adjustable speed drives are manufactured to deliver 1 to 5,000 hp. These smooth operating units can be controlled manually at the unit or by remote control devices. All of the following drives are designed for installation between a prime mover, such as an electric motor, and the driven load. Some units are made with the prime mover integral with the fluid drive.

The major types of these fluid drives include hydrostatic hydrokinetic, and hydroviscous.

Hydrostatic

Hydrostatic drives, typically rated from 10 to 300 hp, incorporate positive displacement pumps and positive displacement motors. Mechanical energy is transmitted from the prime mover to the pump. The pump imparts energy through a fluid to a hydraulic motor. The prime mover can be an electric motor, a gasoline or diesel engine, or a take-off from the main machine drive.

Hydrostatic drives offer several features that make them particularly adaptable to many adjustable speed applications: infinitely adjustable stepless change of speed, torque, and horsepower; no damage even if stalled at full load; operation in both directions of rotation at controlled speeds; set speeds held accurately against driving or braking loads; small size and low weight per horsepower output.

Output speed can be adjusted if either the pump or motor has variable displacement. If both are fixed displacement units, valves control fluid flow to the hydraulic motor.

Variable displacement pumps and motors are usually piston or vane designs. (Gear pumps and motors are generally not adaptable to variable displacement.) Piston units have proven to be the most capable in applications calling for close speed or power regulation, because of their high overall operating efficiencies. Axial piston pumps and motors commonly have wobble or swash plates that determine effective piston stroke, and hence displacement.

Output speed of a hydraulic motor is a direct function of its displacement and the volume of fluid supplied. Hence, varying the displacement of either pump or motor varies drive speed.

Output torque-horsepower relationships — Hydraulic adjustable speed drives are frequently classified according to their output characteristics. Analysis of the load characteristics will usually determine the best drive type for the job.

Broadly speaking, varying the volume of fluid delivered to a fixed displacement motor will produce varying speed, constant torque, and varying horsepower at the output shaft. A fixed rate of fluid supplied to a varying displacement motor develops varying speed, variable torque, and constant horsepower. When both pump and motor are variable displacement types, speed, torque, and horsepower can be varied.

Hydrostatic adjustable speed drives fall into four standard drive categories based on the types of pumps and motors (fixed or variable displacement):

- PV-MF (variable pump, fixed motor)
- PF-MV (fixed pump, variable motor)
- PV-MV (variable pump, variable motor)
- PF-MF (fixed pump, fixed motor) with flow control valves. The general characteristics of these units are summarized in Table 1.

PV-MF — This is the most common design. Output speed is adjusted by varying the pump displacement. The pump can be stroked "across center" to reverse the direction of oil flow and the direction of motor shaft rotation. Since motor displacement is constant, output torque is constant if pressure is constant, Figure 1. Horsepower is variable and a direct function of output shaft speed at a given pressure setting. Applications for this drive include machine tools, printing and processing machinery, foundry and continuous casting equipment, textile machinery, elevators, and hoists and winches.

PF-MV — Pump output is constant with a constant input speed. Hydraulic motor displacement is varied to change output speed. Reducing motor displacement increases output speed. However, if this displacement is reduced to near zero, the drive speed will attempt to reach an infinite value, Figure 2. Therefore, output speeds are usually kept within design limits by limiting displacement extremes with mechanical stops. The displacement range of a variable displacement motor is commonly 4:1.

Output torque is inversely proportional to output speed, maintaining

Table 1 — Performance characteristics of hydrostatic drives based on constant pump speed and torque measured at constant pressure. (C denotes constant; V denotes variable.)

Pump	Motor	Torque	Output speed	Power
Variable	Fixed	C	V	V
Fixed	Variable	V	V	C
Variable	Variable	V	V	V
Fixed	Fixed	C	C	C

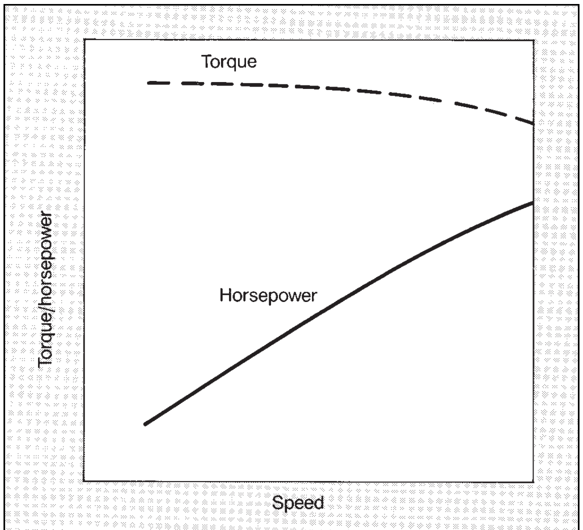


Figure 1 — Torque and horsepower characteristics of PV-MF drive.

relatively constant power. This pattern is particularly useful in rewind drives that require constant web speeds.

PV-MV — A variable-pump, variable-motor design offers the widest operating range of any hydrostatic drive. Output speed can be varied by adjusting the displacement of the pump, the motor, or both. Output torque and power are infinitely adjustable across the complete speed range in both directions of rotation.

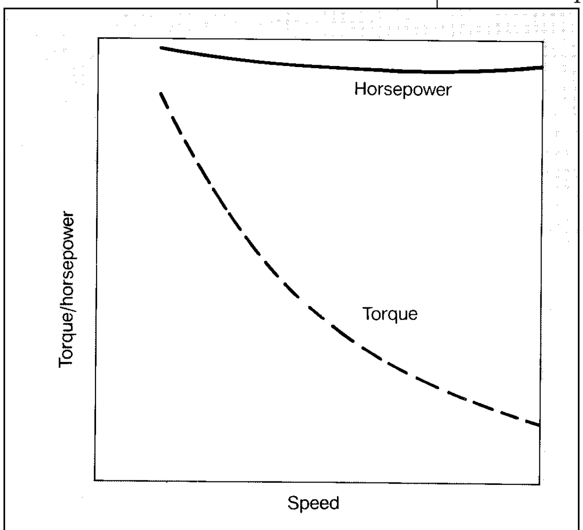


Figure 2 — Torque and horsepower characteristic of PF-MV drive.

Increasing pump displacement and maintaining the hydraulic motor at maximum displacement, delivers essentially constant torque output, at a constant pressure, while increasing output speed and horsepower, Figure 3. With pump displacement and system pressure held constant, the drive delivers essentially constant horsepower. If motor displacement increases, speed drops, and torque increases proportionally, and vice versa. In some installations, pump and motor displacement are controlled simultaneously to provide constant horsepower

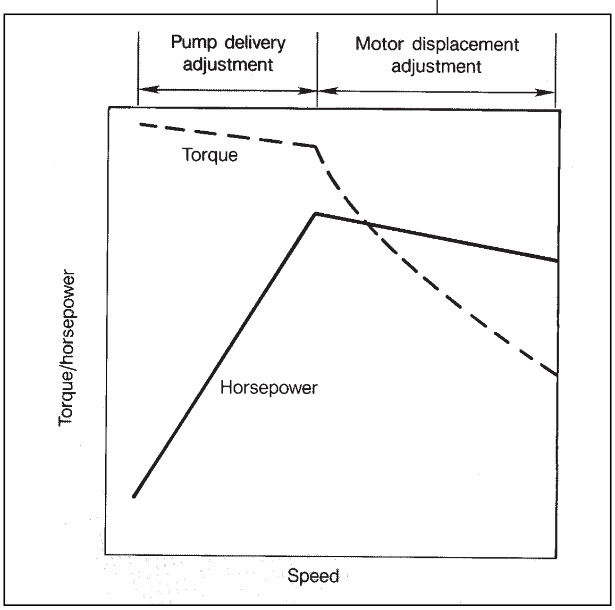


Figure 3 — Torque and horsepower characteristic of PV-MV drive.

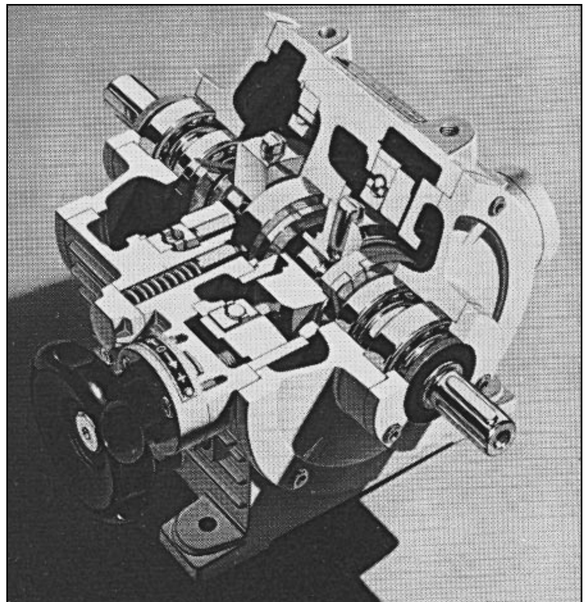


Figure 4 — Typical integrated hydrostatic transmission.

through the speed range.

PF-MF (with valving) — Pump output volume and motor torque are constant, and output speed and horsepower are variable. The flow-control valve limits the amount of fluid available to the motor and thus controls output speed. Efficiency of this system is relatively low compared with other hydrostatic drives, because of the throttling action of the valve. Low in cost, this drive is usually applied where only small speed changes are required.

Integrated hydrostatic transmissions — Frequently termed IHSTs, these units consist of a pump and motor contained in the same housing and share a common valving surface. These compact units offer extremely short paths for oil flow, and eliminate high-pressure oil leaks either to the reservoir or to the outside, Figure 4.

Hydrokinetic

Usually applied in applications rated 1 to 5,000 hp, hydrokinetic adjustable speed drives vary the output speed and torque by varying the amount of fluid in the vortex that couples the input to the output, Figure 5.

The fluid vortex size can be varied during operation by controlling the angle of the scoop tube that removes fluid from the vortex. The tube angle can be controlled manually or by electric, hydraulic, or pneumatic means.

Since the output is only "connected" to the input by the fluid, and without any direct mechanical connection, there is a 2 to 4% slip. This slip reduces efficiency, but offers good shock protection to the driving and driven equipment. A heat exchanger removes the heat generated by this slip.

Hydrokinetic drives offer an operating speed range of about 8:1. In most cases, the minimum speed is specified because operating at too low a speed will cause drive instability.

In addition to controlling the shaft output speed and torque, these units offer a smooth or soft-start characteristic.

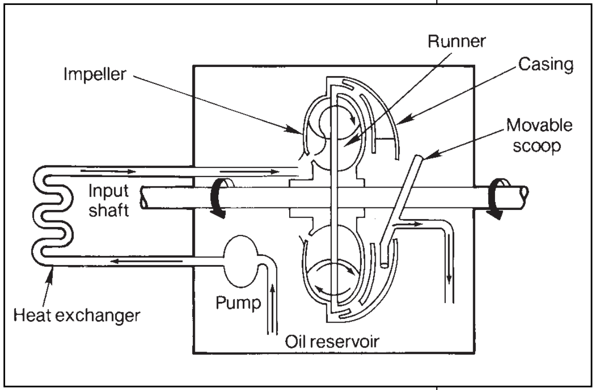


Figure 5 — Hydrokinetic adjustable speed drive.

Hydroviscous

Sometimes termed oil shear drives, these units are adjustable-speed, constant-torque, variable-slip drives. They are similar to other variable-slip drives in efficiency and application. Capable of operating at zero slip, hydroviscous drives are rated from 25 to over 300 hp.

The heart of the drive is the disc stack — alternating layers of steel discs. Alternate discs are faced with a composition material, Figure 6, and are splined to the input shaft. The plain steel discs are keyed to the output shaft. Both sets of discs are free to slide axially. A pump provides cooling oil to the inner diameter of the composition-faced discs, which have a pattern to allow the oil to flow through the disc pack. This oil also flows between the discs and transmits the torque from the input to the output plates.

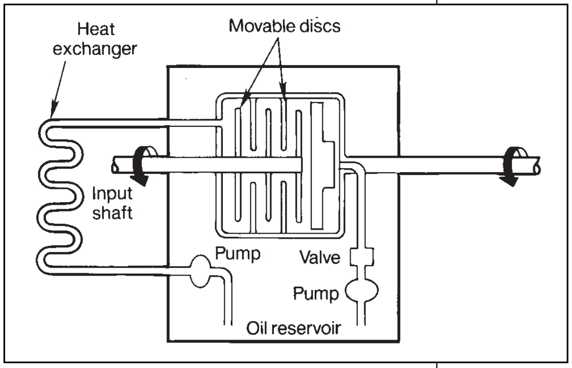


Figure 6 — Hydroviscous drive.

The output shaft contains a cylinder and an actuating piston that produces an axial force on the disc stack. This controls the oil-film thickness between the rotating plates, and adjusts the output torque. For maximum output, the output plates are forced firmly against the input plates with no slip.

A heat exchanger dissipates the heat generated by the slipping action that occurs during reduced speed operation.

ROTARY ACTUATORS

Devices known as rotary actuators produce limited reciprocating rotary force and motion by rotating an output shaft through a fixed arc. Typically, they accomplish their task at higher instantaneous torques and relatively lower speeds than fluid motors, which produce lower torques and unlimited arcs at higher speeds.

Types

Since most types of rotary actuators are permanently lubricated and sealed, they are especially suitable for harsh and demanding environments. The types include:

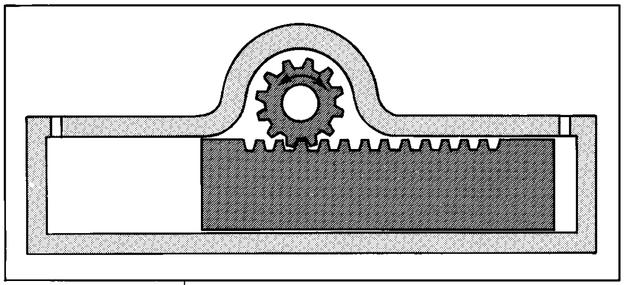


Figure 7 — Rack-and-pinion.

Rack-and-pinion — One side of the piston contains a gear rack that engages a pinion to turn the output shaft. Output torque can be doubled in versions built with two parallel piston-rack units. High tolerance for side and end loading makes these actuators suitable for heavy-duty applications, Figure 7.

Piston-chain — Two pistons, a chain, and a sprocket convert fluid pressure into torque. The larger piston pulls the chain in response to pressurized fluid, while the smaller piston seals the return side of the chain against leakage. Torque remains constant throughout the stroke. Design constraints include the strength of the chain and sprocket as well as the bulk of the unit itself, Figure 8.

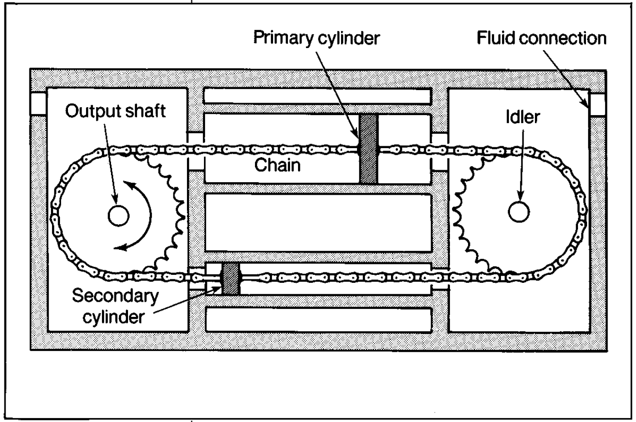


Figure 8 — Piston-chain.

Scotch-yoke — Two pistons are connected by a common rod. At the beginning and end of the stroke, torque output is twice the value produced at the stroke's midpoint. Applications that require a high breaking torque to move the load find this type of actuator appropriate, Figure 9.

Enclosed piston-crank — Also termed linear cylinders, these units feature adjustable stroke for variable shaft rotation up to 110 deg. In opera-

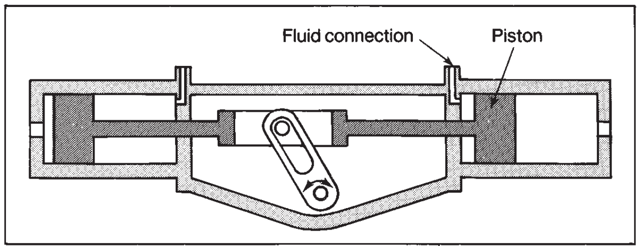


Figure 9 — Scotch-yoke.

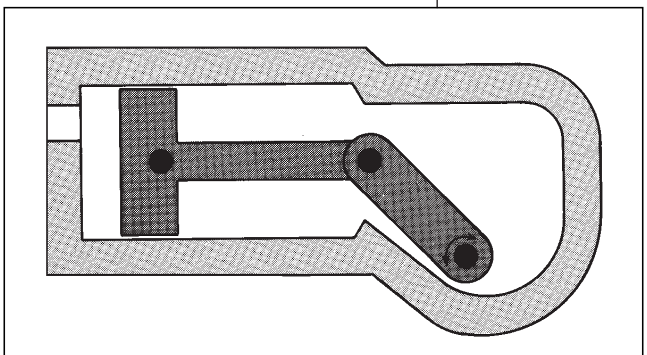


Figure 10 — Enclosed piston-crank.

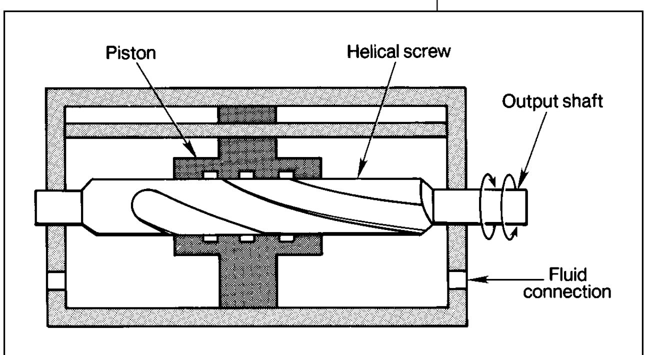


Figure 11 — Helical-spline

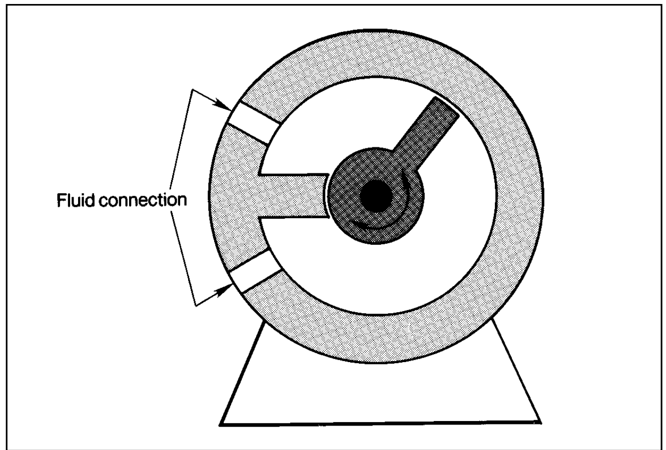


Figure 12 — Single-vane.

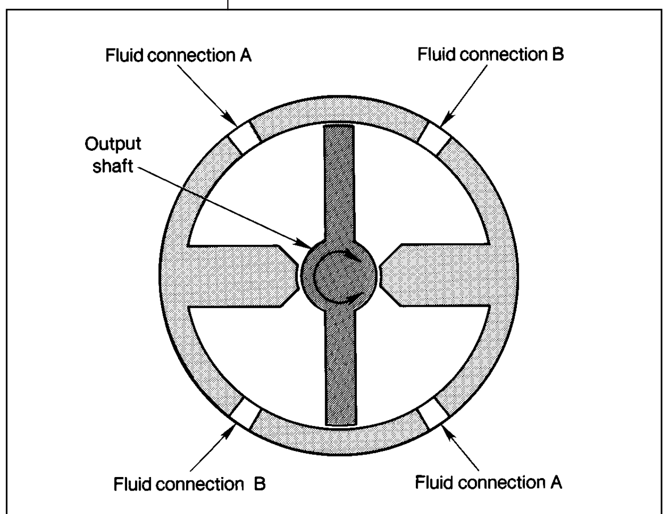


Figure 13 — Double-vane.

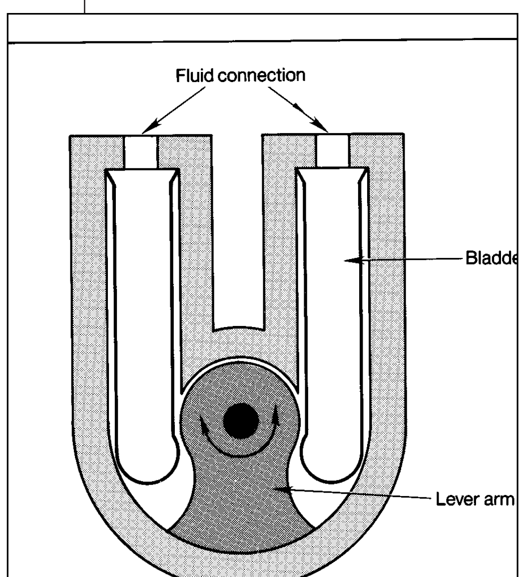


Figure 14 — Bladder type.

tion, a pin-ended rod connected to a crank arm drives the rotating shaft. Fail-safe versions of this actuator contain a spring that returns the shaft to a safe position in the event of power failure or loss of fluid, Figure 10.

Helical-spline — A short piston with a high helical-angle internal thread meshes with a central helical drive shaft. Alternating fluid pressure causes the piston to reciprocate, reversing shaft rotation. Standard rotations vary from 100 to 370 deg, Figure 11.

Single-vane — Differential pressure applied across the vane rotates the drive shaft. Rotation is stopped by a stationary barrier. To reverse rotation, pressure is reversed, Figure 12.

Double-vane — These units offer twice the torque and less than half the rotation of their single-vane counterparts. Two vanes and barriers provide a balance that counteracts the tendencies of unbalanced loads, Figure 13.

Bladder — A pair of rubber bladders are alternately pressurized and exhausted to produce the driving force. When pressurized, the bladder pushes against a cup-shaped lever arm that rotates the output shaft. Zero internal leakage makes this actuator highly accurate and resistant to contamination. Bladder and fluid compatibility is the only requirement for fluid choice.

Versions that use rack-and-pinion mechanisms in conjunction with precharged bladders provide the highest torques (to 45,000 lb-in.), while standard versions are typically rated to 2,750 lb-in, Figure 14.

Applications

General applications for rotary actuators include the following operations:

- Mixing
- Dumping
- Intermittent feeding
- Screw clamping
- Positioning
- Opening and closing
- Turning over
- Automated transfer
- Providing constant tension
- Material handling
- Indexing
- Lifting
- Pushing and pulling

Table 2—Typical ratings for various types of rotary actuators

Rotary actuator type	Maximum torque output (lb-in.)	Maximum shaft rotation (deg)
Rack-and-pinion	50,000,000	1800
Piston chain	23,500	1800
Scotch-yoke	45,000,000	90
Enclosed piston crank	5,000	110
Helical-spline	15,000	100-370 variable
Bladder	45,000	180
Single-vane	350,000	280
Double-vane	700,000	110

FLUID MOTORS

Fluid-powered motors offer the highest power-per-pound ratio of any industrial motor, thus enabling them to be used in space-restricted areas. Since they are totally enclosed, fluid motors can operate in highly contaminated areas, and do not require expensive protective devices in explosive or flammable atmospheres.

Generally, hydraulic and pneumatic motors are designed along similar lines. Though the internal design of each type may be quite different, operating principles are much alike.

Motor types

Fluid motors use one of three basic designs to convert fluid pressure into rotary motion: vane, gear, or piston. Several variations of each type exist; however, the more popular types are discussed here.

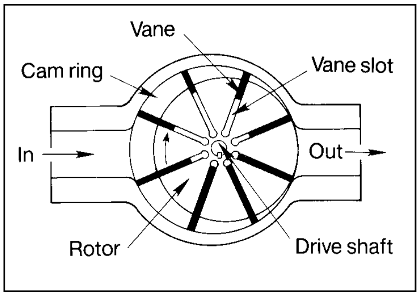


Figure 15 — Radial-vane motor.

Vane-type motors — Radial-vane motors have vanes that slide radially in slots that are machined into a rotor, Figure 15. The eccentric rotor is mounted on a shaft within a cylindrical bore referred to as a cam ring. The vanes are spring loaded to maintain contact with the cam ring during startup and at low speeds. At high speeds, centrifugal force assists in maintaining vane-to-cam contact. As fluid enters the motor, pressure against the vanes turns the rotor, sweeping the fluid from the inlet to the outlet port.

Axial-vane motors use vanes that rotate about fixed points on the circumference of the rotor, Figure 16. Small fixed clearances reduce friction for better start and run-torque efficiencies in a motor that has low and high speed capabilities.

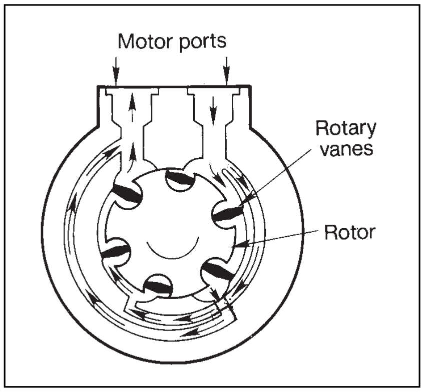


Figure 16 — Axial-vane motor.

Rotary-abutment motors contain vanes that roll in contact with outer sealing services, Figure 17. This design maintains a virtually frictionless seal that is relatively insensitive to wear. It also offers low and high-speed capability.

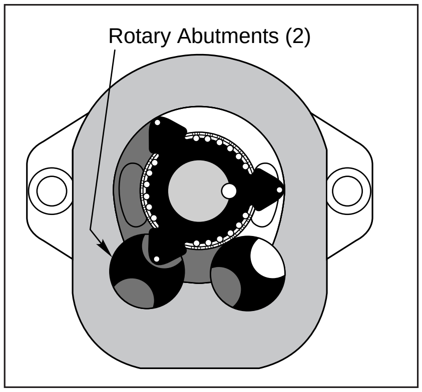


Figure 17 — Rotary-abutment motor. Timing gears that keep rotor and abutments in proper relationship are not shown.

Gear-type motors — Gear-on-gear motors consist of a pair of matched gears enclosed in a housing. Both gears have the same tooth form and are either spur or helical types. One gear is connected to an output shaft; the other functions as an idler. As the gears rotate within the housing, fluid is swept from the inlet to the outlet, Figure 18.

Gear-within-gear motors consist of an inner and outer gearset, Figure 19.

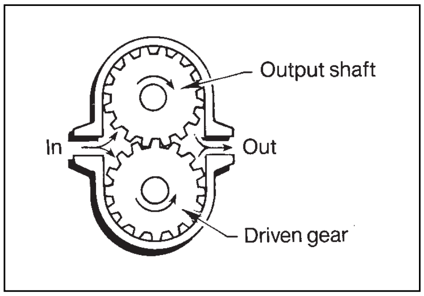


Figure 18 — Gear-on-gear motor.

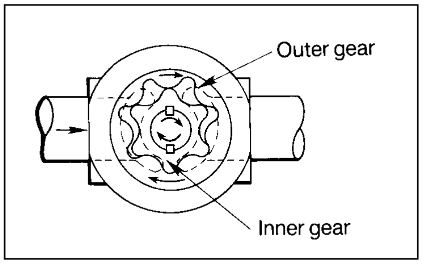


Figure 19 — Gear-within-gear motor.

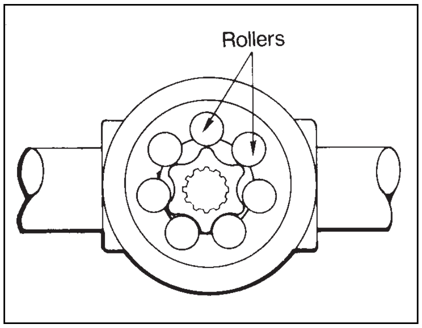


Figure 20 — Roller-vane gerotor.

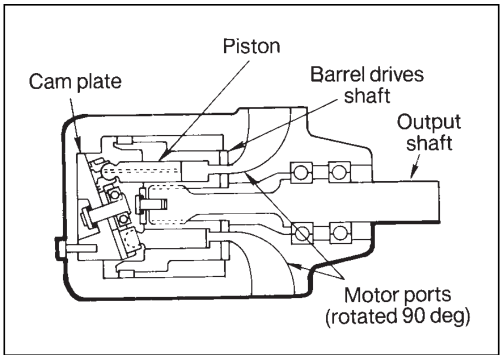


Figure 21 — Axial-piston motor.

Often referred to as gerotors, the inner gear has one less tooth than the outer gear. The shape of the teeth is such that all teeth of the inner gear are in contact with some portion of the outer gear at all times. Because the inner gear has one less tooth than the outer gear, a fluid pocket is formed within the remaining cavity. As the inner gear rotates on a shaft that is mounted eccentric to the bore, fluid travels from inlet to outlet port.

Several variations of the gear-within-gear motor exist, with the most apparent differences occuring in the gerotor design. In most designs, both the inner and outer gear rotate. In other designs, just the inner gear rotates. Another design, the roller-vane gerotor, uses rollers between the inner and outer gears to reduce wear, Figure 20. Regardless of the basic design, gear-type motors offer greater power density and higher torque at low speeds than vane-type motors.

Piston-type motors — These motors use pistons to convert fluid pressure into rotary motion. When compared to other fluid motors, piston motors are very efficient, offer high torque at low speed, but generally have limited high-speed capability. Two basic designs include pistons arranged in either a radial or axial configuration.

Axial-piston motors, Figure 21, contain several pistons (usually seven to nine) that bear against a swash

Table 3 — Typical fluid motor specifications

	Hydraulic motors								
	Radial vane	Axial vane	Rotary abutement	Gear-on-gear	Gear-in-gear	Roller-gerotor	Axial piston	Radial piston (rotary barrel)	Radial piston (fixed cylinder)
Maximum continuous pressure (psi)	2,500	3,000	3,000	3,000	2,000	4,500	2,500-5,000	3,000	5,000
Displacement (in.^{3}/rev)	12	10	12	20	5	57	44	98	2,310
Maximum torque (lb-in.)	4,000	3,200	4,800	6,000	1,500	16,400	17,500	46,000	1,100,000
Starting torque (% of theoretical)	70	97	95	70	70	68	72	88	97
Running torque (% of theoretical)	90	95	95	90	87	85	93	95	97
Continuous speed range (rpm)	80-4,000	0-2,000	5-2,000	100-3,000	100-5,000	0-1,000	50-4,500	1-2,000	0-300
Maximum continuous power (hp)	140	70	65	200	100	32	413	250	300
Leakage (% of max theoretical displ.)	2.5	3	10	8	10	15	2.5	3	3.5
Weight-to-power ratio (lb/hp)	0.3	1.1	1.3	0.2	0.2	1.5	0.7	2	2
Pneumatic motors									
Maximum continuous pressure (psi)	150						150	150	
Rated pressure(psi)	90						90	90	
Maximum rated power (hp)	25						3.5	25	
Maximum design speed (rpm)	6,500						3,000	2,000	

plate. Fluid pressure causes the pistons to create a rotating force in the swash plate, which causes the output shaft to rotate.

Radial-piston motors use pistons that radiate out from the driveshaft, Figure 22, and are available in several design variations.

Piston motors generally cost more than vane or gear-type motors of comparable horsepower. Typically, axial-piston motors have better high-speed capabilities than radial-piston motors, but are limited at low speeds. Conversely, radial-piston motors have better low speed capabilities than axial-piston motors, but are limited at high speeds. Both axial and radial-piston motors are available in fixed or variable-displacement models, which enable their torque-speed curves to be fine tuned to application requirements.

Selecting fluid motors

Table 3 provides typical performance specifications for various hydraulic and pneumatic motors. Many sizes are available in each type with only the maximum values shown. Therefore, on the basis of torque and horsepower, more than one type of motor may meet application requirements. In these cases, performance curves should be obtained from the manufacturer to optimize motor selection.

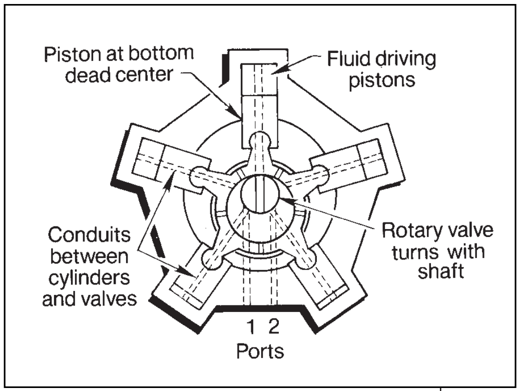


Figure 22 — Radial-piston motor.

HYDRAULIC PUMPS

Two general categories of pumps are used for converting rotating to hydraulic power:

- Nonpositive displacement
- Positive displacement

Nonpositive displscement — Made with a large clearance space between rotating and stationary pump parts, these pumps are generally used for low-pressure, high-volume applications. Operations such as transferring fluids, supplying coolant, and supercharging the inlet of other pumps are examples of suitable applications.

Positive displacement — On the other hand, positive displacement pumps have a very close clearance between rotating and stationary parts. These pumps deliver a specific amount of fluid to the system for each revolution. Pumps used for hydraulic power are positive displacement pumps that can be further subdivided, Figure 23, into two categories.

- Fixed delivery — provides a specific volume displacement per revolution.
- Variable displacement — displacement per cycle can be varied from zero to maximum volumetric capacity.

Selection

To determine a pump's suitability for a given application, three different ratings are typically considered:

Pressure ratings are a major design consideration that tell the specifier how much of a load the pump can withstand and still maintain flow. Since a pump does not create pressure but rather moves fluid, this rating deals with the load on the fluid. The load creates a resistance to flow, which in turn creates pressure.

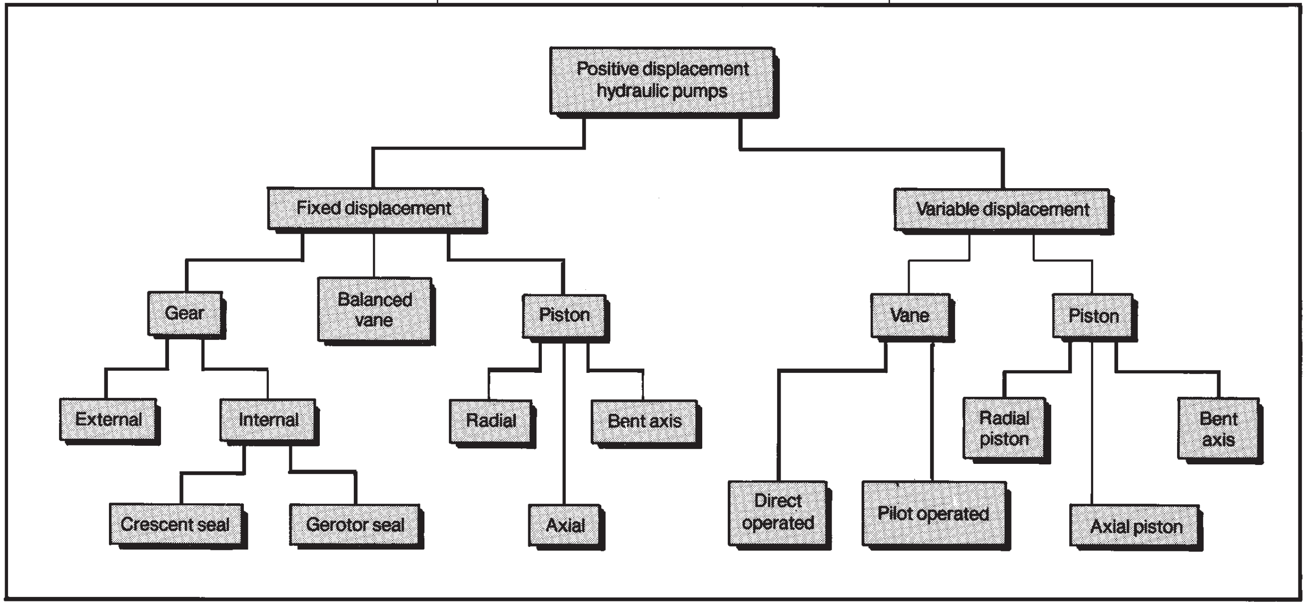
Flow ratings tell the pump specifier at what rate a specific volume of fluid is delivered. Also known as size, capacity, or delivery, the rating is normally expressed in gallons per minute (gpm).

Speed ratngs limit the permissible speed range to avoid cavitation or other damage.

Gear pumps

Variations abound for internal and external type gear pumps. All varieties share the same principles of operation; that is, gear pumps produce

Figure 23 — Classification of the most common positive-displacement hydraulic pumps.



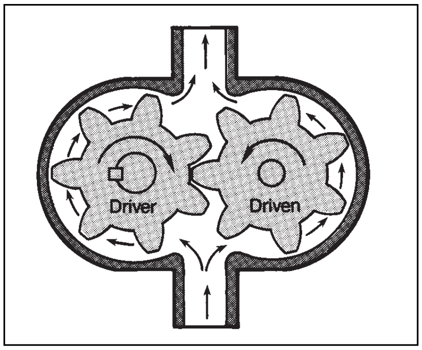


Figure 24 — Spur-gear pump.

flow by using the teeth of two meshing gears to move the fluid.

External gear pumps can be equipped with straight spur (the most common type), helical, or herringbone gears. In operation, the drive gear and driven gear rotate, creating a partial vacuum at the pump inlet (where gear teeth unmesh) that draws fluid into gear teeth. Gear teeth mesh at the outlet, forcing fluid out of the pump.

Internal gear pumps contain one internal and one external gear. They pump fluid in the same manner as external spur gear pumps. In the basic design, the internal gear, which drives the outer gear, has one tooth less than the outer gear. As they mesh, the teeth create sliding seal points. Another design, the crescent pump, uses a crescent-shaped seal to separate the two gears. The gerotor internal gear pump supplies a seal by means of sliding contact, Figure 25.

Screw pumps operate with low noise because fluid does not pulsate; it moves linearly. Single-screw pumps contain a spiraled rotor that rotates eccentrically in an internal stator. Two-screw pumps use two rotors that remain in edge contact as they mesh inside a close-toleranced housing. The same type of housing is used for a three-screw pump, where a central drive rotor meshes with two idler rotors, Figure 26.

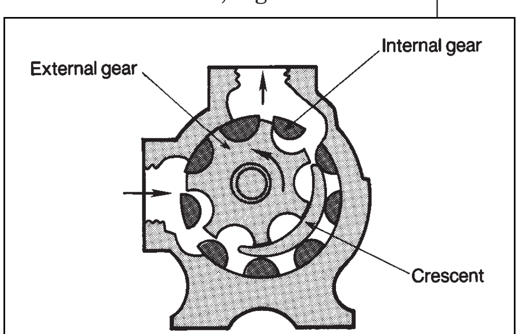


Figure 25 — Crescent pump, a type of gear pump.

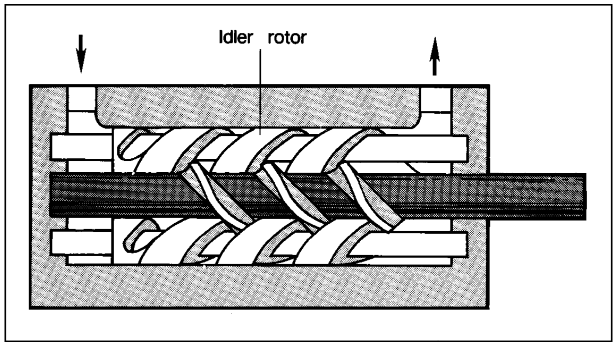


Figure 26 — Axial-flow, three-screw pump.

Piston pumps

High performance characterizes these pumps in general, especially the bent-axis variety used in aerospace applications. This means piston pumps can supply high flows at high rpm. Two basic types of piston pumps — axial and radial piston—are manufactured in both fixed and variable displacement versions.

Axial piston pumps contain one or more pistons that convert rotary shaft motion into axial reciprocating motion. An angled cam or wobble plate rotates, causing pistons to reciprocate and take fluid in as they move toward the thin part of the plate, Figure 27. Fluid is expelled as pistons approach the thick end. In one version, the bent-axis design, both pistons and shaft rotate, making a wobble plate unnecessary. Bent-axis pumps use drive shaft rotation to rotate pistons.

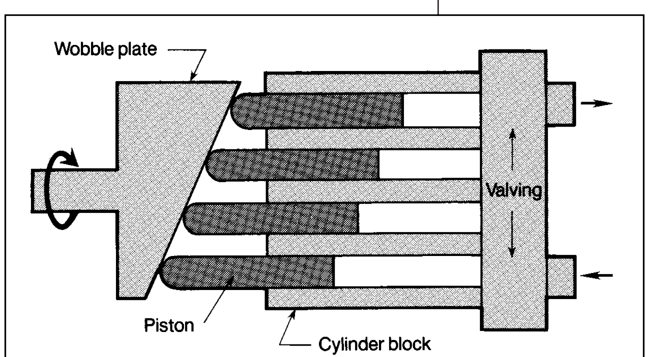


Figure 27 — Axial-piston pump.

Radial piston pumps are characterized by a radial piston arrangement within a cylinder block. As pistons reciprocate, they convert rotary shaft motion into radial motion. One version has cylindrical pistons, while another uses ball-shaped pistons. Another classification refers to porting: check-valve radial piston pumps use a rotating cam to reciprocate pistons; pintle-valve pumps have a rotating cylinder block, and piston heads contact an eccentric stationary reaction ring.

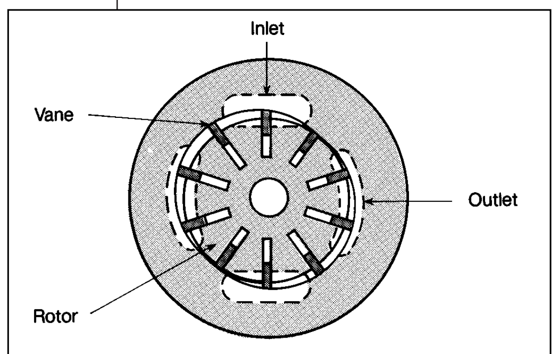


Figure 28 — Balanced-vane pump.

Vane pumps

Typically, a circular rotor mounted eccentrically in a circular chamber comprises a vane pump. Vanes inside the rotor extend and retract due to centrifugal loading as the rotor spins. A high pressure area tends to develop on one side of the rotor and a low pressure area on the other, hence, the name unbalanced vane pump. To eliminate the high bearing loads that result from this tendency, designers offered the balanced vane pump, Figure 28. It uses two diametrically opposed high pressure areas to equalize forces on the pump shaft. Variations on the standard vane pump include a version in which springs hold vanes against the housing, and another in which the vanes are moved outward by pressurized pins. ■