CHAPTER 14

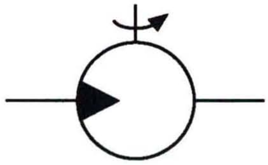
Hydraulic Motors

Hydraulic motors convert the working energy of a hydraulic system into rotary mechanical energy.

Hydraulic motors operate by causing an imbalance which results in the rotation of a shaft. This imbalance is generated in different ways depending on the motor type.

Hydraulic motors are positive displacement devices; that is, as it receives a constant flow of fluid, the motor speed will remain relatively constant regardless of the pressure.

Hydraulic motors used in an industrial system can be divided into vane, gear, and piston types.

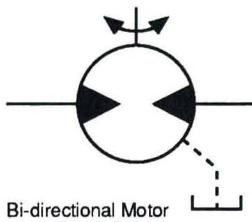


Hydraulic Motor Symbol
(Uni-directional)

motor drains

Motors used in industrial hydraulic systems are almost exclusively designed to be bidirectional (operate in both directions). Even motors which operate in a system in only one direction (unidirectional) are probably bidirectional motors in design.

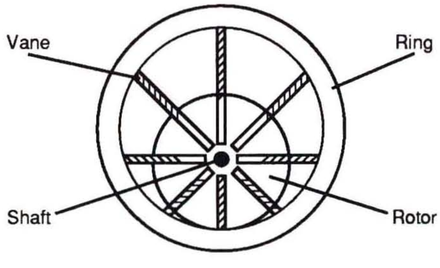
To protect its shaft seal, vane, gear, and piston, bidirectional motors are generally externally drained.



Bi-directional Motor
Symbol

vane motors

A vane motor is a positive displacement motor which develops an output torque at its shaft by allowing hydraulic pressure to act on vanes which are extended.

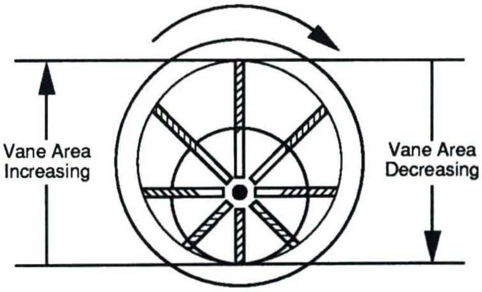


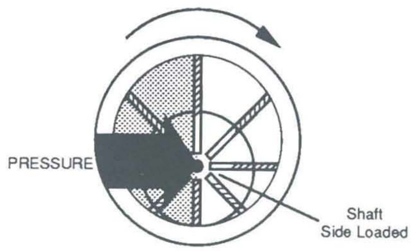
what a vane motor consists of

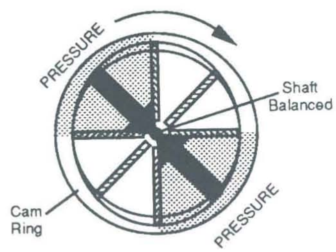
The rotating group of a vane motor basically consists of vanes, rotor, ring, shaft and a port plate with kidney-shaped inlet and outlet ports.

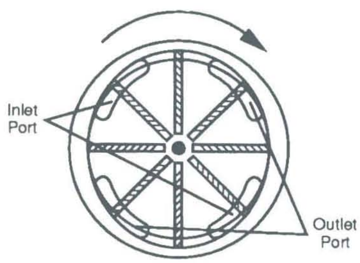
how a vane motor works

All hydraulic motors operate by causing an imbalance which results in the rotation of a shaft. In a vane motor, this imbalance is caused by the difference in vane area exposed to hydraulic pressure. In our illustration, with the rotor positioned off-center with respect to the ring, the area of the vanes exposed to pressure increases toward the top and decreases at the bottom. When pressurized fluid enters the inlet port, the unequal areas of the vanes result in a torque being developed at the motor shaft.

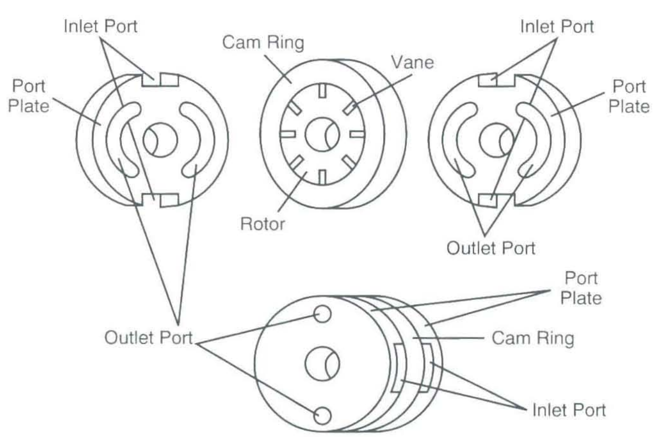








Balanced Vane Motor



Catridge Assembly

The larger the exposed area of the vanes, or the higher the pressure, the more torque will be developed at the shaft. If the torque developed is large enough, the rotor and shaft will turn.

balanced vane motor design

In a hydraulic motor, two different pressures are involved — system working pressure at the inlet and tank line pressure at the outlet. This results in side loading the shaft which could be severe at high system pressures. To avoid shaft side loading, the inner contour of the ring is changed from circular to cam-shaped. With this arrangement, the two pressure quadrants oppose each other and the forces acting on the shaft are balanced. Shaft side loading is eliminated.

A balanced vane motor consists of a cam ring, rotor, vanes, and a port plate with inlet and outlet ports opposing each other. (Both inlet ports are connected together, as are the outlet ports, so that each can be served by one inlet or one outlet port in the pump housing).

Vane motors used in industrial hydraulic systems are generally of the balanced design.

cartridge assembly

The rotating group of industrial vane motors is usually an integral cartridge assembly. The cartridge assembly consists of vanes, rotor, and a cam ring sandwiched between two port plates.

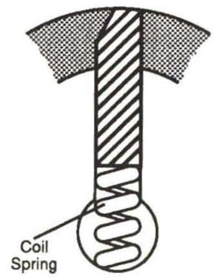
An advantage of using a cartridge assembly is easy motor servicing. After a period of time when motor parts naturally wear, the rotating group can be easily removed and replaced with a new cartridge assembly. Also, if the same motor is required to develop more torque at the same system pressure, a cartridge assembly with the same outside dimensions, but with a larger exposed vane area, can be quickly substituted for the original.

extending a motor's vanes

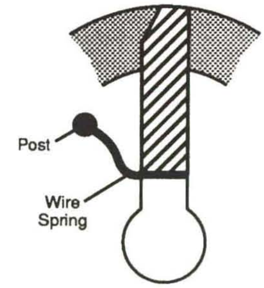
Before a vane motor will operate, its vanes must be extended. Unlike a vane pump, centrifugal force cannot be depended on to throw-out the vanes and create a positive seal between cam ring and vane tip. Some other way must be found.

There are two common means of extending the vanes in a vane motor. One method is spring loading the vanes so that they are extended continuously. The other method is directing hydraulic pressure to the underside of the vanes.

Spring loading is accomplished in some vane motors by positioning a coil spring in the vane chamber.

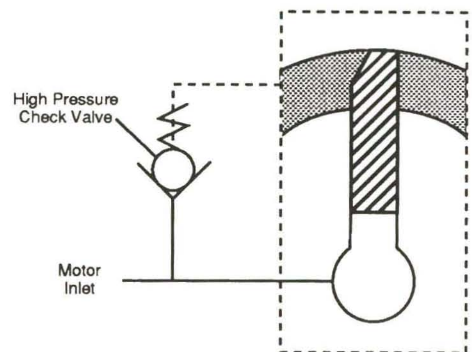


Another way of loading a vane is with the use of a small wire spring. The spring is attached to a post and moves with the vane as it travels in and out of the slot.



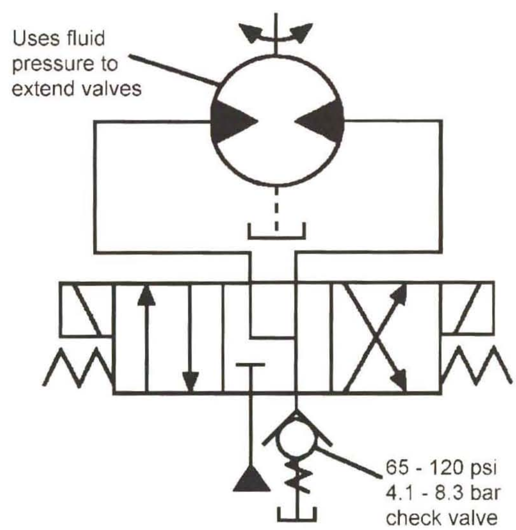
In both types of spring loading, fluid pressure is directed to the underside of the vane as soon as torque is developed.

Another means of extending a motor's vanes is with the use of fluid pressure. In this method, fluid is not allowed to enter the vane chamber area until the vane is fully extended and a positive seal exists at the vane tip. At this time, pressure is present under the vane. When fluid pressure is high enough to overcome the spring force biasing the internal check valve, fluid will enter the vane chamber and develop a torque at the motor shaft. The internal check valve in this instance performs a sequencing function.



freewheeling

When the load attached to a motor's shaft is allowed to freewheel, the load is allowed to coast to a stop. A motor, which uses hydraulic pressure to extend its vanes, requires a 65 psi (4.1 bar) to 120 psi (8.3 bar) check valve in the tank line if the load is allowed to freewheel. The back pressure, which is generated because of the tank line check valve, keeps the vanes from retracting. This slows down the load more quickly.

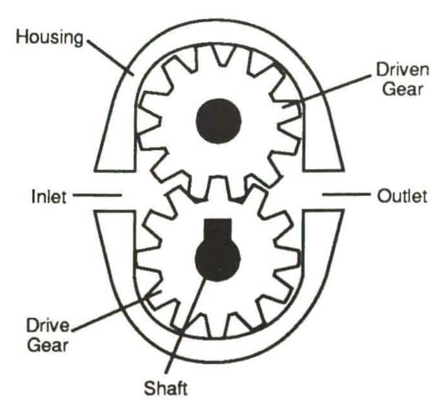


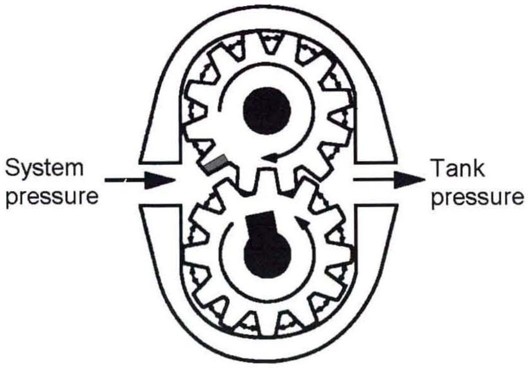
gear motors

A gear motor is a positive displacement motor which develops an output torque at its shaft by allowing hydraulic pressure to act on gear teeth.

what a gear motor consists of

A gear motor basically consists of a housing with inlet and outlet ports, and a rotating group made up of two gears. One gear, the drive gear, is attached to a shaft which is connected to a load. The other gear is the driven gear.



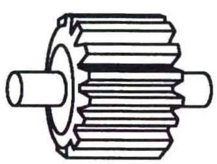


how a gear motor works

Hydraulic motors operate by causing an imbalance which results in the rotation of a shaft. In a gear motor, this imbalance is caused by gear teeth unmeshing.

In the illustration of the gear motor, the inlet is subjected to system pressure. The outlet is under tank pressure. As gear teeth unmesh, it can be seen that all teeth subjected to system pressure are hydraulically balanced except for one side of one tooth on one gear (shaded area). This is the point where torque is developed. Consequently, the torque developed by a gear motor of this type is a function of one side of one gear tooth. The larger the gear tooth or the higher the pressure, the more torque is produced.

You may wonder why the gear teeth do not turn in the opposite direction. To rotate in the opposite direction, gear teeth would have to mesh instead of unmesh. Gears which mesh generate a decreasing volume which pushes fluid out of the housing. The gears have no other choice but to unmesh.


Spur Gear

external gear motor

The gear motor which has been described above is an external gear motor; that is, both meshing gears have teeth on their outer circumferences. The type of gear used in this motor is a spur gear.

internal gear motor

An internal gear motor consists of one external gear which meshes with the teeth on the inside circumference of a larger gear. A popular type of internal gear motor in industrial systems is the gerotor motor.

gerotor motor

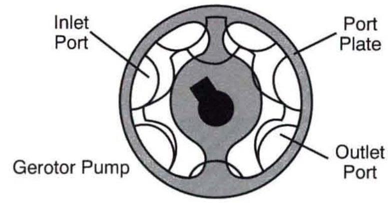
A gerotor motor is an internal gear motor with an inner drive gear and an outer drive gear which has one more tooth than the inner gear. The inner gear is attached to a shaft which is connected to a load.

The imbalance in a gerotor motor is caused by the difference in gear area exposed to hydraulic pressure at the motor inlet.

In the gerotor motor illustration, the exposed area of the inner gear increases at the inlet.

Fluid pressure acting on these unequally exposed teeth, results in a torque at the motor shaft. The larger the gear, or the higher the pressure, the more torque will be developed at the shaft.

Fluid entering the rotating group of a gerotor motor is separated from the fluid exiting the motor by means of a port plate with kidney-shaped inlet and outlet ports.

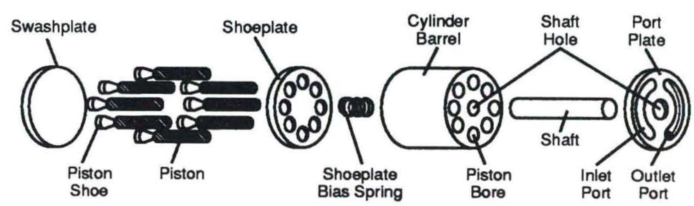


piston motors

A piston motor is a positive displacement motor which develops an output torque at its shaft by allowing hydraulic pressure to act on pistons.

what a piston motor consists of

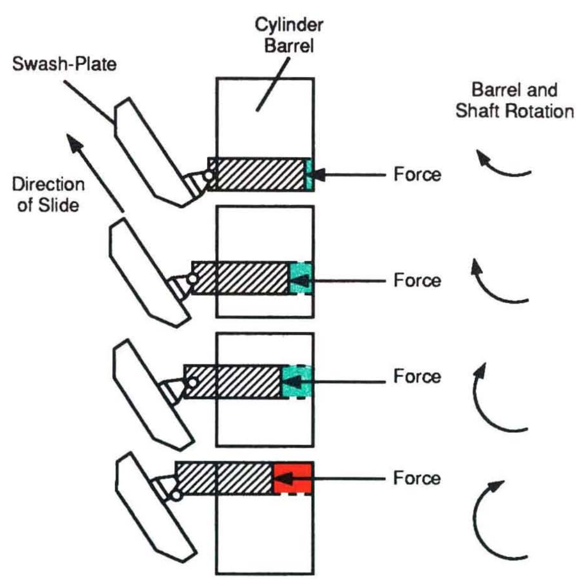
The rotating group of a piston motor basically consists of swashplate, cylinder barrel, pistons, shoeplate, shoeplate bias spring, port plate, and shaft.



The pistons fit inside the cylinder barrel. The swashplate is positioned at an angle and acts as a surface on which the shoe side of the piston travels. The piston shoes are held in contact with the swashplate by the shoeplate and bias spring. A port plate separates incoming fluid from the discharge fluid. A shaft is connected to the cylinder barrel. In our example, it is attached at the port plate end.

how a piston motor works

To illustrate how a piston motor works, let us observe the operation of one piston in a cylinder barrel of an axial piston motor.



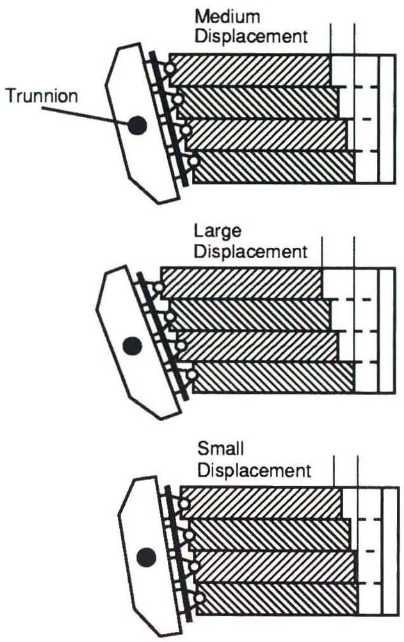
With the swashplate positioned at an angle, the piston shoe does not have a very stable surface on which to position itself. When fluid pressure acts on the piston, a force is developed which pushes the piston out and causes the piston shoe to slide across the swashplate surface. As the piston shoe slides, it develops a torque at the shaft attached to the barrel. The amount of torque depends on the angle of slide caused by the swashplate and the pressure in the system. If the torque is large enough, the shaft will turn.

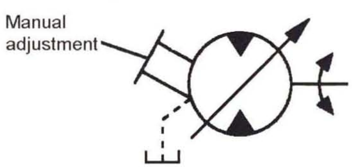
Torque continues to be developed by the piston as long as it is pushed out of the cylinder barrel by fluid pressure. Once the piston passes over the center of the circle, it is pushed back into the cylinder barrel by the swashplate. At this point, the piston bore will be open to the outlet port of the port plate.

A single piston in a piston motor develops torque for only half of the full circle of rotation of the cylinder barrel and shaft. In actual practice, a cylinder barrel of a piston motor is fitted with many pistons. This allows the motor shaft to continuously rotate as well as obtain maximum torque.

Of the vane, gear, and piston motors which have been described, only piston motors are available as variable displacement.

variable displacement axial piston motors





Variable Displacement Motor

The displacement of an axial piston motor, or any piston motor, is determined by the distance the pistons are reciprocated in the cylinder barrel.

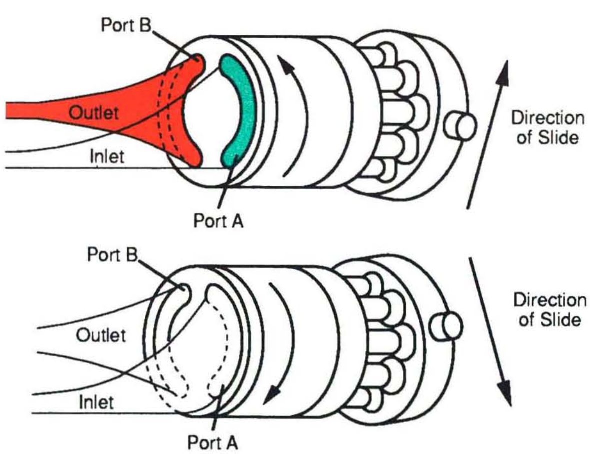
Since the swashplate angle controls this distance in an axial piston motor, we need only to change the angle of the swashplate to alter the piston stroke and motor displacement.

With a large swashplate angle, the pistons have a long stroke within the cylinder barrel.

With a small swashplate angle, the pistons have a short stroke within the cylinder barrel.

By varying the angle of the swashplate then, the motor's displacement and consequently its shaft speed, and torque output can be changed.

overcenter axial piston motors

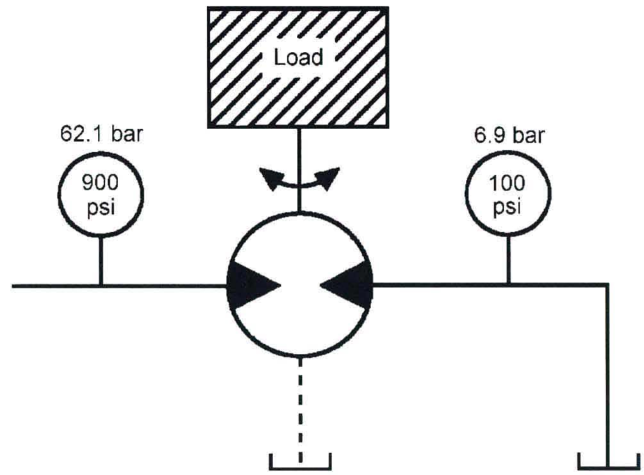


Some swashplates of axial piston motors have the capability of crossing overcenter. A motor of this type is able to reverse its shaft rotation without changing the direction of flow through the motor.

In the overcenter axial piston motor illustrated, the motor shaft is not shown. But, you can imagine it as being attached to the cylinder barrel at the port plate end through the swashplate side. We can see from the illustration that changing the angle of the swashplate by crossing overcenter results in a different direction of slide for the pistons. Consequently, cylinder barrel and motor shaft rotate in the reverse direction. This takes place with fluid flow passing through the motor in the same direction.

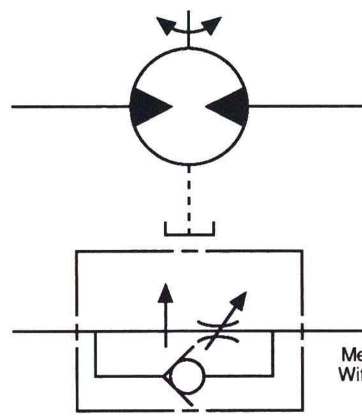
hydraulic motors in a circuit

We have seen that the torque developed by a hydraulic motor is the result of hydraulic pressure acting on the motor's rotation group. In these situations, we made the assumption that no hydraulic pressure was present after the motor. Even though this side of the motor is generally drained to tank, tank line pressure, or back pressure, can be as high as 100 psi (6.9 bar) in some systems. The force generated by the back pressure on the rotating group must be overcome before a load can be turned.



In the illustration, the load attached to the motor's shaft can be turned, theoretically, with a pressure of 800 psi (55.2 bar) at the motor inlet. The back pressure in the tank line is 100 psi (6.9 bar). With this condition, the load will not turn. An additional 100 psi (6.9 bar) must be present at the motor inlet to equal or offset the 100 psi (6.9 bar) backpressure. With 900 psi (62.1 bar) at the inlet, 900 psi (62.1 bar) is used to develop and turn the load. 100 psi (6.9 bar) offsets the back pressure. The 800 psi (55.2 bar) which was calculated to turn the load actually indicated the required pressure differential.

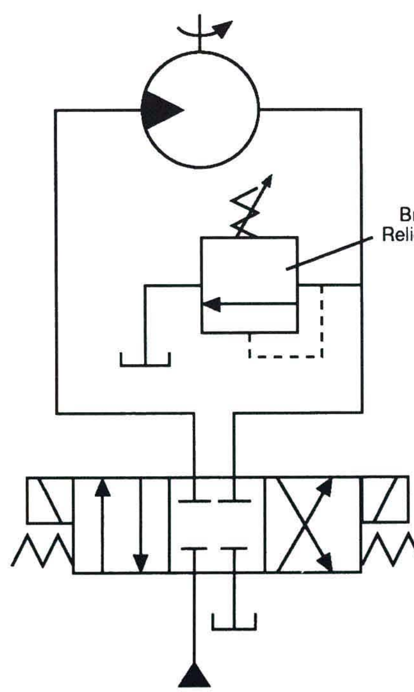
To accurately control the speed of a hydraulic motor, a meter-out circuit is used.



Meter-Out With Motor

Hydraulic motors are generally externally drained. This means a portion of the flow entering the motor ends up as leakage. As the torque requirement and the pressure at the motor increases, more flow runs out the drain. As a result, motor shaft speed decreases.

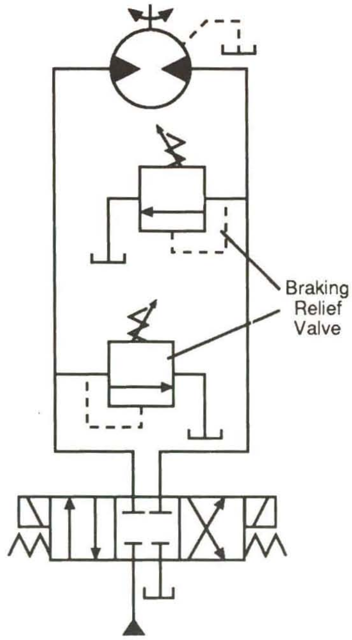
A meter-out circuit controls the flow as it discharges from the motor and is not concerned with leakage. This is the only circuit which can control a motor's shaft speed accurately regardless of load.

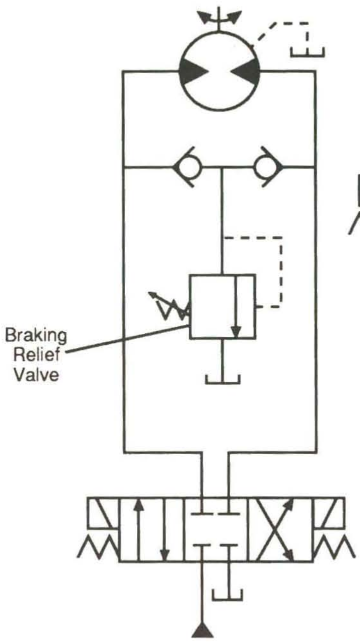


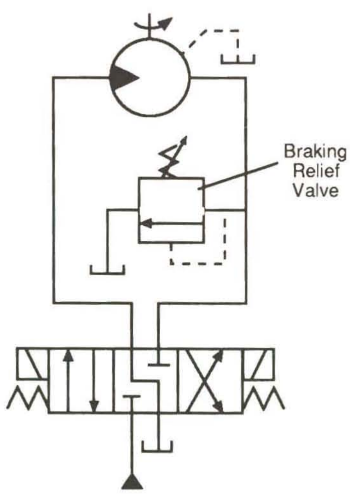
One of the major concerns in motor circuits is the control of the load attached to the motor shaft. We have seen previously that a brake valve will keep a load from running away as well as allow the motor to develop full torque.

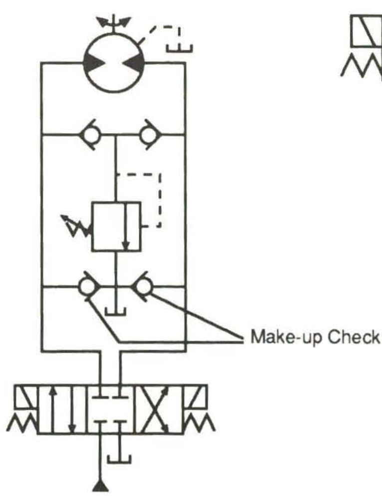
A brake valve senses the load. It automatically responds to the load's demand. Many times, the braking function is required to be a matter of choice rather than automatic. For example, in a conveyor system, which has no overrunning load and requires braking only periodically, a directional valve is used to select the braking function.

Braking is performed by shifting the directional valve, usually to its center position, and blocking the flow out of the motor. When the pressure at the motor outlet increases to the braking relief valve setting, the valve opens and brakes the motor.









If the motor requires braking in both directions, a braking relief valve can be connected through check valves to both motor lines. No matter which way the motor is rotated, braking is performed by the same valve.

In some applications, two braking pressures are necessary. For example, a conveyor, which is loaded in one direction and unloaded in the opposite direction, would require two different braking pressures to make most efficient use of its cycle time.

When two different braking pressures are required, two braking relief valves are connected in the motor lines. Each valve handles flow in different directions. Braking relief valves applied in this manner can also be used to achieve approximate starting and stopping positions with dissimilar loads in opposite directions.

A braking relief valve is a common, ordinary relief valve placed in a motor line. It is not a special valve.

The setting of a braking relief valve is higher than the setting of the system relief valve.

motor cavitation

All of the motor circuits shown so far do not take into account that hydraulic motors can cavitate. They will cavitate just as a pump if a sufficient supply of fluid is not received at its inlet port while turning. This means that anytime a motor is braking, the motor inlet must not be blocked.

In a unidirectional motor circuit, this requirement can be met by allowing the motor inlet to be connected to tank through the center position of the directional valve.

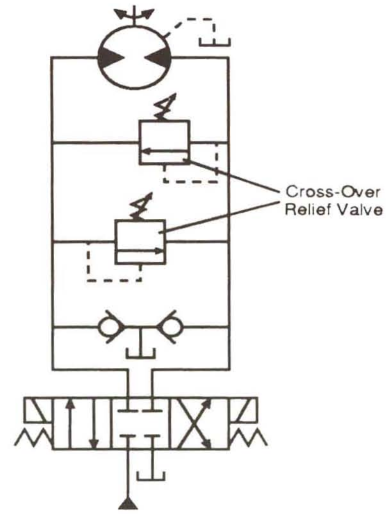
When braking occurs, any less-than- atmospheric pressure at the motor inlet will result in fluid being drawn from the reservoir.

make-up checks

In a bidirectional motor circuit, supplying liquid to the motor inlet during braking is usually done with low pressure (5 psi .34 bar or less) check valves positioned in each line. These are known as make-up check valves.

crossover relief valves

A bidirectional motor circuit, using braking relief valves in both directions, can be designed so that the discharge from the relief valves is connected to the opposite motor lines. From first glance, it may appear that these "crossover" relief valves would keep the motor's inlet well supplied since the motor's discharge fluid is re-directed to motor inlet. However, make-up checks are still required since some fluid is lost through the motor drain and leakage across the directional valve. This arrangement of crossover relief valves and make-up checks is a very common bidirectional motor circuit.

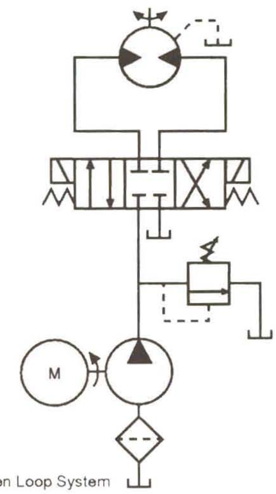


hydrostatic drive

Hydraulic motors used in combination with various pumps is termed a hydrostatic drive. A hydrostatic drive can be either "open loop" or "closed loop."

open loop

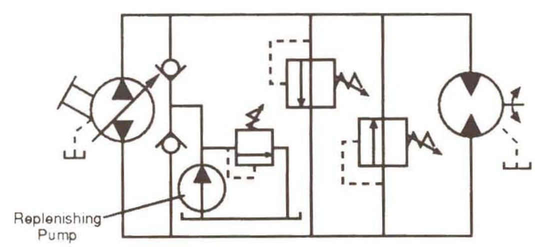
An open loop hydrostatic drive has the motor inlet connected to pump outlet and the motor outlet connected to tank. The motor rotation is stopped or reversed with a directional valve. The speed of the motor depends on pump flow rate and motor displacement.



Open Loop System

closed loop

A closed loop hydrostatic drive has motor inlet connected to pump outlet and motor outlet connected to pump inlet. The closed loop schematic shows motor rotation in either direction with variable pump input which will vary motor speed and direction. Any leakage in the system is made up by the replenishing pump. A small reservoir is used in this system since most of the system fluid is carried and stored in the system piping. Closed loop hydrostatic drives are compact.

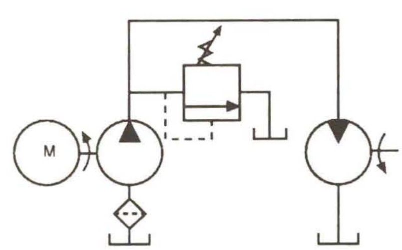


Closed Loop System

pump-motor combinations

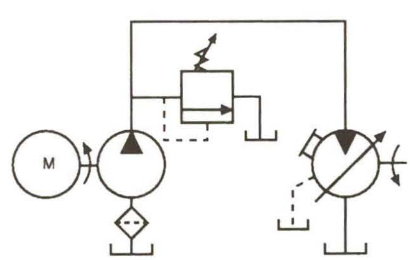
Various types of pumps and motors can be combined to achieve different system requirements.

A constant displacement pump used with a fixed displacement motor results in a fixed hydraulic horsepower being developed by the pump. Torque and shaft speed are constant at the motor. (Assume input rpm is constant.)

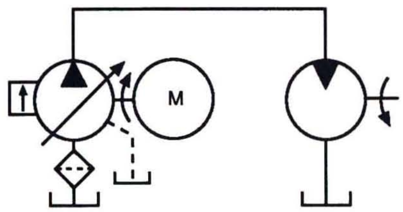


Fixed Hp. Torque and Speed

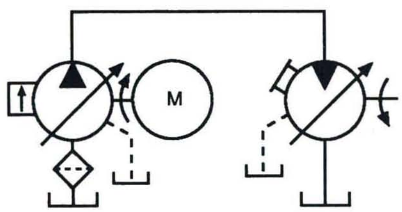
A constant displacement pump combined with a variable displacement motor results in a fixed



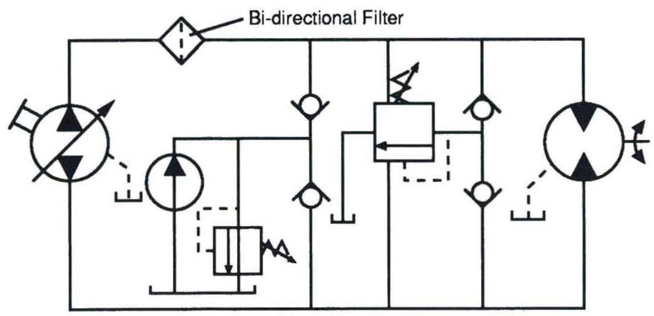
Fixed Hp. Variable Speed and Torque



Variable Hp. and Speed, Constant Torque



Variable Hp., Speed, and Torque



Closed Loop
Hydrostatic Transmission

hydraulic horsepower being delivered to a motor. But, shaft speed and torque are variable at the motor.

A variable displacement pump used with a fixed displacement motor results in a constant torque at the motor. Since the pump's flow rate can be changed, the horsepower delivered to the motor and the motor shaft speed can be varied.

A system using both a variable displacement pump and a variable displacement motor has the flexibility of variable speed, torque, and horsepower.

hydrostatic transmission

In common terminology, anytime a variable displacement pump or motor is used in a pump-motor circuit, the system is labelled a hydrostatic transmission.

In the closed loop hydrostatic transmission illustrated, the variable displacement, overcenter pump can vary the speed of the motor shaft as well as reverse shaft rotation. In closed loop systems of this nature, a small pump, called a replenishing pump, is used to make up for any leakage which occurs in the system.

Closed loop hydrostatic transmissions are compact systems. The reason being the reservoir is small and flow controls and directional valves are not needed to reverse or control the speed of shaft rotation.

hydraulic motors vs. electric motors

Hydraulic motors have certain advantages over electric motors. Some of these advantages are:

1. instant reversing of a motor's shaft
2. stalling for indefinite periods without damage
3. torque control throughout its operating speed
4. dynamic braking easily accomplished
5. a weight to horsepower ratio of .5 lb./hp (0.2668 kg) compared to 10 lb/hp (4.536 kg) for electric motors.

motor torque

The amount of torque developed by a specific motor is a function of system pressure acting on the imbalance of the motor displacement. This is expressed by the formula:

$$\text{Torque (lb. in.)} = \text{Pressure (lb/in}^2\text{)} \times \frac{\text{Motor Disp. (in}^3\text{)}}{2\pi}$$

$$\text{Torque (N-m)} = \text{Pressure (N/m}^2\text{)} \times \frac{\text{Motor Disp. (m}^3\text{)}}{2\pi}$$

The formula indicates that the higher the pressure or the greater the motor displacement, the more torque will be developed. The equation for torque is very similar to the equation for cylinder force.

$$\text{Force (lbs.)} = \text{Pressure (lb/in}^2\text{)} \times \text{Area (in}^2\text{)}$$

$$\text{Force (N)} = \text{Pressure (bar)} \times \text{Area (m}^2\text{)}$$

Instead of using force (lbs./N), the motor formula uses torque (lb. in./N-m). psi [(lb/in^2) (N/m^2)] denotes fluid pressure in both equations. The cylinder force formula indicates area [(in^2) (m^2)]; the motor torque formula indicates motor displacement [(in^3) (m^3)]. But by dividing displacement [(in^3) (m^3)] by 2π, in^3 (m^3) displacement can be treated as the unbalanced area within the motor.

Assume that a motor with an 8 in^3 (13.11 x 10^{-5} m^3) displacement is subjected to 500 psi (34.48 bar). To determine the output torque in terms of lb. in., the above information is plugged into the motor torque formula.

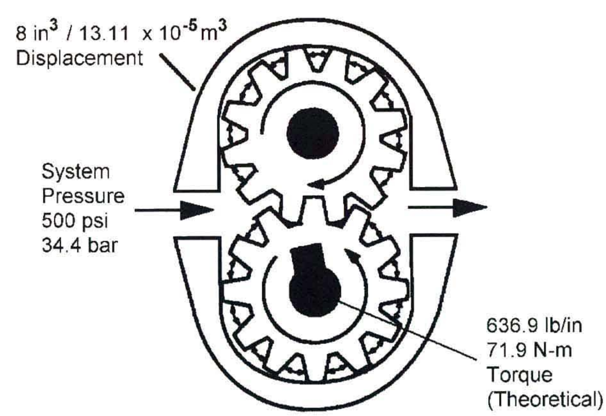
$$\text{Torque (lb.in.)} = \text{Pressure (lb/in}^2\text{)} \times \frac{\text{Motor Disp. (in}^3\text{)}}{2\pi}$$

$$= \frac{500 \times 8}{2 \times 3.14}$$

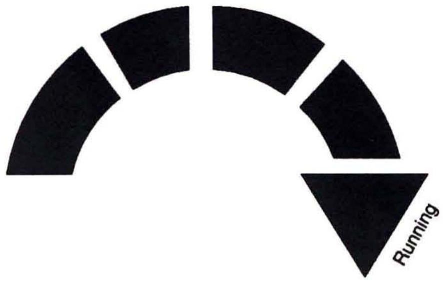
$$= \frac{4000}{6.28}$$

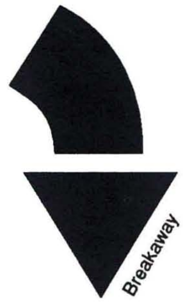
$$= 636.9 \text{ lb. in.}$$

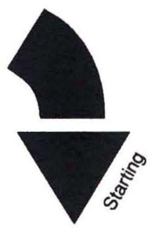
$$(= 71.9 \text{ N-m})$$



With 500 psi (34.48 bar) present at the inlet of an 8 in^3 (13.11 x 105m^3) motor, the equation indicates that 636.9 lb. in. (71.9 N-m) of torque is developed at the motor shaft.







running, breakaway, and starting torque

The equation for motor torque refers to theoretical torque; it does not take into account motor inefficiency.

Running torque indicates the amount of torque a motor produces to keep a load turning. Running torque may also refer to the requirement of the load to keep it turning.

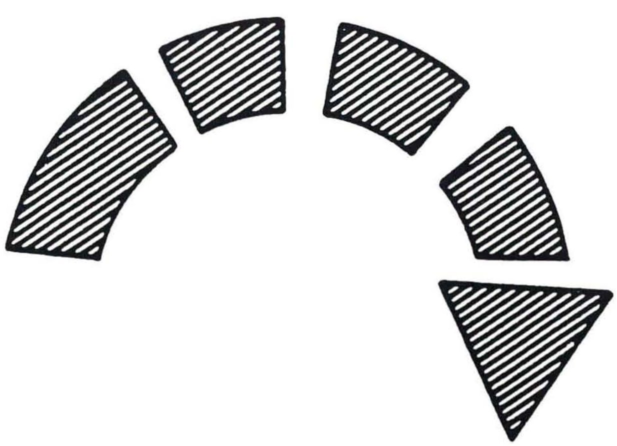
When it refers to a motor, running torque indicates the actual torque that a hydraulic motor can develop to keep a load turning. It takes into account motor inefficiency and is expressed as a percentage of theoretical torque. The running torque of common gear, vane, and piston motors is approximately 90% of theoretical.

Breakaway torque refers to a demand of a load which must be satisfied before it will rotate.

Breakaway torque is the torque required of a hydraulic motor to get a load turning. More torque is required to start a load moving than to keep it moving. If a hydraulic motor is not capable of developing sufficient torque to breakaway a load, the load will not move.

Starting torque refers to a capability of a hydraulic motor; it indicates the amount of torque which a motor can develop to start a load turning. In some cases, this is much less than running torque.

Starting torque is expressed as a percentage of theoretical torque. It ranges between 60-90% of theoretical. Assume a load needs 500 lb-in (56.5 N-m) of torque to keep it turning, but the breakaway torque required is 600 lb-in (67.8 N-m). A specific motor may be capable of developing a running torque of 500 lb-in (56.5 N-m), but its starting torque capability at a maximum system pressure may only be 450 lb-in (50.85 N-m). The starting torque capability of a hydraulic motor must be equal to or greater than the breakaway requirement of the load. In this example, the motor could not turn the load.



motor shaft speed

Speed at which the output shaft of a hydraulic motor rotates is determined by how quickly the motor rotating group is filled with liquid. This is illustrated by the expression:

$$\text{Motor shaft speed (rev/min)} = \frac{\text{Flow (gal/min)} \times 231}{\text{Motor displacement (in}^3\text{/rev)}}$$

$$= \frac{\text{Flow (lpm} \times 1000)}{\text{Motor displacement (cm}^2\text{/rev)}}$$

The expression shows the relationship between shaft speed, flow rate, and motor displacement. The larger the flow rate, or the smaller the motor displacement, the more quickly the motor will be filled. Consequently, the more shaft revolutions will be made in one minute.

Consider an 8 in^3 (131.1 cm^3) displacement motor which has 15 gpm (56.85 lpm) flowing to its inlet. Motor shaft speed can be calculated by plugging the information into the shaft speed formula:

$$\text{Motor shaft speed (rev/min)} = \frac{\text{Flow (gal/min)} \times 231}{\text{Motor displacement (in}^3\text{/rev)}}$$

$$= \frac{\text{Flow (lpm/min)} \times 1000}{\text{Motor displacement (cm}^2\text{/rev)}}$$

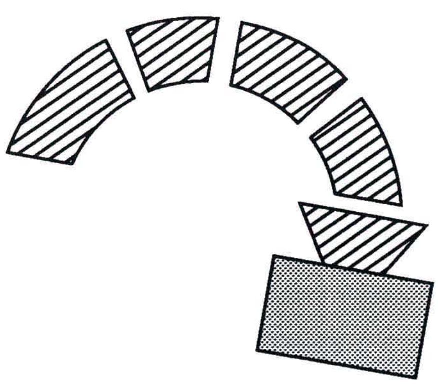
$$= \frac{15 \times 231}{8} \qquad \frac{56.85 \times 1000}{131.1 \text{ cm}^2}$$

$$= \frac{3465}{8} \qquad \frac{56850}{131.1}$$

$$= 433 \text{ rpm} \qquad 433 \text{ rpm}$$

With 15 gpm (56.85 lpm) flowing onto an 8 in^3 (131.1 cm^2) displacement motor, the formula indicates that the motor shaft speed will be 433 rpm.

The equation for motor shaft speed indicates theoretical values. It does not take into account volumetric inefficiencies which are present just as in a pump. For this reason, manufacturer's catalog must be consulted for actual values.



motor horsepower

Hydraulic horsepower is gpm (lpm) and psi (bar) flowing through a system. As hydraulic horsepower enters a motor inlet, it is converted into rotary mechanical horsepower at motor output shaft. The expression which describes this action is:

$$\text{Motor Horsepower} = \frac{\text{Shaft speed (rev/min)} \times \text{Torque (lb. in.)}}{63025}$$

$$\text{kW} = \frac{\text{Torque T (N-m) x shaft speed (rpm)}}{9543}$$

Assume that a motor develops 620 lb-in (70 N-m) of torque at 800 rpm. To calculate motor horsepower, the equation can be used:

$$\text{Motor Horsepower} = \frac{\text{Shaft speed (rev/min) x Torque (lb.in.)}}{63025}$$

$$\text{kW} = \frac{\text{T (N-m) x rpm}}{9543}$$

$$= \frac{800 \times 620}{63025} \qquad \frac{70 \times 800}{9543}$$

$$= \frac{496000}{63025} \qquad \frac{56000}{9543}$$

$$= 7.9 \text{ hp} \qquad = 5.87 \text{ kW}$$

The equation indicates that a motor developing 620 lb-in (70 N-m) of torque at 800 rpm is generating 7.9 hp (5.86 kW).

Since motor power consists of values of shaft speed and torque, it might be assumed that ordinary hydraulic motors can develop power consisting of high torque at low speed. This is not the case.

The common gear, vane, or piston motor is not capable of developing smooth, low rpm shaft speeds at full torque. Because of the increased force required to start a load moving, and the increased internal motor leakage and static friction at high pressures, smooth shaft rotation at low rpm and high pressure is difficult, if not impossible to achieve. To receive smooth shaft speed as well as high torque, these motors must be operated at a minimum of 200-400 rpm.

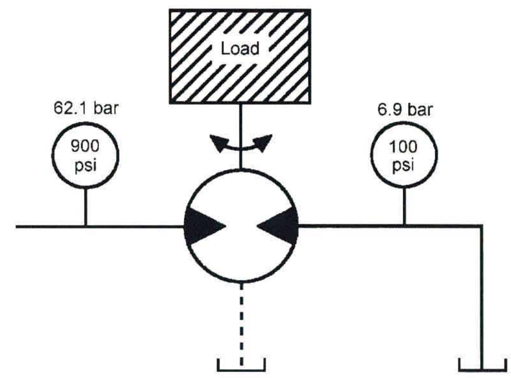
The high operating speed of these motors generally ranges from 2400-3600 rpm.

If low shaft speed and low torque are required for an application, the ordinary hydraulic motor may be capable of satisfying the need. But, if high torque is required at a low speed, a special class of motors is used. These are identified as hi-torque low speed motors. Shaft speed for these motors ranges from 1 rpm to approximately 1000 rpm.

With basic motor types defined and with their relationships between flow and pressure indicated, we find in the next section how hydraulic motors operate in a system. We begin by seeing how motor torque is affected by backpressure.

back pressure affects motor torque

As shown in the formula, motor torque depends on system pressure acting on the imbalance within a motor rotating group. The formula does not take into account backpressure at motor outlet.



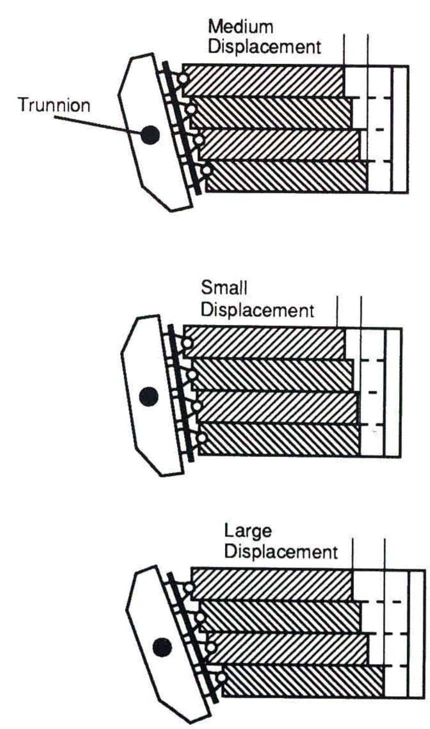
In the illustrated circuit, assume a load attached to a motor shaft requires a pressure of 800 psi (55.17 bar) within the motor rotating group to overcome load resistances. This assumes that no backpressure is present at motor outlet.

With 800 psi (55.17 bar) at motor inlet and 100 psi (6.89 bar) backpressure, a force is generated on the rotating elements to turn the shaft in the opposite direction. This subtracts from the torque at the motor shaft. The motor, in effect, develops a torque equal to 700 psi (48.28 bar) acting on the rotating group.

If a motor requires 800 psi (55.17 bar) to equal load resistances, an 800 psi (55.17 bar) differential must exist from motor inlet to motor outlet. Therfore, pressure at the inlet must be at least 900 psi (62.1 bar).

variable displacement motor affects torque

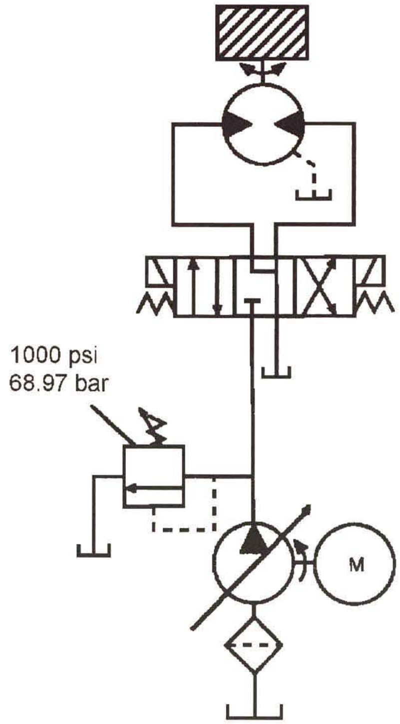
An axial piston motor can be designed to be variable displacement. With this arrangement, output torque can be varied as required.



Maximum pressure developed by pump/electric motor is usually limited by a relief valve or a pressure compensator. With motor torque being a function of pressure and motor displacement, the maximum torque of a fixed displacement motor is reached once the relief valve or compensator setting has been reached.

In the circuit illustrated, a hydraulic motor requires a pressure of 800 psi (55.17 bar) to equal load resistances and backpressure. System relief valve is set at 1000 psi (68.97 bar).

Operating under normal conditions, pressure at motor inlet is 800 psi (55.17 bar). Now assume that motor load increases so that pressure required at motor inlet is 1100 psi (75.86 bar). With the relief valve set for a maximum pump/electric motor



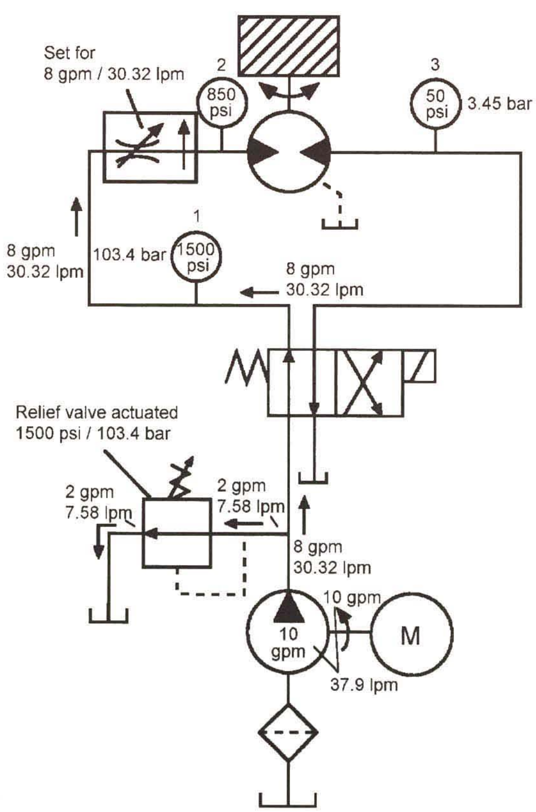
pressure of 1000 psi (68.97 bar), the motor stalls. Since motor torque is a function of psi (bar) and motor displacement, torque has therefore reached its maximum. Motor displacement is fixed and system pressure is maximum. With a variable displacement motor, motor displacement can be changed when this condition arises generating more of an imbalance inside of its rotating group. Consequently, more torque is developed with the same system pressure. This assumes, of course, that the motor had not been at maximum displacement initially.

controlling motor speed

Shaft speed of a hydraulic motor is determined by how quickly the motor rotating group is filled with liquid. A motor receiving 5 gpm (18.95 lpm) at its inlet develops a certain shaft speed. If the same motor received 10 gpm (37.9 lpm), it would fill twice as fast; therefore, its shaft speed would be nearly twice as much.

In some cases, motor shaft speed is required to be periodically adjustable and at the same time accurate. For these reasons, a flow control valve is used.

Three types of flow control circuits were illustrated previously — meter-in, meter-out, and bleed off. Bleed off circuits generate the least amount of heat, but they are the least accurate since they only indirectly control actuator speed and cannot compensate for system leakage. Bleed off circuits are normally used in applications where control of motor speed is not critical. In illustrating motor flow control circuits, we will consider meter-in and meter-out circuits, and compare their accuracies.

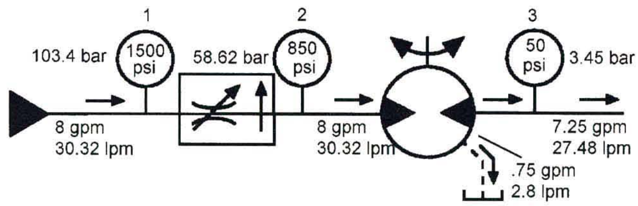


motor speed with a meter-in circuit

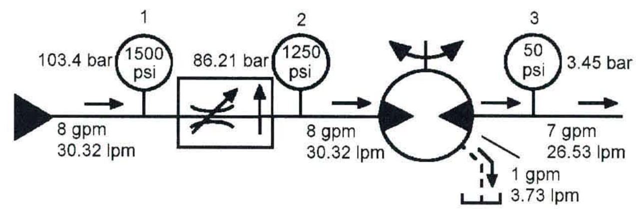
With a meter-in circuit, a flow control valve is positioned upstream or ahead of motor inlet; flow is controlled as it passes into the motor. In the example circuit, a pressure compensated flow control valve is used.

In the circuit, assume that the motor load requires 800 psi (55.17 bar), backpressure is 50 psi (3.45 bar), and system relief valve is set at 1500 psi (103.4 bar). Pump flow is 10 gpm (37.9 lpm), but the pressure compensated flow control is set for 8 gpm (30.32 lpm).

With the system operating, gage 1 indicates the relief valve setting of 1500 psi (103.4 bar); gage 2 indicates 850 psi (58.62 bar) ahead of the motor; and gage 3 reads a 50 psi (3.45 bar) backpressure. The pressure compensated flow control is measuring or metering 8 gpm into the motor.



The 8 gpm (30.32 lpm) flowing into the motor is not all used to fill the motor rotating group; some of it is wasted. Hydraulic motors have internal leakage just as pumps. As pressure differential across a motor increases, leakage also increases. To avoid fluid accumulation in the housing, hydraulic motors are many times externally drained, but may be internally drained as well.



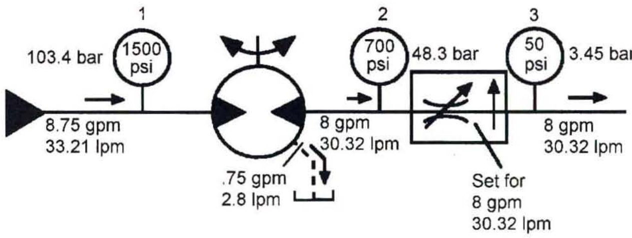
As fluid enters a hydraulic motor, leakage occurs between clearances of stationary parts or across rotating elements. In vane and gear motors, fluid in an external drain is only leakage between clearances of stationary parts. Leakage fluid across vanes or gear teeth pass into other vane or gear chambers and out the outlet. With an axial piston motor, leakage across the pistons ends up in the housing along with leakage through stationary parts. An externally drained axial piston motor separates all internal leakage from motor discharge flow.

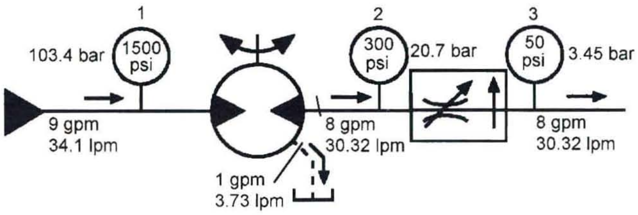
With an axial piston motor in our example, it can be seen that as 8 gpm (30.32 lpm) entered motor inlet, .75 gpm (2.8 lpm) leaked out the drain at a pressure differential of 800 psi (55.17 bar). 7.25 gpm (27.48 lpm) discharged from the motor outlet indicating that 7.25 gpm (27.48 lpm) determined motor shaft speed.

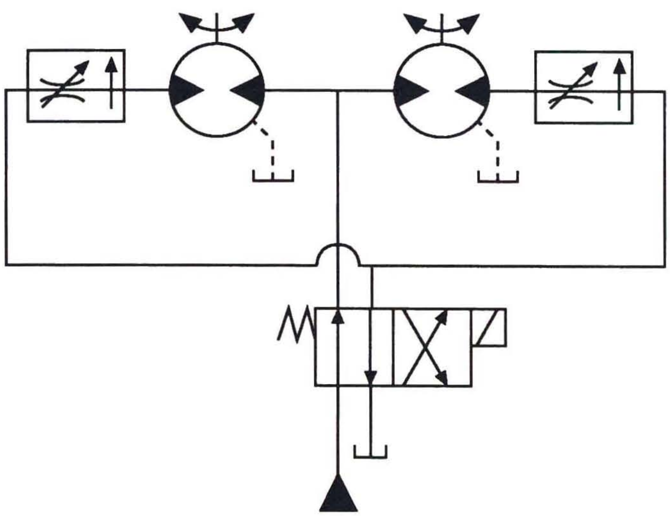
In the next illustration, motor load has increased to 1200 psi (82.76 bar). Gage 1 indicates the 1500 psi (103.4 bar) relief valve setting once again; gage 2 indicates 1250 psi (86.21 bar); gage 3 reads a backpressure of approximately 50 psi (3.45 bar). The pressure compensated flow control is still metering 8 gpm (30.32 lpm) into the piston motor. However, with a pressure differential of 1200 psi (82.76 bar) across the motor, leakage increases to 1 gpm (3.73 bar). Now 7 gpm (26.53 lpm) discharges from the motor oulet indicating that 7 gpm (26.53 lpm) is causing shaft rotation. Shaft speed reduces with an increased load.

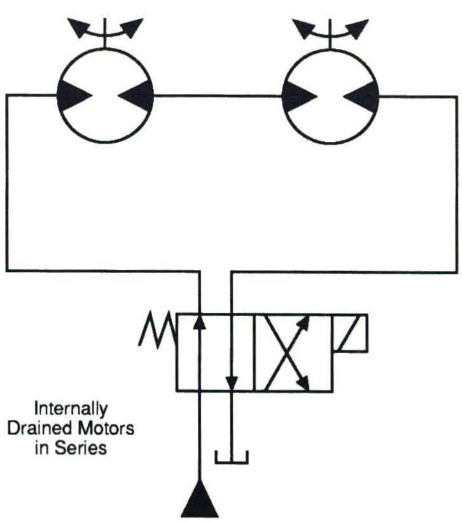
motor speed with a meter-out circuit

Metering flow into a motor does not provide accurate speed control. As load resistance and pressure differential increase, motor shaft speed slows. To receive a more accurate speed control of hydraulic motors, a meter-out circuit is generally used.









In the illustration, a pressure compensated flow control valve is set to measure or meter flow out of an externally drained axial piston motor. The valve is adjusted for 8 gpm (30.32 lpm).

With the system operating, gage 1 indicates the 1500 psi (103.4 bar) relief valve setting; gage 2 indicates a 700 psi (48.3 bar) backpressure at motor outlet; gage 3 reads a tank pressure of 50 psi (3.45 bar). A pressure differential of 800 psi (55.17 bar) across the motor overcomes load resistances, but also generates a leakage of .75 gpm (2.8 lpm). 8.75 gpm (33.2 lpm) enters the motor. Leakage out the drain is .75 gpm (2.8 lpm). 8 gpm (30.32 lpm) discharges from motor outlet indicating that 8 gpm (30.32 lpm) is used to develop shaft speed.

In the next illustration, motor load has increased. The motor now requires a pressure differential of 1200 psi (82.8 bar) to equal load resistances. Gage 1 indicates the relief valve setting of 1500 psi (103.4 bar); gage 2 indicates 300 psi (20.7 bar); and gage 3 reads a tank pressure of 50 psi (3.45 bar). With a pressure differential of 1200 psi (82.8 bar), 1 gpm leaks out the drain. 9 gpm (34.11 lpm) enters motor inlet; 8 gpm (30.32 lpm) discharges motor outlet through the flow control valve back to tank. 8 gpm (30.32 lpm), the discharge flow, indicates the amount of fluid turning the piston motor shaft. Since this is the same flow rate as when pressure differential was 800 psi (55.17 bar), motor shaft speed remains the same.

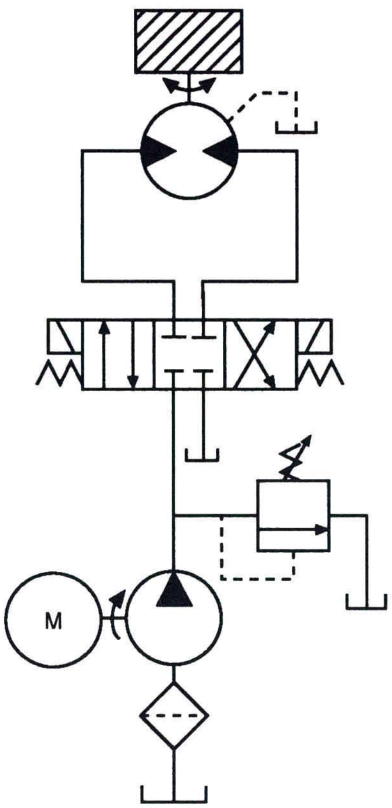
To achieve accurate speed control with an externally drained motor, a meter-out circuit is used. Since internally drained motors do not separate any leakage from motor discharge flow, speed cannot be accurately controlled as load resistance changes.

synchronizing two motors

A very difficult thing to accomplish in hydraulics is synchronizing the shaft speed of two hydraulic motors.

In the illustrated circuit, a pressure compensated flow control is positioned at the outlet of each hydraulic motor; they are both adjusted for 8 gpm (30.32 lpm). Assume that the motors are of the axial piston variety. Even though the meter-out arrangement compensates for motor leakage, flow control valves will react slightly different to the same set of conditions which affects shaft speed. This brings the motor speeds out of synchronization.

In some cases, two motors are used in series. The outlet of one motor feeds the inlet of the other. If they are externally drained, the second motor in the series will always run slower than the first motor because of leakage. Even if the motors are internally drained, because of differences in machining tolerances, leakage rates will probably be different and consequently shaft speeds vary.



achieving position with a motor

When the load attached to a motor shaft is allowed to coast to a stop, it is referred to as freewheeling.

In some situations, the load is required to achieve some sort of mechanical position as it comes to a stop. This can be accomplished to a degree with a directional valve.

In the illustrated circuit, a closed center directional valve is used to control the reversing motion of a hydraulic motor. With the valve shifted so that parallel arrows are in the circuit, motor shaft and load rotate in a clockwise direction. When the load is required to stop, the directional valve is centered. If the load in this application is light, it will appear to stop instantly and a slight system shock will be generated. A heavy load presents another problem.

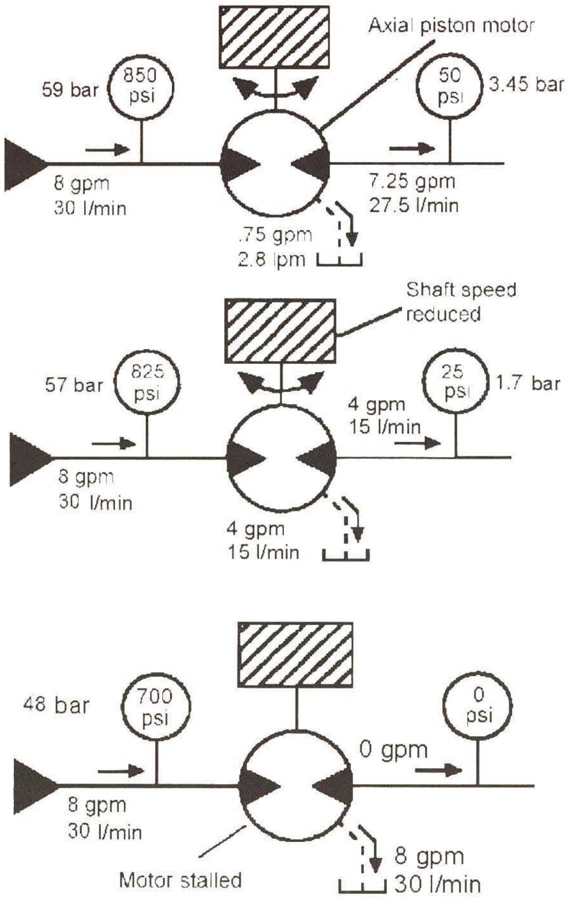
With a heavy load attached to a motor shaft, an excessive shock will be generated as the directional valve is centered. This results from load inertia which attempts to keep pushing fluid from the motor outlet.

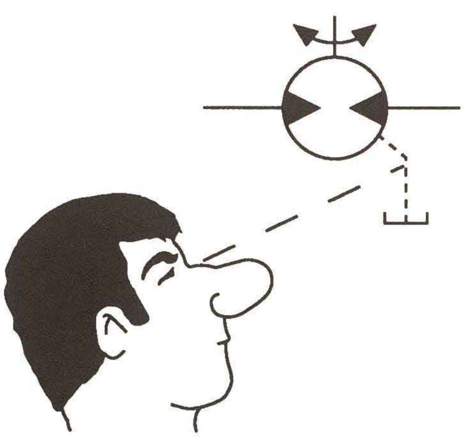
With a heavy load developing a considerable push on the fluid and no place for it to go, a high shock pressure is generated at motor outlet. With a heavy load, the load will not appear to stop immediately. Depending on its inertia, it will continue to rotate as long as enough pressure is developed to cause motor leakage. This may continue for one, two, or more seconds.

A hydraulic motor is not used to hold a load rigidly in place. Because of the leakage it can generate within a motor and associated valving, a heavy load will continue to drift once it has been stopped. If the load must be held in place, a mechanical device such as a brake must be used.

hydraulic motor wear

Hydraulic motors wear just as pumps or any other rotating elements. Wear in a hydraulic motor shows up as increased leakage and reduced shaft speed.





As illustrated earlier, while motors operate, internal leakage is generated by pressure differential across clearances of stationary parts or rotating elements. In a gear motor, this occurs between gear teeth, side plates, and housing. In a vane motor, leakage occurs between rotor, vanes, cam ring, and port plate.

In a piston motor, leakage occurs between cylinder barrel, pistons, and port plate. As wear increases, leakage increases especially across rotating elements. With the same flow entering a worn motor, shaft speed decreases. Approximately the same pressure is required to equal load resistances; but, since leakage paths have increased in size, more flow can be pushed through the clearance with the same pressure.

Finally, if wear is allowed to continue, a point is reached where all inlet flow goes into leakage at a pressure less than work pressure. This results in no movement at the motor shaft.

Assume a load requires 800 psi (55.17 bar) differential across a motor to equal resistances. As wear causes leakage to increase, motor speed decreases. Finally, when the motor is excessively worn, a pressure differential of less than 800 psi (55.17 bar) can push all incoming flow back to tank. The motor stalls.

check for hydraulic motor wear

A check for hydraulic motor wear is performed by comparing drain flows and/or shaft speeds.

With an externally drained axial piston motor, all internal leakage discharges through the drain. If drain flow is excessive as compared to original conditions, motor wear is excessive. This can be checked with a flow meter or by replacing the normal external drain line with a hose. With the motor loaded, the open end of the hose can be held over a container and its discharge flow estimated or timed as it fills the container.

Since the external drain of a gear or vane motor only indicates leakage through clearances of stationary parts, drain flow could have increased relatively little between original and worn conditions. However, fluid bypassing gears and vanes could have increased significantly. Motor wear in these motors can be only indirectly determined by comparing present motor shaft speeds with original shaft speed. The same is true with an internally drained motor since leakage is not separated from motor discharge at all.

exercise
hydraulic motors
50 points

INSTRUCTIONS: In the maze of letters are hidden words which are the answers to the questions below. Circle the words.

M	E	G	A	I	P	L	T	P	P	O	S	R	C	A	Q	R	P	J
O	S	V	I	G	I	S	R	O	R	D	T	P	A	B	I	C	E	W
T	H	I	C	K	S	M	L	X	I	M	P	G	V	M	F	L	X	L
H	T	N	Q	S	T	B	F	N	M	Y	S	E	I	X	R	M	T	S
V	S	W	Y	U	O	C	A	M	B	J	N	R	T	L	E	T	E	P
P	C	E	M	F	N	H	M	C	R	X	T	O	A	C	E	S	R	A
L	V	J	Q	K	C	L	O	S	E	D	K	T	T	V	W	P	N	N
Z	N	A	L	U	F	X	P	V	A	C	G	O	I	R	H	A	A	R
T	H	O	R	K	E	G	A	X	K	A	E	R	O	I	E	J	L	I
R	B	L	P	I	D	N	J	G	A	A	R	X	N	P	E	Q	F	C
J	W	F	X	E	A	Y	C	E	W	E	W	T	T	C	L	K	C	F
B	B	O	P	E	N	B	V	E	A	D	U	P	A	E	I	T	M	H
S	B	W	Y	U	S	R	L	N	Y	L	R	S	C	T	N	V	E	R
M	T	V	D	R	I	V	E	E	B	N	C	F	U	F	G	R	J	I

1. The internal check valve in a vane motor which uses fluid pressure to extend its vanes, performs the function of a(n) ____________ valve.

2. A motor with its inlet connected to pump outlet and its outlet conected to the reservoir is a(n) ____________ loop system.

3. A replenishing pump is generally used in a(n) ____________ loop system.

4. A ____________ type motor can be variable displacement.

5. A hydrostatic transmission with variable horsepower, speed, and torque consists of a variable displacement pump and a ____________ displacement motor.

6. Make-up check valves are used to avoid hydraulic motor ____________.

7. ____________ indicates that a load attached to a motor's shaft is allowed to coast to a stop.

8. Hydraulic motors used in combination with various pumps is known as a hydrostatic ____________ .

9. ____________ torque is the torque required of a hydraulic motor to get its load moving.

10. A bi-directional motor generally has a(n) ____________ drain.