MODULE 4

HYDRAULIC ACTUATORS

ACTUATORS:

It is a device used for converting hydraulic energy into mechanical energy. The pressurized hydraulic fluid delivered by the hydraulic pump is supplied to the actuators, which converts the energy of the fluid into mechanical energy. This mechanical energy is used to get the work done.

TYPES OF ACTUATORS:

1. Linear Actuators (Hydraulic cylinders)
2. Rotary Actuators (Hydraulic motors)
    a. Continuous rotary actuators
    b. Semi rotary actuators

HYDRAULIC CYLINDERS:

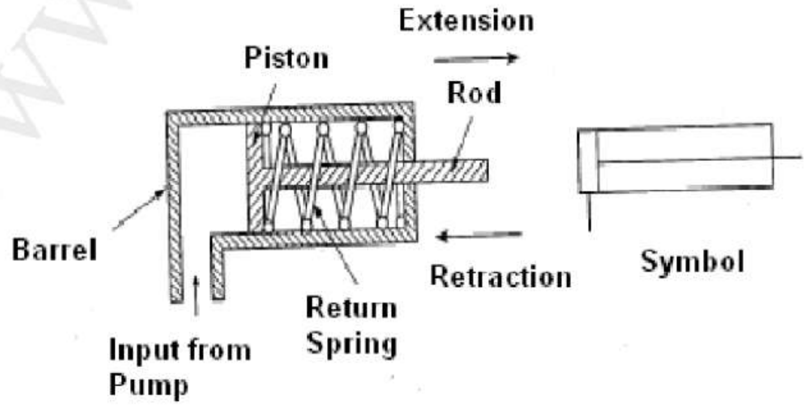
A hydraulic cylinder is a device, which converts fluid power into linear mechanical force and motion. It usually consists of a movable element, a piston and a piston rod operating within a cylinder bore.

TYPES OF HYDRAULIC CYLINDERS:

1. Single acting cylinders
2. Double acting cylinders
3. Telescoping cylinders
4. Double rod cylinder
5. Tandem cylinder

SINGLE ACTING CYLINDER:

A single acting cylinder is designed to apply force in only one direction. It consists of a piston inside a cylindrical housing called barrel. Attached to end of the piston is a rod which extends outside. At the other end (Blank end) is a port for the entrance and the exit of oil. A single acting cylinder can exert a force only in the extending direction, as fluid from the pump enters through the blank end of the cylinder. Single acting cylinders do not hydraulically retract. Retraction is accomplished by using gravity or by the inclusion of a compression spring at the rod end.

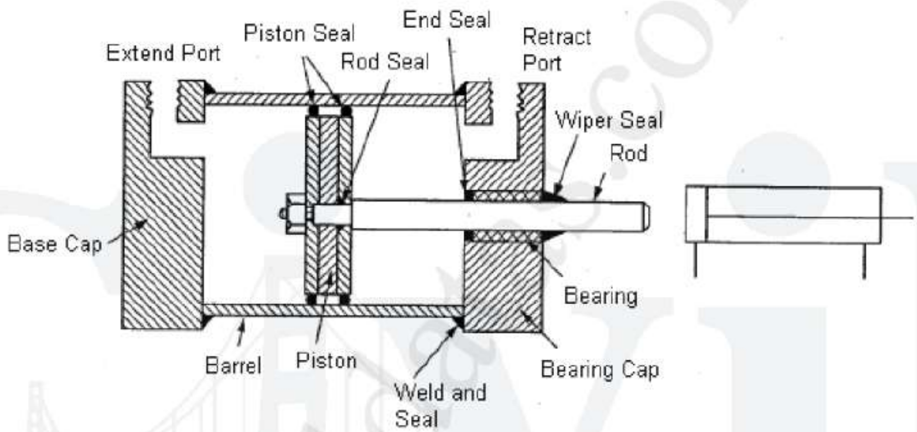


Advantages and Disadvantages:

1. The single acting cylinders are very simple to operate, and compact in size.
2. The single acting cylinders with spring return cannot be used for larger stroke length.

DOUBLE ACTING CYLINDER:

A double acting cylinder is capable of delivering forces in both directions. The barrel is made of seamless steel tubing, honed to affine finish on the inside surface. The piston which is made of ductile iron contains U cup packing to seal the leakage between the piston and the barrel. The ports are located in the end caps which are secured to the barrel by tie rods. The load of the piston rod at the neck is taken by a rod bearing, which is generally made of brass or bronze.

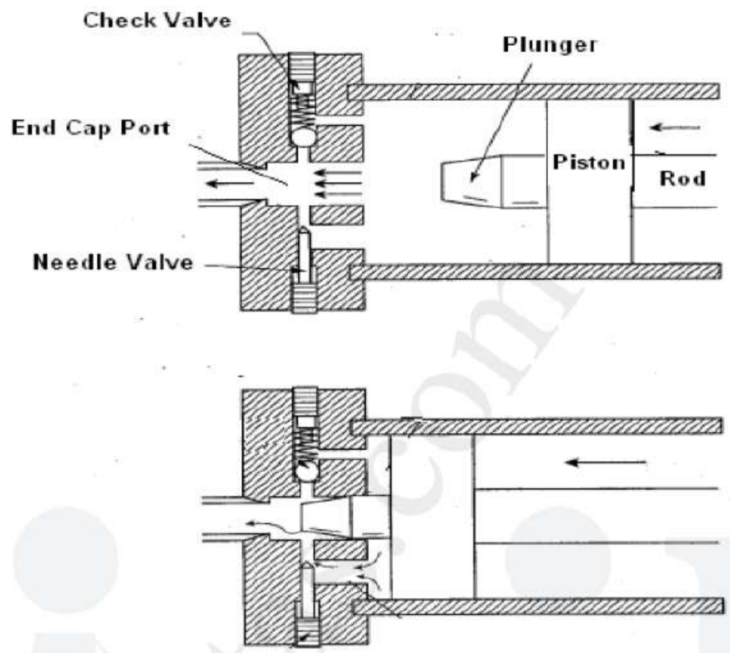


A rod wiper is provided at the end of the neck to prevent foreign particles and dust from entering into the cylinder along with the piston rod. When the fluid from the pump enters the cylinder through port 1, the piston moves forward and the fluid return to the reservoir from the cylinder through port 2. During the return stroke the fluid is allowed to enter the cylinder through port 2 and fluid from the other side of the piston goes back to the reservoir through port 1.

CYLINDER CUSHIONING:

As long as the piston is moving in the middle range of the cylinder, nothing will hit the piston head. But, due to the inertia forces of the moving parts at the end of the piston travel, the piston will hit the cylinder head at full speed. To overcome this, the designers provide a cushioning arrangement by which the hydraulic cylinder can be slowly retarded or cushioned, during the last portion of the stroke. The figure shows the position of the piston at the start of the cushioning action. In this position, the fluid from the pump enters into the rod end of the cylinder moving the piston towards the left. The fluid from the head end of the cylinder flows freely to the reservoir through the fluid port.

As the stroke nears completion, the cushion nose starts entering in the space of the cylinder head. Due to the taper front of the cushion nose, the fluid port path is gradually closed. So the fluid cannot flow through the port or through the passage of check valve. Now entrapped fluid can escape only through the passage controlled by the needle valve. Thus due to the restricted outflow during the last portion of the stroke, the piston decelerates slowly. By adjusting the needle valve,



rate of deceleration is controlled. For starting the forward stroke of the piston, the fluid is allowed to enter the fluid port. The fluid will now flow from all passages. Thus the full piston area will be subjected to the system pressure.

During deceleration of the load, extremely high pressures will develop within the cylinder cushion. Ideally, the back pressure will be constant over the entire cushioning length. But in practice, the cushion pressure is higher when the piston rod has just entered the cushion.

SPEED OF A HYDRAULIC CYLINDER:

Every hydraulic cylinder has its own economical and practicable range of speeds. If the speed of the cylinder is increased beyond this limit, the sudden stoppage of the piston will create shock load on the piston head, piston rod and other mechanical parts causing serious damages. The high speed will also create difficulty in the accurate positioning of the movable parts. So at the time of deciding the speed of a hydraulic cylinder, proper care is to be taken in the design stage itself.

The maximum speed of the piston rod is limited by the rate of fluid flow in and out of the cylinder and the ability of the cylinder to withstand the impact forces which occur when the piston movement is arrested. In an un-cushioned cylinder it is normal to limit the maximum piston movement is arrested. In an un-cushioned cylinder it is normal to limit the maximum piston velocity to 8m/min. This value is increased to 12m/min for a cushioned cylinder and 45m/min is permissible with high speed cylinders. Oversized ports are necessary in cylinders that are used in high speed applications.

Velocity equations:

Consider a double acting cylinder

D – Diameter of the piston

d – Diameter of piston rod

A – Area of Blank end - $\frac{\pi D^2}{4}$

a- Piston rod area - $\frac{\pi d^2}{4}$

Q – Input flow rate

q_E – Flow rate from rod end of the cylinder when extending

q_R – Flow rate from blank end of cylinder when retracting

Rod End Area – (A-a) = $\frac{\pi}{4}$ (D^2-d^2)

1. **When Piston rod is extending:**

Piston velocity $V_E = \frac{Q}{A} = \frac{q_E}{(A-a)}$

Thus $q_E = Q \frac{(A-a)}{A} = Q \frac{(D^2-d^2)}{D^2}$

Thus as the piston rod is extending, the flow rate of the fluid leaving the cylinder is less th the flow rate of fluid entering the cylinder.

2. **When piston rod is retracting:**

Piston velocity $V_R = \frac{Q}{A-a} = \frac{q_R}{A}$

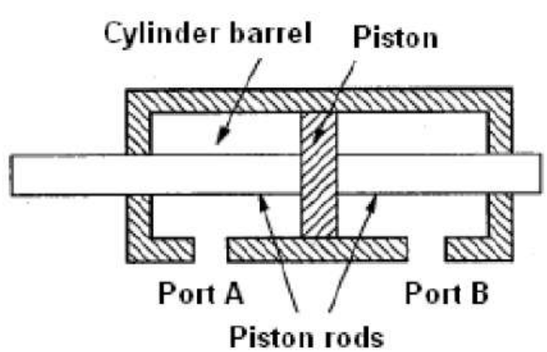
Thus $q_R = Q \frac{A}{(A-a)} = Q \frac{D^2}{(D^2-d^2)}$

Thus when the piston rod is retracting, the rate of fluid leaving the cylinder is greater than t flow rate of fluid entering the cylinder.

SPECIAL TYPE CYLINDERS:

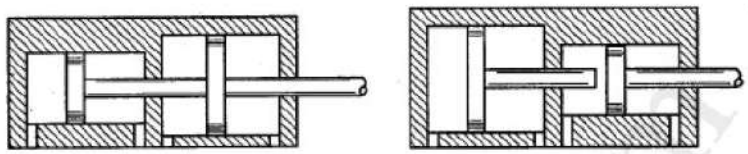
DOUBLE ROD CYLINDER:

It is a cylinder with single piston and a piston rod extending from each end. This cylinder allows work to be performed at either or both ends. It may be desirable where operating speed and return speed are equal.



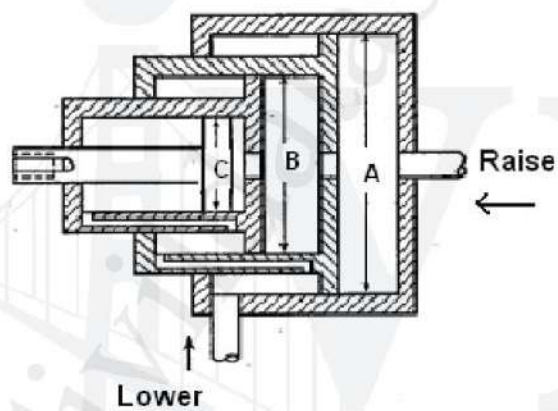
TANDEM CYLINDER:

It design has two cylinders mounted in line with pistons connected by a common piston rod. These cylinders provide increased output force when the bore size of a cylinder is limited. But the length of the cylinder is more than a standard cylinder and also requires a larger flow rate to achieve a speed because flow must go to both pistons.



TELESCOPING CYLINDER:

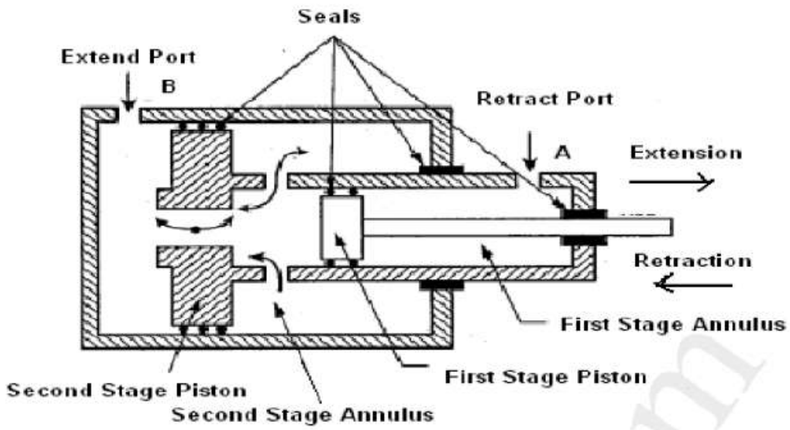
They are used where long work strokes are needed. A telescoping cylinder provides a relatively long working stroke for an overall reduced length by employing several pistons which telescope into each other.



Since the diameter A of the ram is relatively large, this ram produces a large force for the beginning of the lift of the load. When ram A reaches the end of the stroke, ram B begins to move. Now ram B provides the required smaller force to continue raising the load. When ram B reaches the end of its stroke, then ram C moves outwards to complete the lifting operation. These three rams can be retracted by gravity acting on the load or by pressurized fluid acting on the lip of each ram.

TWO STAGE DOUBLE ACTING TELESCOPING CYLINDER:

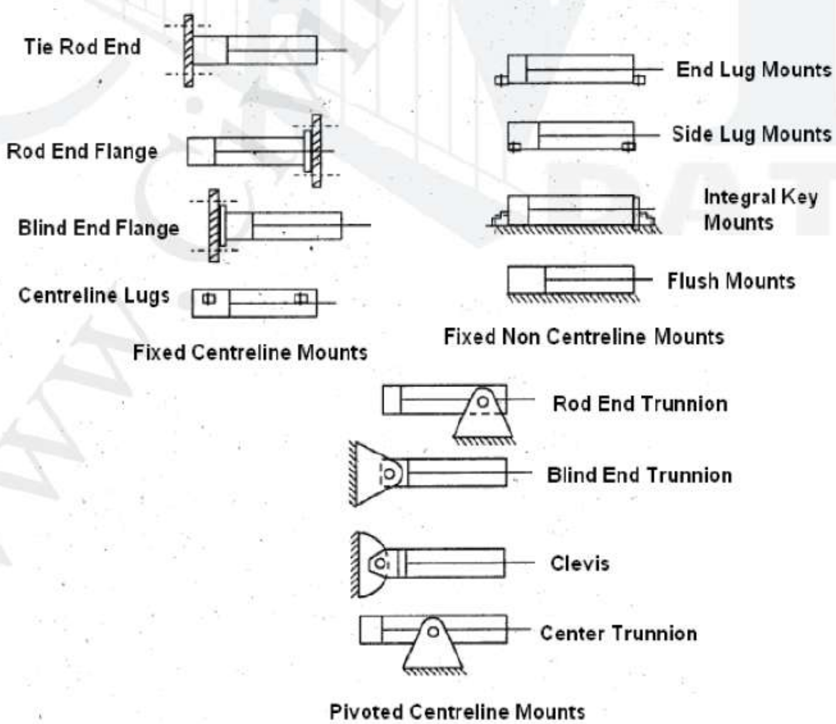
Retraction stroke: During the retraction stroke, the fluid is fed into the first stage annulus via retract port A. therefore the first stage piston is forced to the left until it uncovers the fluid ports connecting this with the second stage annulus. This, in turn, moves the larger piston to the left until both the pistons are fully retracted into the body of the cylinder.



Extension Stroke: During the extension stroke, the fluid is fed through the extend port B. Now the fluid forces both pistons to the right until the cylinder is fully extended.

MOUNTING CONFIGURATIONS:

The type of mountings on cylinder is numerous, and they can accommodate a wide variety of applications. The most common mountings are lugs, flange, trunnion, clevis and extended tie rods. One of the important considerations in selecting a particular mounting style is whether the major force applied to the load will result in tension or compression of the piston rod. The ratio of rod length to diameter should not exceed 6:1 proportion at full extension. This helps to prevent the rod from buckling due to compression or tensile shock forces.



Alignment of the rod with the resistive load is another important consideration while selecting cylinder mounts. Misalignment or non axial loading also tends to place unnecessary loads on the rod and the rod guides, bushes or bearings. Due to the immense loads and the extreme forces induced by the rod there are large stresses on the rod at full extension. Centre lugs, centre trunnions and clevis arrangements tend to help keep the rod or shaft in line with the load.

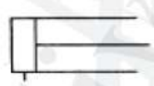
Fixed centerline mounts: These are used for thrust that occur linearly or in the centerline with the cylinder. Proper alignment is essential to prevent compound stresses that may cause excessive friction and bending as the piston rod extends. Additional holdings strength may be essential with long stroke cylinders.

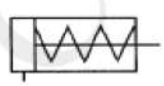
Fixed non-centerline mounts: These are convenient where exceptionally heavy linear thrusts are encountered. Generally, integral keys or pins are used if excessive hydraulic shock is expected. This helps to relieve shear loads. Since the cylinder has to expand and contract with temperature changes, only one end should be keyed or pinned.

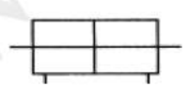
Pivoted centerline mounts: These are used to compensate for thrusts that occur in multiple planes or if the attached load travels in a curved path. Ball joints, trunnions and clevis mounts allow thrust to be taken up along the cylinder centerlines.

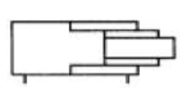
GRAPHIC SYMBOLS FOR LINEAR ACTUATORS:


Double Acting Cylinder


Single Acting Cylinder


Single Acting with Spring return


Double Rod Double Acting


Telescopic Double Acting


Telescopic Single Acting

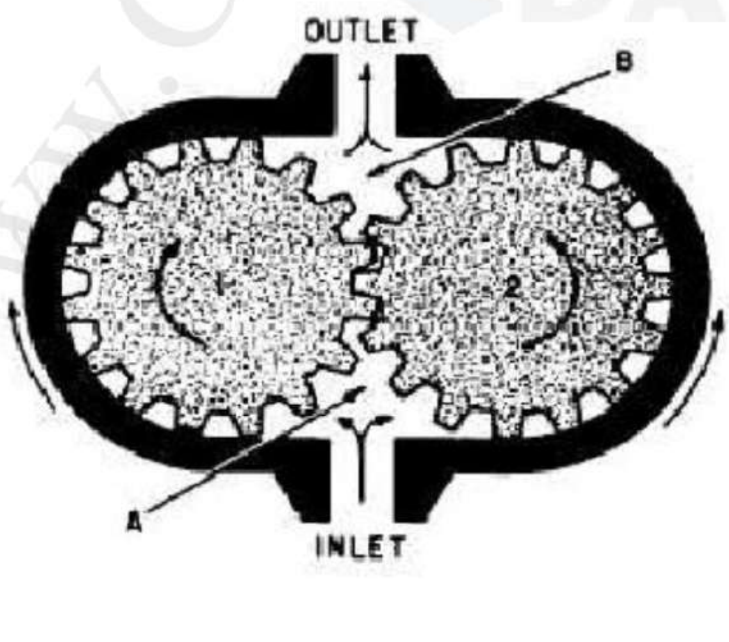
HYDRAULIC MOTORS:

A hydraulic motors converts fluid power into mechanical power in the form of rotational motion. Motors perform the opposite function of the pump, which converts mechanical power from an electric motor or engine into fluid power. Motors take pump flow and pressure as their input and output rotational motion and torque. Motor displacement is the volume. Pump displacement is the volume of the pump outputs per revolution of the pump shaft, a similar concept. Like pump motors can be fixed or variable displacement. Increasing the displacement of a motor decreases its speed because it requires more fluid to turn it each revolution. Increasing displacement increase torque output because more area within the motor is subjected to pressure. Decreasing motor displacement increases speed and decreases torque.

Hydraulic motors are most commonly gear, vane or piston type. All have a construction similar to the hydraulic pump of the same type. They also have similar properties. Gear motors are the least efficient, most dirt tolerant and have the lowest pressure ratings of the three. Piston motors are the most efficient, least dirt tolerant and have the highest pressure ratings. Vane and piston motors can be fixed or variable displacement like vane and piston pumps. Gear motors like gear pump are not available with variable displacement.

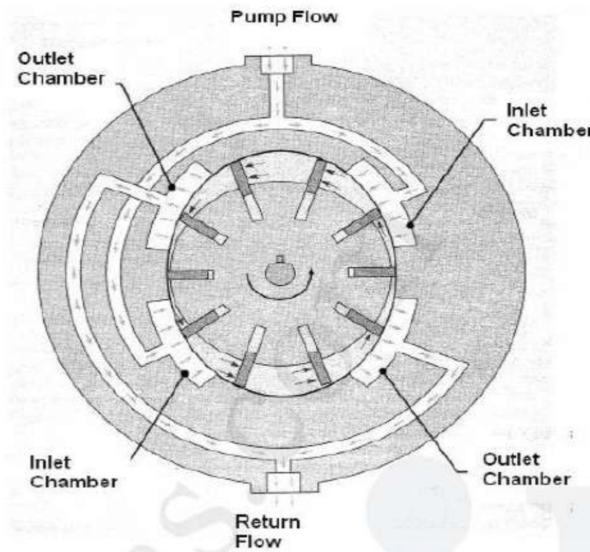
GEAR MOTOR:

The operation of gear motor is shown in the figure. One of the gears is keyed to an output shaft, while the other is simply an idler gear. Pump flow and pressure are sent to the inlet port of the motor. The pressure is then applied to the gear teeth, causing the gears and the output shaft to rotate. The pressure builds until enough torque is generated to rotate the output shaft against the load. Most gear motors are bi-directional the direction of rotation can be reversed by simply reversing the direction of flow.



VANE MOTORS:

In this type of motors the pump flow and pressure are applied to the vanes and the output shaft is rotated. The figure shows the balanced vane type motor. Recall from the discussion on vane pumps that balanced means that pressure is applied on both sides of the shaft resulting in no net force on the bearings.



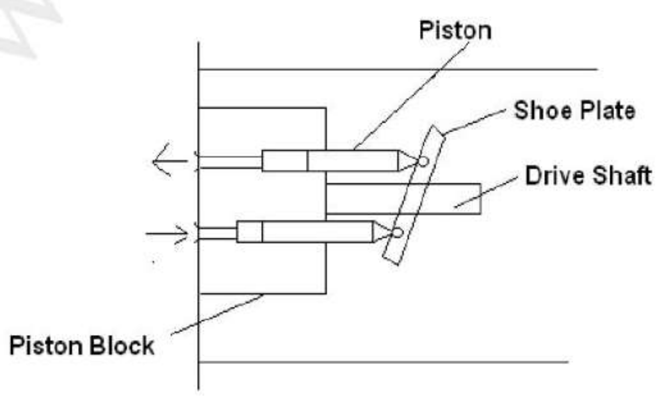
This increases the maximum operating pressure and drive speed at which the motor can operate. The vanes extent and retract twice per revolution of the rotor, which necessitates the use of two inlet and two outlet chambers. These chambers are combined into one common inlet and one common outlet within the motor housing. Most of the vane motors are bidirectional.

PISTON TYPE MOTORS:

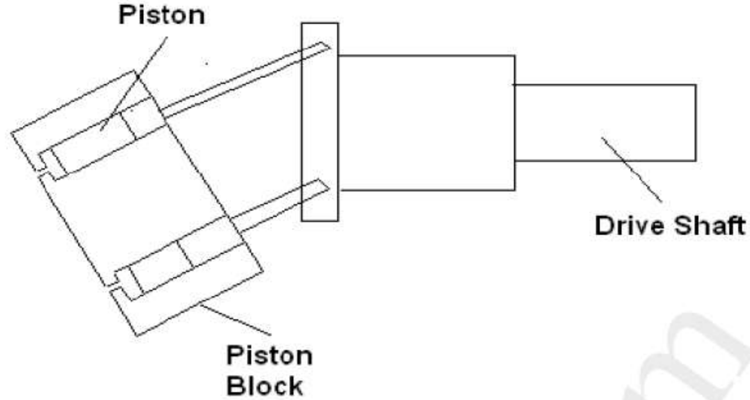
Piston motor develops an output torque at its shaft by allowing hydraulic pressure to act on pistons. Piston designs may be either axial piston type or radial piston type.

Axial piston motors:

Swash plate or bent axis type: It consists of a port plate, cylinder barrel, pistons, shoe plate, swash plate and a shaft. The arrangement is similar to a swash plate type pump. When fluid pressure acts on a piston, a force is developed which pushes the piston out and causes the piston shoe to slide across the swash plate surface. As the piston shoe slides, it develops a torque attached to the barrel.



Swash Plate Type



Bent Axis Type

The amount of torque depends on the angle of slide caused by the swash plate and the pressure in the system. Since the swash plate angle controls the stroke in pistons of an axial piston motor, changing the angle will alter the stroke and motor displacement. The operating principle of an **bent axis motor** is similar to swash plate type. The angle of the cylinder block assembly with respect to drive shaft determines the stroke or motor displacement. Both these motors are used in high speed application only.

SEMI ROTARY ACTUATORS:

These are used to convert fluid pressure energy into torque which turns through an angle limited by the design of the actuator. With the majority of designs, the angle of rotation is within 360 degrees although it is possible to considerably exceed this when using piston operated actuators.

DESIGN CONSIDERATIONS FOR HYDRAULIC CYLINDERS AND RAMS

General-purpose hydraulic cylinders are rated for their ability to perform at a specific maximum pressure value. Hydraulic rams are designed for specific applications. The very nature of the device precludes the design of a general-purpose family of products. Many hydraulic cylinders and most hydraulic rams are thus designed for their anticipated use. General char-

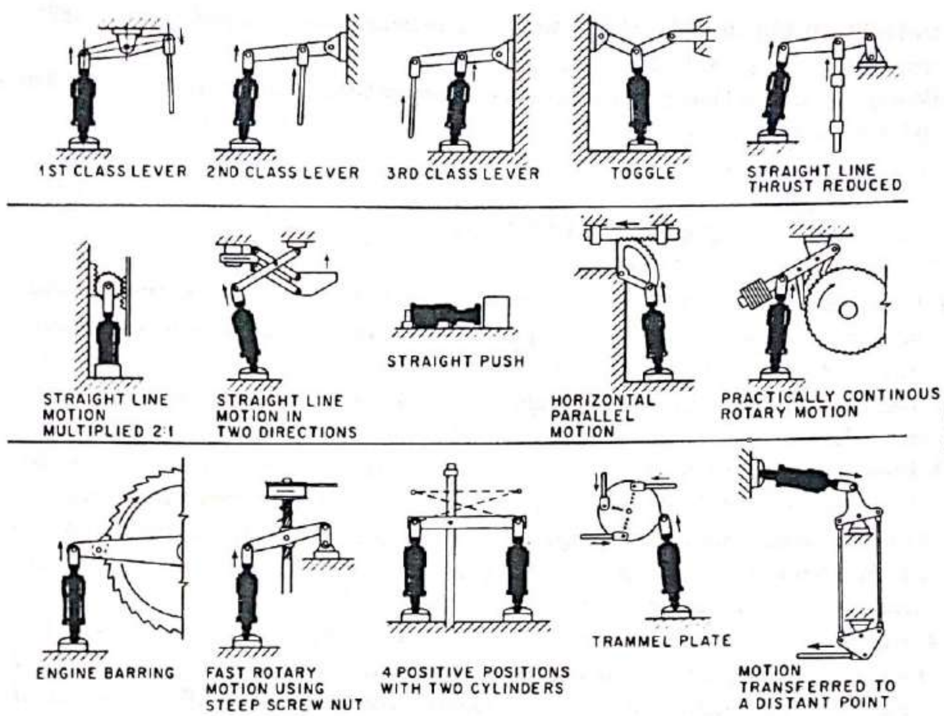


Fig. 4-16 Typical applications of cylinders to provide mechanical movements.

acteristics required for special applications generate a family of products. Some manufacturers gear their production output to a specialized industry. Some examples of the special-purpose products and their unique characteristics follow:

1. Steel mill and general heavy equipment
   Features: Fabricated from steel plate with heavy-duty thick-wall steel tubing. Oversize piston rods. Heavy-duty packing designed for quick, easy change. Extremely rugged.

2. Agricultural cylinders
   Features: Medium to light duty—often throw-away type with nonreplaceable packing. Construction carefully designed to match expected service life, which reflects seasonal activity with relatively short service life. Simple, easy replacement of a total unit may be featured in place of field repairs.

3. Machine Tool Cylinders
   Features: Precise construction designed for long service life. Easy seal and packing replacement. Rugged construction. Some mechanical protection is anticipated. Good maintenance can be expected.

4. Marine Applications

Features: Rustproof construction. Oversize piston rods. Fail-safe structures.

5. Construction Machinery

Features: Flange-type connectors for plumbing. Heavy-duty construction. Weatherproof design. Packing-gland protection. Long service life.

6. Aircraft cylinders

Features: Maximum strength with lightweight materials. Careful design to reduce all excess physical weight. Anticipate maintenance on a carefully calculated schedule.

Machine-tool hydraulic cylinders are usually considered the general-purpose product. All cylinders follow a common pattern relative to operational characteristics.

The first decision that a designer must make relates to the type of cylinder as determined by the anticipated use. The second decision is governed by the available pressurized fluid. The force needed must be divided by available maximum pressure to determine the required area of the cylinder. If 30,000 lb [133,440 N] of thrust is needed, and 3000 psi [20,685 kPa] is available, the 30,000 [133,440 N] divided by 3000 [20,685 kPa] equals 10 in^2 [6.452 cm^2].

If this cylinder must move 24 in [60.96 cm] in 30 s, it will require 24 in [60.96cm] times 10 in^3 [64.52 cm^3], or 240 in^3 [3933.6 mL] per min. Thus, slightly more than 2 gpm [7.87 L/min] will provide the needed rate of movement and force at 3000 psi [20,685 kPa]. Two gal/min equals 2 x 231 equals 462 in^3/min.

To avoid bending under load, heavy-duty rods are often designed to be equal to one-half the area of the piston so that the return speed is twice the rate of the forward speed and the return force capability is one-half that of the forward stroke. Increased return speed and greater strength provide plus design values.

Available space may limit the size of a fluid-power cylinder. Thus, to provide the same force, the pressure must be increased as the number of square inches of area is decreased.

Pneumatic or light-duty hydraulic cylinders usually function at 1000 psi [6895 kPa], or less. Many machine-tool cylinders are rated at 2000 psi [13,790 kPa].

Agricultural cylinder design usually conforms to the 2000-psi [13,790-kPa] rating. Hydraulic pumps supplied as a standard option on tractors quite often have a 2000-psi [13,790-kPa] rating.

Mill cylinders, marine presses, and construction machinery use pressures in excess of 2000 psi [13,790 kPa]. Some presses and construction machines use pressures to 5000 psi [34,475 kPa], and above.

11.2 SELECTION OF A HYDRAULIC CYLINDER

Hydraulic cylinders are defined by their ability to exert a linear force and hold it at any specified position indefinitely. The parameters relate to the selection of hydraulic cylinders are discussed here.

Purpose The purpose of the actuator describes the type of cylinder. The cylinder may move the load in one direction only, to move in both directions or to have equal velocities as it travels in both direction. Single acting cylinders with a gravity or spring type is used to move the load in one direction. Double acting cylinders move the load in both directions under pressure. Cylinders with double end rod provide equal velocity in both directions because of equal areas on both sides of the piston. Tandem cylinders exert twice the force available from single piston cylinders by providing twice the effective piston area in two chambered spaces.

Stroke requirement The cylinder stroke determines the length of the cylinder. The stroke length is the difference between the fully extended and fully retracted length. For a simple cylinder, the stroke should be less than the barrel length. For a given bore size, stroke also determines the amount of fluid required for a specified cylinder velocity. If the length of the cylinder is restricted and the stroke requirement is more, telescoping cylinders are preferable.

Thrust The output thrust required from a hydraulic cylinder and hydraulic pressure available for the purpose determine the area and bore diameter of the cylinder. In dynamic applications, the dynamic thrust is taken into account. Dynamic thrust is less than the static thrust due to seal friction, fluid friction, piston inertia etc. As a first approximation dynamic thrust can be taken as 0.9 times the static thrust.

Speed The maximum speed of the piston is limited by the rate of fluid flow in and out of the cylinder and the ability of the cylinder to withstand the impact forces which occur, when the piston movement is arrested. In an uncushioned cylinder, it is normal to limit the piston velocity to 8m/min. This value is increased to 12m/min for a cushioned cylinder and 45m/min is permissible with high speed cylinders.

Acceleration and deceleration The additional forces being imparted, when a body being accelerated or decelerated must be considered. Hydraulic shocks to the cylinder are minimised by slowing down the piston. Cushioning devices are provided for this. During cushioning, high pressures will develop within the cylinder cushion. The pressure generated on cushion side must be considered. Since too much pressure would rupture the cylinder.