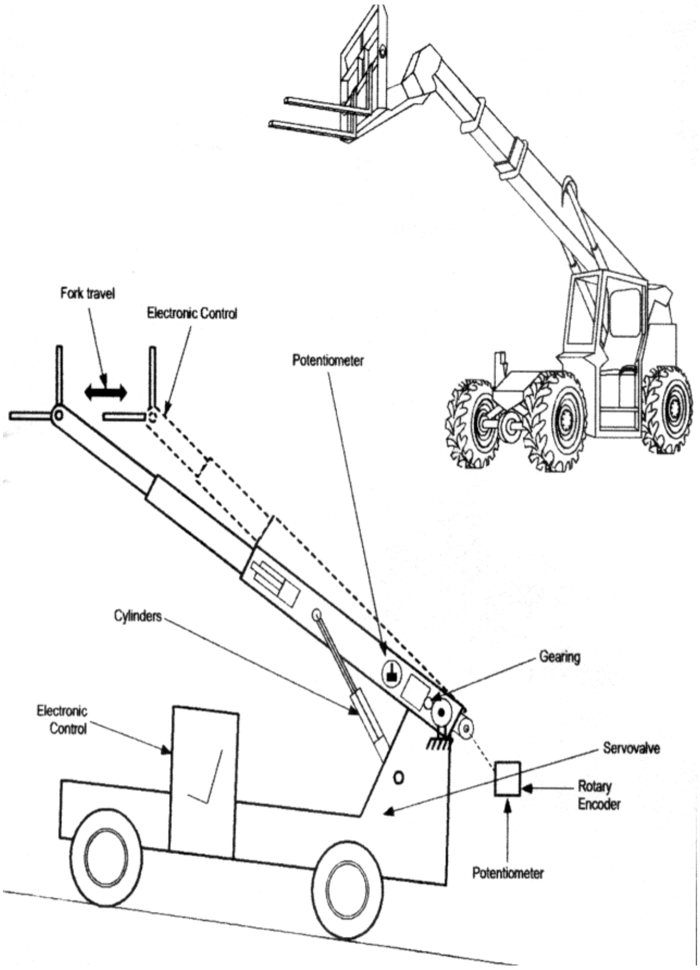
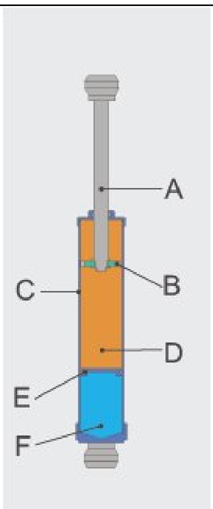
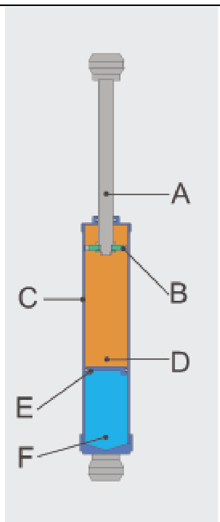
Hydraulic Cylinders

1- INTRODUCTION

Pumps perform the Function of Adding Energy to the Fluid of a Hydraulic System for Transmission to Some Output Location.
Hydraulic Cylinders and Hydraulic Motors do just the Opposite.
They Extract Energy from the Fluid and Convert it to Mechanical Energy to Perform Useful Work.
Hydraulic Cylinders (called Linear Actuators*)* Extend and Retract A Piston Rod to provide a Push or Pull Force to drive The External Load along a Straight-line Path.
Hydraulic Motors (called Rotary Actuators*)* Rotate a Shaft Provide a Torque to Drive the Load along a Rotary Path.
A Hydraulic Shock Absorber is a Device that Brings a Moving Load to a Gentle Rest through The Use of Metered Hydraulic Fluid. They use Orifices to Meter Internal Oil Flow to accomplish A Uniform Gentle Deceleration of the Moving Load. Two Common Applications of Hydraulic Shock Absorbers are in Moving Cranes and Automobile Suspension Systems.

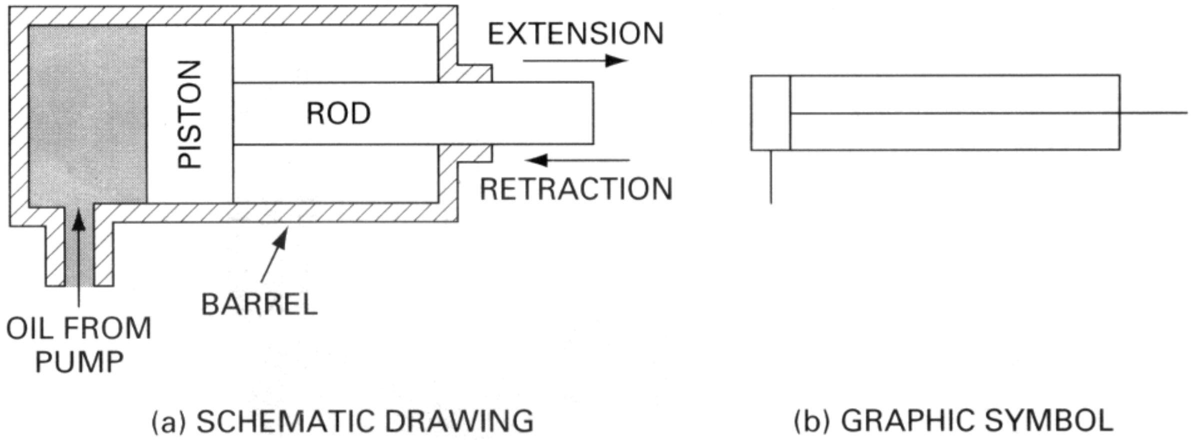


		The Components are: A - Rod, B - The Piston with Seals, C - The Cylinder, D - Oil Reservoir, E - Floating Piston, F - Air Chamber.

Shock Absorber with Internal Reservoir

2- HYDRAULIC CYLINDER

OPERATING FEATURES

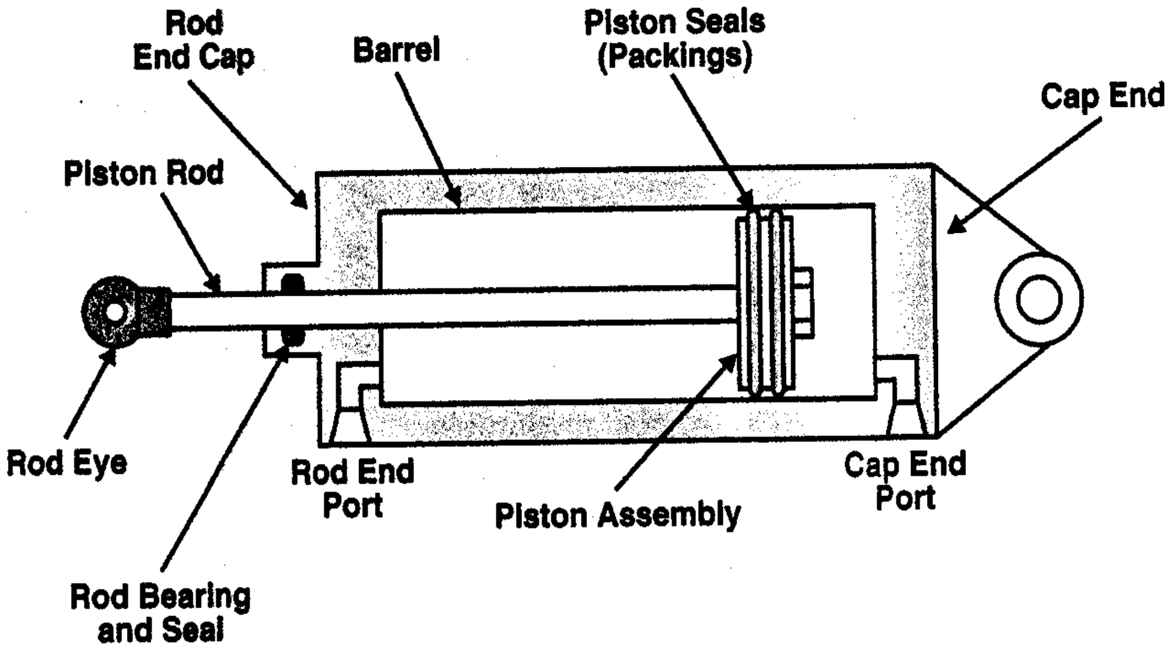


Single-Acting Hydraulic Cylinder

The Simplest Type of Hydraulic Cylinder is the Single-Acting Design. It consists of a Piston inside a Cylindrical Housing called a Barrel. Attached to One End of the Piston is a Rod, which Extends Outside One End of the Cylinder (Rod End).

At the Other End (Blank End) is a Port for the Entrance and Exit of Oil. A Single-Acting Cylinder can exert a Force in Only the Extending Direction as Fluid from the Pump enters the Blank End of the Cylinder.

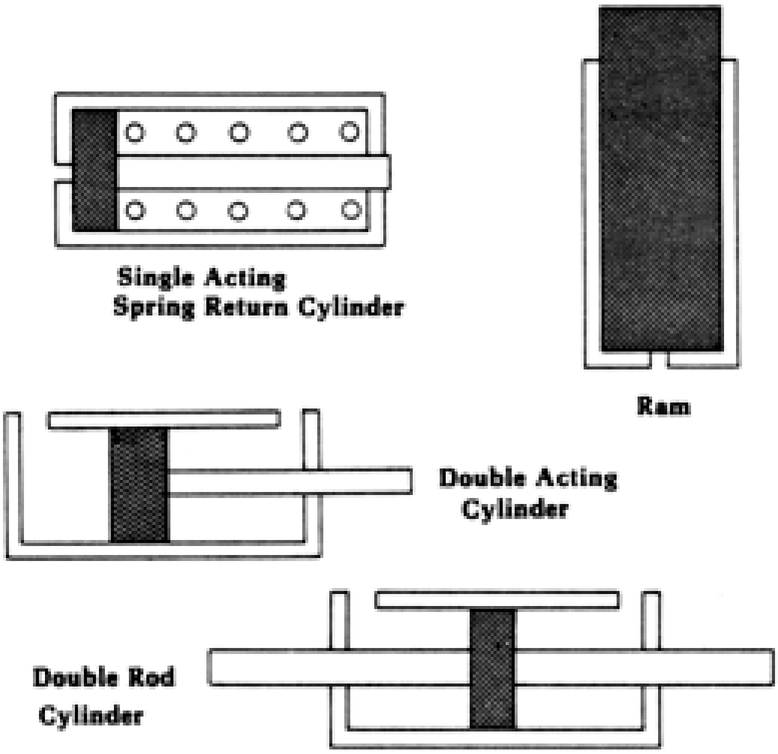
Single-Acting Cylinders do Not Retract Hydraulically. Retraction is accomplished by Using Gravity or by The Inclusion of a Compression Spring in the Rod End.



Double-Acting Hydraulic Cylinder

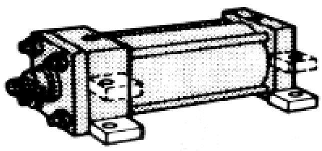
Such a cylinder can be Extended and Retracted Hydraulically. Output Force can be applied in Two Directions (Extension and Retraction).

Hydraulic Cylinders

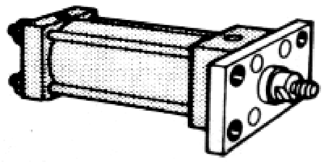


3- CYLINDER MOUNTINGS

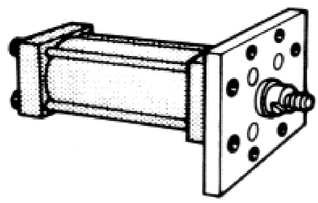
The Rod Ends are usually threaded so that They can be attached Directly to The Load, A Clevis, A Yoke, or Some Other Mating Device.



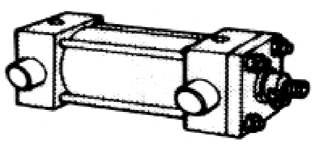
FOOT AND CENTERLINE LUG MOUNTS



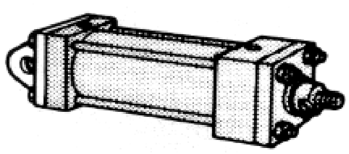
RECTANGULAR FLANGE MOUNT



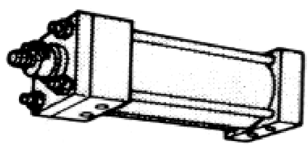
SQUARE FLANGE MOUNT



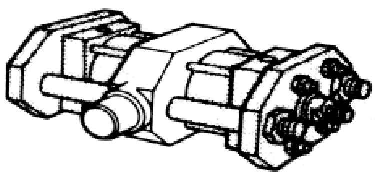
TRUNNION MOUNT



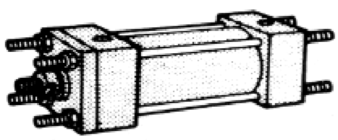
CLEVIS MOUNT



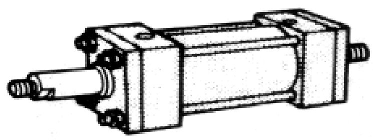
FLUSH SIDE MOUNT



INTERMEDIATE TRUNNION MOUNT



EXTENDED TIE ROD



DOUBLE ROD END

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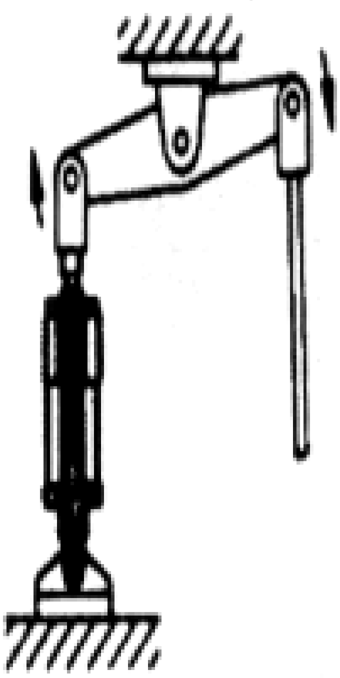
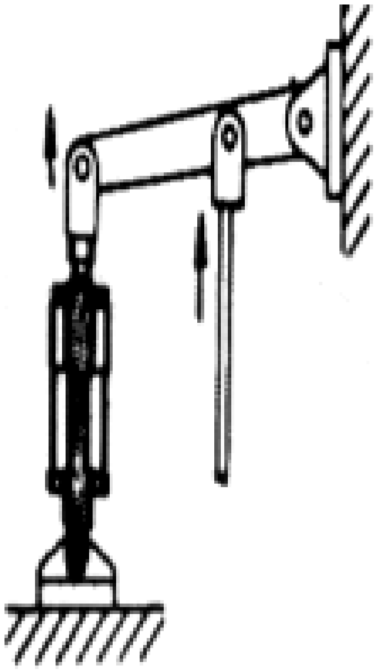
MECHANICAL LINKAGES

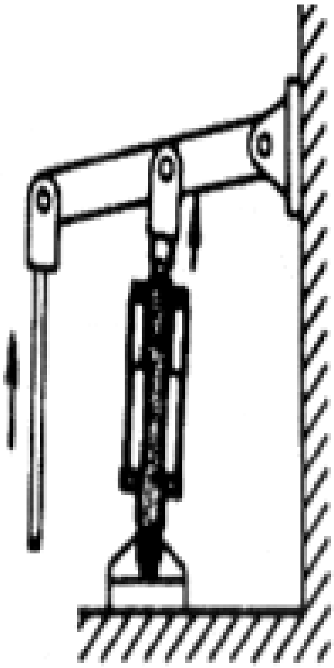
These Linkages can transform a Linear Motion into either an Oscillating or Rotary Motion. Linkages can also be employed to Increase or Decrease the Effective Leverage and Stroke of a Cylinder. Much Effort has been made by Manufacturers of Hydraulic Cylinders to Reduce or Eliminate the Side Loading of cylinders created as a result of Misalignment. It is Almost Impossible to achieve Perfect Alignment even though the Alignment of a Hydraulic Cylinder has a Direct Bearing on its life.



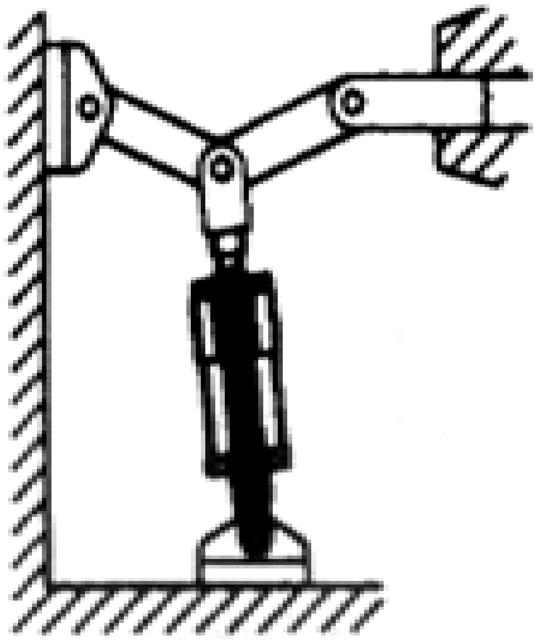
First-class lever



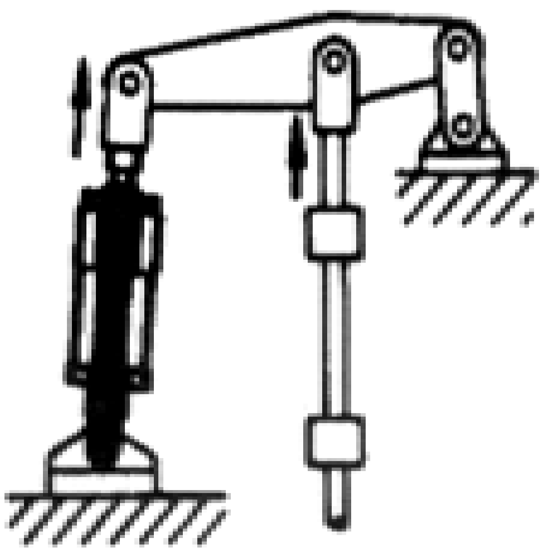
Second-class lever



Third-class lever



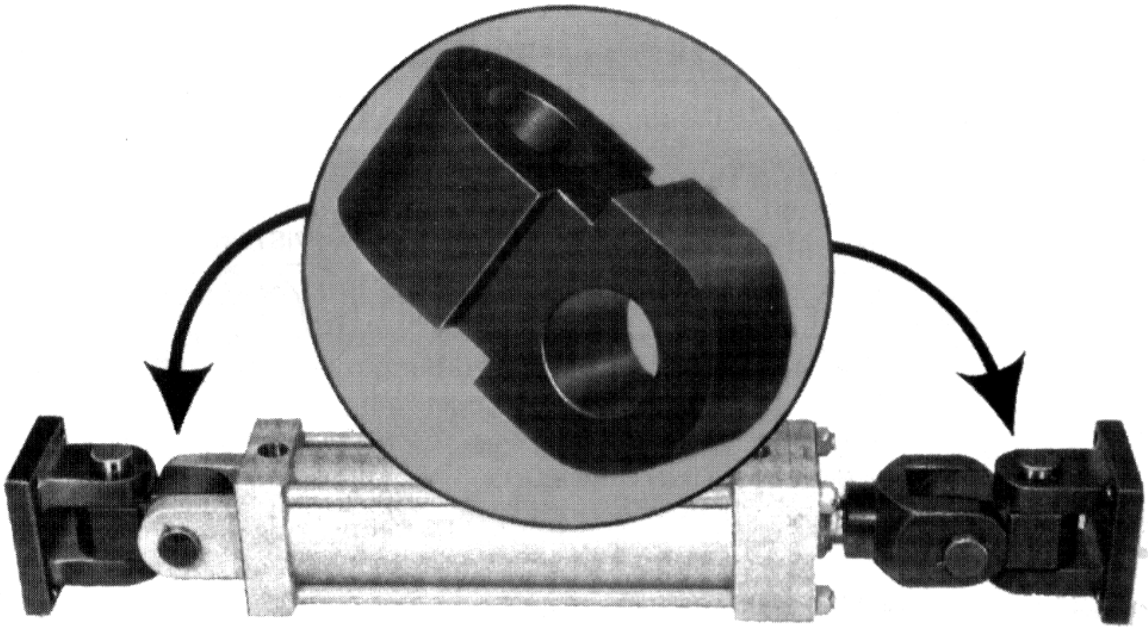
Toggle



Straight-line thrust reduced

Hydraulic Cylinders

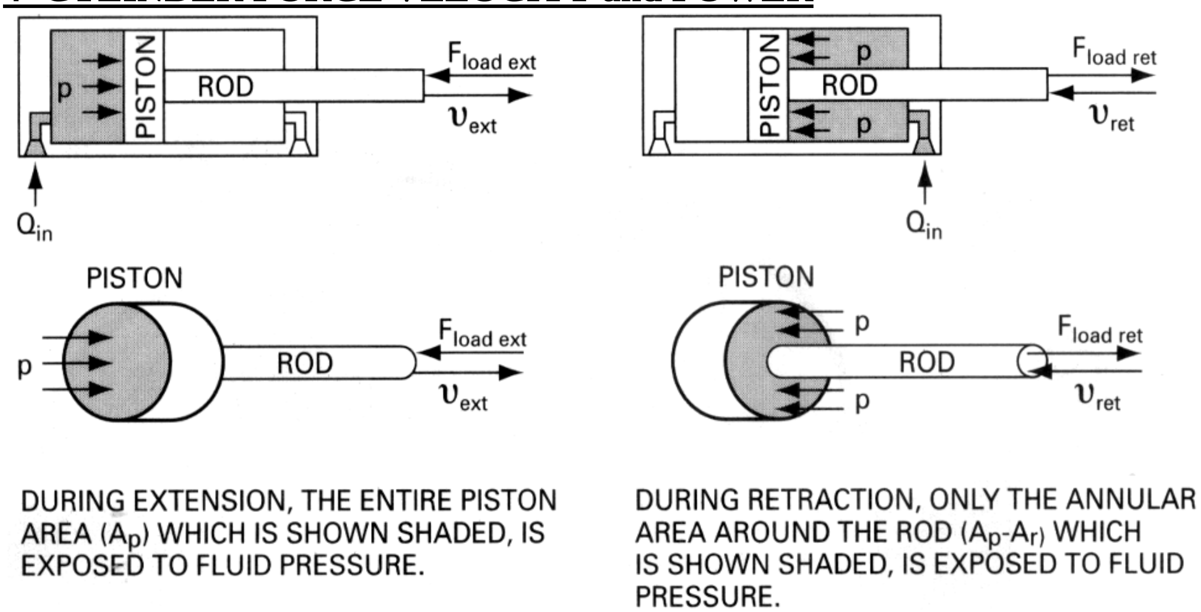
A Universal Alignment Mounting accessory designed to Reduce Misalignment Problems.



By Using one of these Accessory Components and a Mating Clevis at Each End of the Cylinder (see Figure 6), the following Benefits are obtained:

1. Free Range of Mounting Positions
2. Reduced Cylinder Binding and Side Loading
3. Allowance for Universal Swivel
4. Reduced Bearing and Tube wear
5. Elimination of Pston Blow-By caused by Misalignment

4- CYLINDER FORCE VELOCITY and POWER



(a) EXTENSION STROKE (b) RETRACTION STROKE

Output Force, (F) and Piston Velocity (V) of Double-Acting Cylinders are Not the Same for Extension and Retraction Strokes. During the Extension Stroke, Fluid enters the Blank End of the cylinder through the Entire Circular Area of the Piston (Ap). During the Retraction

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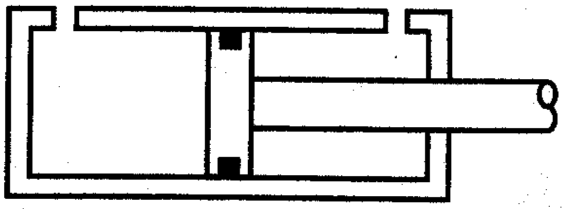
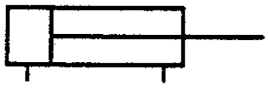
Stroke, Fluid enters the Rod End through The Smaller Annular Area between the Rod and Cylinder Bore (Ap - Ar) where Ap equals the Piston Area and Ar equals the Rod Area. This Difference in Flow-Path Cross-Sectional Area accounts for The Difference in Piston Velocities Since Ap > (Ap - Ar), **The Retraction Velocity > The Extension Velocity** for the Same Input Flow-Rate.

Similarly, during the Extension Stroke, Fluid Pressure bears on Entire Circular Area of the Piston During the Retraction Stroke, Fluid Pressure bears Only on The Smaller Annular Area between the Rod and Cylinder Bore. This Difference in Area accounts for the Difference in Output Forces. Since Ap > (Ap - Ar), **The Extension Force > The Retraction Force** for the Same Operating Pressure.



a. Single-Ended Cylinder (double-acting)



Symbol

Next Equations allow for the Calculation of The Output Force and Velocity for the Extension and Retraction Strokes of 100% Efficient Double-Acting Cylinders.

Extension Stroke

$$F_{ext}(\text{lb}) = p\,(\text{psi}) \times A_p(\text{in}^2)$$

$$F_{ext}(\text{N}) = p\,(\text{Pa}) \times A_p(\text{m}^2)$$

$$v_{ext}(\text{ft/s}) = \frac{Q_{in}(\text{ft}^3/\text{s})}{A_p(\text{ft}^2)}$$

$$v_{ext}(\text{m/s}) = \frac{Q_{in}(\text{m}^3/\text{s})}{A_p(\text{m}^2)}$$

Retraction Stroke

$$F_{ret}(\text{lb}) = p\,(\text{psi}) \times (A_p - A_r)\text{in}^2$$

$$F_{ret}(\text{N}) = p\,(\text{Pa}) \times (A_p - A_r)\text{m}^2$$

$$v_{ret}(\text{ft/s}) = \frac{Q_{in}(\text{ft}^3/\text{s})}{(A_p - A_r)\text{ft}^2}$$

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$$v_{ret}(\text{m/s}) = \frac{Q_{in}(\text{m}^3/\text{s})}{(A_p - A_r)\text{m}^2}$$

Power developed by a Hydraulic Cylinder = Force X Velocity during a given Stroke.
Using this Relationship and Eqs., we arrive at the same result:

Power = P X Q_{in}.

Power developed = Pressure X Cylinder Input Volume Flow-Rate for Both the Extension and Retraction Strokes.

The Horsepower developed by a Hydraulic Cylinder for either the Extension or Retraction Stroke can be found

$$\text{Power (HP)} = \frac{v_p\,(\text{ft/s}) \times F\,(\text{lb})}{550} = \frac{Q_{in}\,(\text{gpm}) \times p(\text{psi})}{1714}$$

Using Metric Units, for either the Extension or Retraction Stroke

$$\text{Power (kW)} = v_p\,(\text{m/s}) \times F\,(\text{kN}) = Q_{in}\,(\text{m}^3/\text{s}) \times p(\text{kPa})$$

5- CYLINDER LOADS DUE TO MOVING OF WEIGHTS

The Force a Cylinder Must Produce Equals the Load the Cylinder is required to Overcome. In Many Cases the Load is due to the Weight of an Object the Cylinder is attempting to Move. In the Case of a Vertical Cylinder, the Load Equals the Weight of the Object because Gravity acts in a Downward, Vertical Direction.

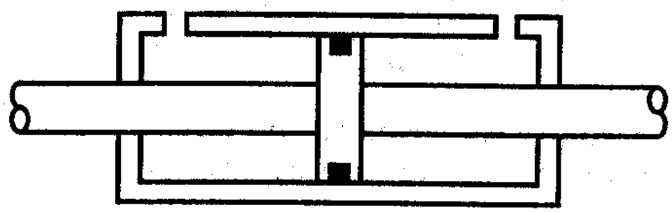
Sometimes a Cylinder is used to Slide an Object along a Horizontal Surface. In this Case, the Cylinder Load is Theoretically Zero. This is because there is No Component of the Object's Weight Acting along the Axis of the Cylinder (a Horizontal Direction). However as the Object slides across the Horizontal Surface, the Cylinder must Overcome the Frictional Force created between the Object and the Horizontal Surface. This Frictional Force which equals the Load acting on the Cylinder, Opposes the Direction of Motion of the Moving Object.

If the Cylinder is Mounted in Neither a Vertical Nor Horizontal Direction, the Cylinder Load equals the Component of the Object's Weight acting along the Axis of the Cylinder, Plus a Frictional Force If the Object is Sliding along an Inclined Surface.

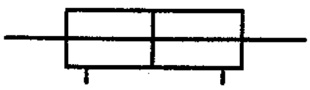
For an inclined cylinder, the Load the Cylinder Must Overcome is less than the Weight of the Object to be moved If the object is Not Sliding on an Inclined Surface.

The Cylinder Loads described up to Now are based on Moving an Object at a Constant Velocity. However, an Object to be Moved at a given Velocity is Initially at Rest. The Object has to be Accelerated from Zero Velocity up to a Steady State (Constant) Velocity as determined by the Pump Flow-rate Entering the Cylinder. This Acceleration represents an Additional Force (called an Inertial Force) that must be added to the Weight Component and any Frictional Force involved.

6- SPECIAL CYLINDER DESIGNS



b. Double-Ended Cylinder (double-acting)



Symbol

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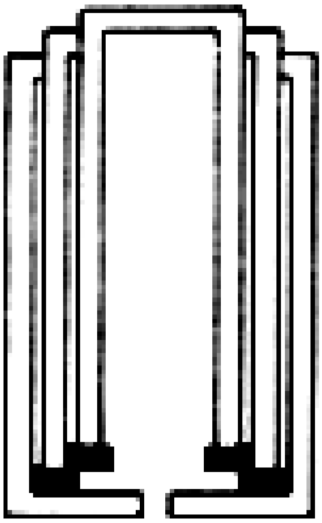
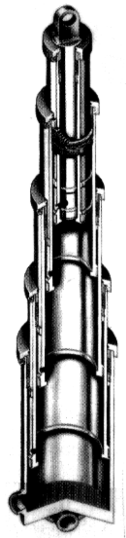
Double-Rod Cylinder in which the Rod Extends Out of the Cylinder at Both Ends. For such a Cylinder, the words Extend and Retract have No Meaning. Since the Force and Speed are the Same for Either End, this Type of Cylinder is typically Used The Same Task is to be performed at Either End. Since Each End contains the Same Size Rod, The Velocity of the Piston is the Same for Both Strokes.

Internal Design features of a **Telescopic cylinder** contain multiple cylinders that slide inside Each Other. They are used where Long Work Strokes are required but The Full Retraction Length Must be Minimized. One Application for a Telescopic Cylinder is the High-Lift Fork Truck





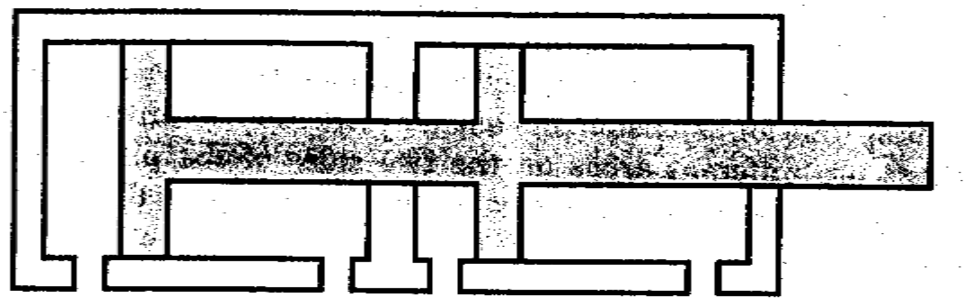
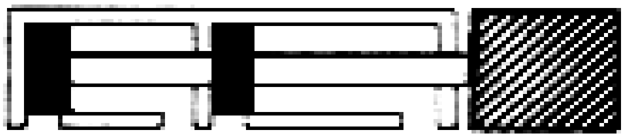
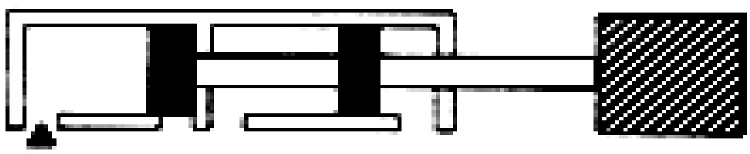


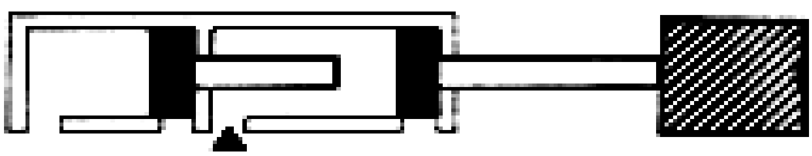
Figure 6.4 In the tandem cylinder pressure acts on both pistons, providing almost twice the force capability of a standard cylinder of the same size.



Duplex cylinder position 1

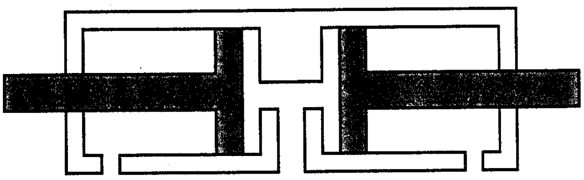


Duplex cylinder position 2

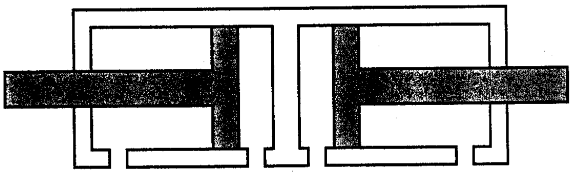


Duplex cylinder position 3

Hydraulic Cylinders



a. Both pistons are pressurized at the same time.



b. Each piston can be pressurized independently

7- CYLINDER LOADINGS THROUGH MECHANICAL LINKAGES

In Many Applications, the Load Force that a Hydraulic Cylinder must Overcome does not Act Along the Axis of the Hydraulic Cylinder. Thus, the Load Force and the Hydraulic Cylinder Force are in general Not Equal. The Following is an Analysis on How to determine The Hydraulic Cylinder Force required to Drive Non-Axial Loads using the First-Class, Second-Class, and Third-Class Lever Systems. In Lever Systems, the Cylinder Rod and Load Rod are Pin connected by a Lever that can Rotate about a Fixed Hinge Pin. A similar analysis can be made of any of the Other Types of Linkage Arrangements.

A First-Class Lever System, which is characterized by The Lever Fixed-Hinge Pin being Located between the Cylinder and Load Rod Pins. Note that the Length of the Lever Portion: From the Cylinder Rod Pin to the Fixed Hinge is L_1, whereas From the Load Rod Pin to the Fixed Hinge is L_2. To Determine the Cylinder Force F_{cyl} required to Drive a Load Force F_{load}, We Equate Moments about the Fixed Hinge, which is the Pivot Point of the Lever. The Cylinder Force attempts to Rotate the Lever Counterclockwise about the Pivot and this creates a Counterclockwise Moment. Similarly, the Load Force creates a Clockwise Moment about the Pivot. At Equilibrium, these Two Moments are Equal in Magnitude:

Counterclockwise Moment = Clockwise Moment

$$F_{cyl}(L_1 \cos\theta) = F_{load}(L_2 \cos\theta) \quad \text{or} \quad F_{cyl} = \frac{L_2}{L_1} F_{load}$$

When $L_1 > L_2$ Then **Cylinder Force < Load Force**

This Results in **Load Stroke < Cylinder Stroke**, as required by the Conservation of Energy Law.

Excavator contains Hydraulic Cylinders whose Loadings occur through Mechanical Linkages

It is Lifting a Huge Concrete Pipe at a Construction Site, via a Chain Connecting the Pipe to the Pinned End of the Hydraulically Actuated Bucket.

Observe that there are a Total of Four Hydraulic Cylinders used to Drive the Three Pin-Connected Members called the Boom, Slick, and Bucket.

The Boom is the Member that is Pinned at One End to the Cab Frame.

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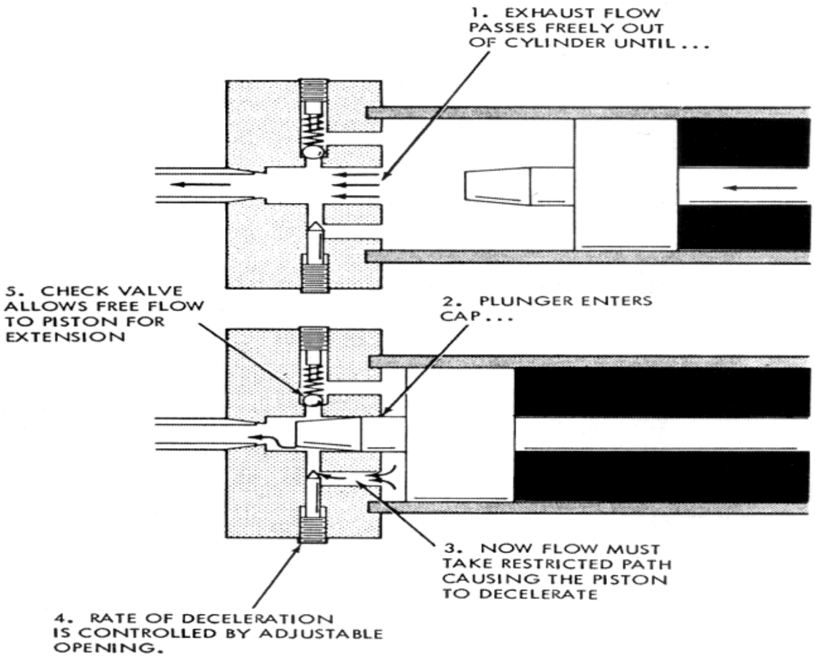
The Stick is the Central Member that is Pin Connected at One End to the Boom and Pin Connected at the Other End to the Bucket.
Two of the Cylinders Connect the Cab Frame to the Boom. A Third Cylinder connects the Boom to the Stick, and The Fourth Cylinder connects the Stick to the Bucket.
The Problem is to determine the Load on Each Cylinder for given Positions of the Boom, Slick, and Bucket. In Order to Do this, it is necessary to Make a Force Analysis Using The Resulting Mechanical Linkage Configuration and the Given External load Applied to the Bucket. To Determine the Load on All 4 Cylinders also requires knowing the Weights and Center of Gravity Locations of the Boom, Stick, and Bucket. For the Excavator of Figure 15, the Maximum Size Bucket is 1.1 cubic yards and the Maximum Lifting Capacity at Ground Level is 16,000 Ib

8- HYDRAULIC CYLINDER CUSHIONS

Double-Acting Cylinders sometimes contain Cylinder Cushions at the Ends of the Cylinder to Slow the Piston Down Near the Ends of the Stroke. This Prevents Excessive Impact When the Piston is Stopped by the End Caps. Deceleration Starts the Tapered Plunger Enters the Opening in the Cap. This Restricts the Exhaust Flow from the Barrel to the Port. During the Last Small Portion of the Stroke, The Oil Must exhaust through an Adjustable Opening.



The Cushion Design also incorporates a **Check Valve** to Allow Free Flow to the Piston during Direction Reversal. The Maximum Pressure developed by Cushions at the Ends of a Cylinder Must be Considered since Excessive Pressure Buildup would Rupture the Cylinder