The function of a cylinder in a fluid power system is to convert energy in the fluid stream into an equivalent amount of mechanical energy. Its power is delivered in a straight-line, push-pull motion.

**Graphic Symbols:** Following diagram illustrates standard ANSI (American National Standards Institute) graphic symbols for use in circuit diagrams. Six of the more often used are shown:

- Standard Double-Acting
- Double-End-Rod
- Ram-Type, Single-Acting
- Single-Acting
- Single-Acting, Spring Return
- Telescopic

The standard double-acting cylinder with piston rod out one end, is used in the majority of applications. It develops force in both directions of piston travel. The double-end-rod type is a variation of the standard cylinder but having a piston rod extending out both end caps. It is occasionally used where it is necessary to have equal area on both sides of the piston, such as a steering application, or where one of rod extensions is to be used for mounting a cam for actuation of a limit switch, or for mounting a stroke limiting stop. The single-acting cylinder develops force in one direction, and is retracted by the reactive force from the load or an internal or external spring. The single-acting ram is a construction often used on fork lift mast raise, or a refuse body tailgate raise, or a high tonnage press cylinders. The telescoping cylinder is built in both single-acting and double-acting types. Its purpose is to provide a long stroke with a relatively short collapsed length. The single-acting telescopic is a construction often used to raise dump trucks and dump trailers. The double-acting telescopic is a construction often used in garbage bodies to pack and eject the load.

**Force Produced by a Cylinder:**
A standard double-acting cylinder has three significant internal areas. The full piston area when exposed to fluid pressure, produces force to extend the piston rod. The amount of this force, in pounds, is calculated by multiplying piston square inch area times gauge pressure, in PSI.

Example: The extension force is 95 PSI x 50 sq. in. = 4750 lbs. The opposing force on the rod side is 25 PSI x 40 sq. in. = 1000 lbs. Therefore, the net force which the cylinder can exert against a load in its extension direction is 4750 - 1000 = 3750 lbs. In making cylinder force calculation we sometimes assume that the opposite side of the piston is at atmospheric pressure, and that the counter-force is zero. On some kinds of loads this can lead to serious error.

**Cylinder Force Against a Load:** The force which a cylinder can exert against a load is determined by making two calculations. First, extension force is calculated according to piston area and PSI pressure against it. Then, the opposing force on the opposite side of the piston is calculated the same way. Net force against a load is the difference between the two.

*Caution! It is incorrect, on a single-end-rod cylinder to calculate cylinder net force as piston area times ΔP (pressure drop, psid) across the piston. This is true only for double-end-rod cylinders which have equal areas on both sides of the piston.*

Example: The extension force is 95 PSI x 50 sq. in. = 4750 lbs. The opposing force on the rod side is 25 PSI x 40 sq. in. = 1000 lbs. Therefore, the net force which the cylinder can exert against a load in its extension direction is 4750 - 1000 = 3750 lbs. In making cylinder force calculation we sometimes assume that the opposite side of the piston is at atmospheric pressure, and that the counter-force is zero. On some kinds of loads this can lead to serious error.

*Note: Most designers try to eliminate back pressure to get full extend force, but there will always be back pressure.*
Designing With Cylinders

Standard catalog cylinder models are not designed to take any appreciable side load on the piston rod. They must be mounted so the rod is not placed in a bind at any part of the stroke. If the direction of the load changes during the stroke, hinge mounting must be used on both the rod end and rear end. Use guides on the mechanism, if necessary, to assure that no side load is transmitted to the cylinder rod or piston.

Rod Buckling

Column failure or buckling of the rod may occur if the cylinder stroke is too long relative to the rod diameter. The exact ratio of rod length to rod diameter at which column failure will occur cannot be accurately calculated, but the “Column Strength” table in this manual shows suggested safe ratios for normal applications.

Tension and Compression Failures

All standard cylinders have been designed with sufficiently large piston rods so failure will never occur either in tension or compression, provided the cylinder is operated within the manufacturer's pressure rating.

Rod Bearing Failure

Rod bearing failures usually occur when the cylinder is at maximum extension. Failures occur more often on hinge or trunnion mount cylinders, in which the rear support point is located considerably behind the rod bearing. If space permits, it is wise to order cylinders with longer stroke than actually required, and not permit the piston to approach to the front end while under full load.

Stop Collar

On those applications where it is necessary to let the piston “bottom out” on the front end, the cylinder may be ordered with a stop collar. The stop collar should be especially considered on long strokes if the distance between support exceeds 10 times the rod diameter, if the maximum thrust is required at full extension, and if the cylinder has a rear flange, clevis, tang, or trunnion mounting.

MINIMUM PISTON ROD DIAMETER

Figures in body of chart are suggested minimum rod diameters, in inches.

<table>
<thead>
<tr>
<th>Load, Pounds</th>
<th>Exposed Length of Piston Rod, Inches / Rod Diameter, Inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,000</td>
<td>10&quot; 20&quot; 40&quot; 60&quot; 70&quot; 80&quot; 100&quot; 120&quot;</td>
</tr>
<tr>
<td>1,500</td>
<td>5/8 7/8 1-1/8 1-1/4 1-3/8</td>
</tr>
<tr>
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</tr>
<tr>
<td>4,000</td>
<td>1 1-1/4 1-1/4 1-3/16 1-5/8 1-12/16</td>
</tr>
<tr>
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</tr>
<tr>
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<td>1-1/2 1-3/16 1-3/8 1-5/8 2 2-1/4</td>
</tr>
<tr>
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</tr>
<tr>
<td>300,000</td>
<td>2-3/4 2-7/16 2-3/4</td>
</tr>
</tbody>
</table>

Commerical Hydraulics

Parker Hannifin Corporation
Mobile Cylinder Division
Youngstown, OH
Cylinder Working a Rotating Lever:

A cylinder working a hinged lever can exert its maximum force on the lever only when the lever axis and cylinder axis are at right angles. When Angle “A” is greater or less than a right angle, only part of the cylinder force is effective on the lever. The cylinder force is found by multiplying the full cylinder force times the sine (sin) of the least angle between cylinder and lever axes. Cylinder Force, FF, is horizontal in this figure. Only that portion, EF, which is at right angles to the lever axis is effective for turning the lever. The value of EF varies with the acute angle “A” between the cylinder and lever axis.

Example: Find the effective force exerted by a 3-inch bore cylinder against a lever when the cylinder is operating at 3000 PSI and when its axis is at an angle of 55 degrees with the lever axis.

First, find the full force developed by the cylinder: FF (full force) = \(7.07 \times \text{piston area} \times 3000 \text{ PSI} = 21,210 \text{ lbs.}\)

Next, find the effective force at 55°: EF (effective force) = \(21,210 \times \sin(55°) = 17,371 \text{ lbs.}\)

Since maximum cylinder force is delivered in the right angle position, the hinge points for the cylinder and lever should be located, if possible, so the right angle falls close to the lever position which requires the greatest torque (force).

Note: The working angles on a hinged units, such as a dump truck, refuse body packer blade, or a crane, are constantly changing, it may be necessary to construct a rough model on a sheet of paper, to exact scale, with cardboard arms and thumbback hinge pins. This will show the point at which the greatest cylinder thrust is needed. An exact calculation can then be made for this condition.
Cylinders on Cranes and Beams:

Example 1: Calculation to find cylinder force required to handle 15,000 lbs. when the beam is in the position shown.

First find the force $F_2$ at right angles to the beam which must be present to support the 15,000 lb. load.

$$F_2 = W \times \cos 50^\circ = 15,000 \times 0.643 = 9,645 \text{ lbs.}$$

Next, find the force $F_1$, also at right angles to the beam, which must be produced by the cylinder to support the 15,000 lb. load. This is calculated by proportion. $F_1$ will be greater than $F_2$ in the same ratio that arm length 17 feet is greater than arm length 5 feet.

Arm length ratio of $17 \div 5 = 3.4$. Therefore, $F_1 = 9,645 \times 3.4 = 32,793 \text{ lbs.}$

Finally, calculate the cylinder force, at an angle of $30^\circ$ to the beam, which will produce a force of 32,793 lbs. at its rod hinge point at right angles to the beam.

$$F (\text{cylinder force}) = F_1 \div \sin 30^\circ = 32,793 \div 0.500 = 65,586 \text{ lbs.}$$

Example 2: Calculation to find maximum load that can be lifted with a cylinder force of 15,000 lbs. when the beam is in the position shown.

First, translate the cylinder thrust, $F$, of 15,000 lbs. into 7,500 lbs. at right angles to the beam using power factor of 0.500 (sin) from the power factor table, for a $30^\circ$ angle.

Next, translate this to $F_2$, 2,500 lbs. at the end of beam where the weight is suspended. This is done with simple proportion by the length of each arm from the base pivot point. $F_2$ is $1/3$rd $F_1$ since the lever arm is 3 times as long.

Finally, find the maximum hanging load that can be lifted, at a $45^\circ$ angle between beam and load weight, using sin (power factor) for $45^\circ$:

$$W = F_2 \div \sin 45^\circ = 2500 \div 0.707 = 3535 \text{ lbs.}$$
Calculations for a Heavy Beam:

On a heavy beam it is necessary to calculate not only for concentrated loads such as the suspended weights and cylinder thrust, but to figure in the weight of the beam itself. If the beam is uniform, so many pounds per foot of length, the calculation is relatively easy. In the example shown in figure “B”, the beam has a uniform weight of 150 lbs. per foot, is partially counterbalanced by a weight of 500 lbs. on the left side of the fulcrum, and must be raised by the force of a cylinder applied at a point 9 feet from the right side of the fulcrum.

The best method of solution is to use the principle of moments. A moment is a torque force consisting of (so many) pounds applied at a lever distance of (so many) feet or inches. The solution here is to find how much cylinder thrust is needed to just balance the beam. Then, by increasing the hydraulic cylinder thrust 5 to 10% to take care of friction losses, the cylinder would be able to raise the beam.

Using the principle of moments, it is necessary to calculate all of the moment forces which are trying to turn the beam clockwise, then calculate all the moment forces trying to turn the beam counter-clockwise, then subtract the two. In this case they must be equal to balance the beam.

Clockwise moment due to the 15 feet of beam on the right side of the fulcrum: This can be considered as a concentrated weight acting at its center of gravity 7 1/2 feet from the fulcrum. Moment = 150 (lbs. per foot) x 15 feet x 7 1/2 feet = 16,875 foot pounds.

Counter-clockwise moment due to the 5 feet of beam on the left side of the fulcrum: 150 (lbs. per foot) x 5 feet x 2 1/2 feet (CG distance) = 1875 foot pounds.

Counter-clockwise moment due to hanging weight of 500 pounds: 500 x 5 feet = 2500 foot lbs.

Subtracting counter-clockwise from clockwise moments: 16,875 - 1875 - 2500 = 12,500 foot pounds that must be supplied by the cylinder for balance condition. To find cylinder thrust: 12,500 foot pounds ÷ 9 feet (distance from fulcrum) = 1388.8 pounds.

Remember when working with moments, that only the portion of the total force which is at right angles to the beam is effective as a moment force. If the beam is at an angle to the cylinder or to the horizontal, then the effective portion of the concentrated of distributed weight, and the cylinder thrust, can be calculated with the power factors (refer to chart).