## Design Engineering Guide

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BASIC CYLINDER OPERATING PRINCIPLES

Cylinders are used to convert fluid power into mechanical motion. A cylinder consists of a cylindrical body, closures at each end, movable piston, and a rod attached to the piston.

When fluid pressure acts on the piston, the pressure is transmitted to the piston rod, resulting in linear motion. The piston rod thrust force developed by the fluid pressure acting on the piston is easily determined by multiplying the line pressure by the piston area.

\[
\text{FORCE} = \text{PRESSURE} \times \text{AREA} \quad \text{or} \quad F = PA
\]

**EXAMPLE:** Find the thrust force of a 4” diameter piston operating with a line pressure of 100 psi.

The piston area has to be determined first to solve this problem. The area of a circular surface is \( \pi r^2 \), where “r” is the radius.

In the case of a 4” diameter piston, the area equals 12.57 square inches (\( \pi r^2 \)). Since a pressure of 100 psi acts on each square inch, the total thrust force will be 100 x 12.57 or 1257 lbs.

When calculating the pull force of a cylinder, the area covered by the piston rod must be subtracted from the total area of the piston. The pressure does not act on the area covered by the piston rod.

Tables are provided on pages 182-183 (as well as within each Series’ Section) to save mathematical calculations for determining thrust force, pull force, and cylinder speed. See page 31, Series H; page 67, Series LH; and page 97, Series A and Series MN.

TYPES OF CYLINDERS

Standard cylinders have been designed to meet the wide range of applications. The following types of cylinders provide an overview of what is available.

- **SINGLE-ACTING CYLINDER**
  - The single-acting cylinder is pressurized at one end only, with the opposite end vented to atmosphere through a breather filter (air cylinder) or vented to a reservoir (hydraulic cylinder).
  - The return stroke of the cylinder is accomplished by some external means.

- **SPRING RETURN CYLINDER**
  - The spring return cylinder is normally considered a single acting cylinder.
  - The operation of this type of cylinder is the same as a single acting cylinder, except that a spring is used to accomplish the return stroke.

- **DOUBLE-ACTING CYLINDER**
  - The most familiar double acting cylinder is the single rod end. This type of cylinder provides power in both directions, with a pressure port at either end. Single rod end cylinders exert greater forces when extending than when retracting, since the piston area on the blind end is larger than the piston area on the rod end (due to the area covered by the piston rod).

- **DOUBLE ROD END CYLINDER**
  - The double rod end cylinder is used when it is necessary for the cylinder to exert equal force and operate at equal speed in both directions. It also can be used to operate limit valves or switches.

- **POSITIONAL OR DUPLEX CYLINDER**
  - Duplex cylinders are similar to tandem cylinders in that both are cylinders connected in line, but the pistons of a duplex cylinder are not physically connected; the rod of one cylinder protrudes into the non-rod end of the second, and so forth. A duplex cylinder may be more than two in-line cylinders and the stroke lengths of the individual cylinders may vary. This results in a component that can achieve a number of different fixed stroke lengths depending on which of the cylinders and on which end the cylinders are pressurized.

- **TANDEM CYLINDER**
  - A tandem cylinder consists of two cylinders mounted in line with the pistons, connected by a common piston rod. The main advantage of this cylinder is the multiplication of force, during the entire stroke, without requiring higher operating pressures or larger bores.
DESIGN INFORMATION

■ TIE ROD MOUNT

When using tie rods extended on the rod end, the best application is a tension load. For a thrust load application, the tie rods should be extended on the blind end of the cylinder. Tie rod mounts are suited for many applications, but it should be noted that they are not as rigid as flange mounted cylinders and often require additional support for long stroke applications.

■ SIDE AND LUG MOUNTS

The side or lug mounted cylinder provides a fairly rigid mount. This type of mount can tolerate a slight amount of misalignment when the cylinder is fully extended, but as the piston moves toward the blind end, the tolerance for misalignment decreases. It is important to note that if the cylinder is used properly (without misalignment), the mounting bolts are either in simple shear or tension without compound stresses.

■ FLANGE MOUNT

The flange mount is one of the strongest, most rigid methods of mounting. With this type of mount, there is little allowance for misalignment. When long strokes are required, the free end opposite the mounting should be supported to prevent sagging and possible binding of the cylinder. When the cylinder is used in a thrust load application, a blind end flange should be used. For tension applications, rod end flange mounts should be used.

■ PIN AND TRUNNION MOUNT

All pin and trunnion mounted cylinders need a provision on both ends for pivoting. This type of mounting is designed to carry shear loads and requires that the trunnion or pivot pins are rigidly held by closely fit bearings for the entire pin length.

■ SOLID FLANGE MOUNT

The solid flange mount is the strongest, most rigid method of mounting a cylinder. Industry standards for this type of mounting only cover 1½" through 8" bore cylinders. Milwaukee Cylinder, however, offers this mount on cylinders up to 12" bore.

■ KEY MOUNT

The key mount retainer plate is a mounting option designed to add stability to foot and side mounted cylinders. The retainer plate is extended below the mounting surface of the cylinder. This extension may be fit into a milled keyway, eliminating the need for welded keys or locator pins.

■ DOUBLE ROD END CYLINDERS

Double rod end cylinders are available in every mounting style except the clevis mount (61) and fixed eye mount (62). It should be noted by the designer that when a double flange mount is required, there will be tie rod nuts protruding on one end.
MOVING LOAD

■ SLIDING LOAD

Cylinders perform a wide variety of applications and are often used in place of larger, more expensive mechanical systems. One such application is when a cylinder is used to move a high friction sliding load. Some examples of this are: machine slides, pallet shuttle systems on automated machinery, milling machine tables, and grinder tables.

There are a number of things to consider when sizing a cylinder for a sliding load application. These include the unit weight (load), lubrication, and required speed. For applications where there is light lubrication, the cylinder should provide a thrust force capable of moving a load equal to 50% to 75% of the actual load. Once in motion, a thrust force capable of moving 20% of the actual load weight is adequate.

Because air is a compressible medium, air cylinders should not be used for slow or controlled feed or motion in a sliding load application. The designer should be aware that a jerky motion will result if an air cylinder is used to perform this type of work. Because oil is non-compressible, a hydraulic cylinder with a metered out speed control would be more effective. For indexing applications, from one positive stop to another, air cylinders usually provide better response and more rapid action than hydraulic cylinders.

■ ROLLING LOAD

Cylinders can be used to move rolling loads or loads which are moved on low friction bearings. For this type of application, the cylinder should have a thrust force capable of moving a load equal to 10% of the actual load. When using a cylinder to move a rolling load, some means of deceleration at the end of the cylinder stroke should be used to prevent the momentum of the load from damaging either the cylinder or the machine.

CYLINDERS FOR LIFTING

■ VERTICAL LIFTING

Air cylinders must be sized to have more force than needed to just balance the load it must move. The more the cylinder is oversized, with respect to the load, the faster it can move the load (this is not true of hydraulic cylinders).

In the figure at the right, the cylinder has enough upward force to just balance the weight of the load. It cannot move the load upward, it can only hold it from dropping. To start the load in motion, it will have to have additional force. This can be provided by increasing the air pressure to more than 80 psi or by use of a larger bore cylinder.

The exact speed of an air cylinder cannot be calculated. Air cylinder sizing depends on the degree of overpowering to move the load, valving, piping, and other factors which usually are unknown and cannot be measured. For further information on air cylinder sizing and speed, refer to page 100.

An air cylinder should not be used for a platform or hoist lift application. If the lift is stopped in mid stroke, it will have a tendency to drift due to the compressibility of air. A hydraulic system or air over oil system should be used in these types of applications, since force applied to a confined liquid exhibits about the same effect of rigidity as a solid.
ROD SIZE

■ ROD BUCKLING

Correct rod size selection is an important factor in sizing a cylinder for an application. If the piston rod diameter is too small in relation to the load column, failure or rod buckling is likely to occur.

The standard rod for each bore size that Milwaukee Cylinder manufactures is sufficient to carry the maximum tension force that the cylinder is capable of producing. It is in compression applications that the column strength needs to be considered. For proper rod size selection in compression applications, refer to Table 1 on page 31, Series H; page 67, Series LH; and page 97, Series A and Series MN.

■ ROD BEARING FAILURE

Side load is the most common cause of rod bearing failure. Milwaukee Cylinder has designed its standard line of cylinders to operate with a minimum amount of side load. When mounting a cylinder, it is critical that the alignment is checked both in the extended and the retracted positions. When the rod is fully extended, extensive leverage can be developed. If a side load condition exists, it will cause the piston to score the barrel and rapidly reduce the effective life of the rod bushing.

The designer has three methods which can be used to either eliminate or reduce the effects of side load. The first is to use a pin or trunnion mounted cylinder so as to move with the side load. The second is to guide the load and the piston rod, which will eliminate the side load condition. The third solution is to use a cylinder with more stroke than necessary to perform the function. This will increase the distance between the two bearing areas of the cylinder (the piston and rod bushing), reducing the overall effect of the side load condition.

■ STOP TUBE

The use of a stop tube is the preferred method for reducing piston and bearing loads on long stroke cylinders. It is also used to prevent jack-knifing or buckling of horizontally mounted cylinders used in long stroke compression applications.

For reducing bearing loads on the rod, a stop tube is more effective, less costly, and lighter weight than an oversized piston rod. A stop tube is placed between the piston and rod end cap to restrict the extension of the rod. This space between the two bearing areas provides additional strength and support for the extended rod.

At Milwaukee Cylinder, we offer two stop tube designs. The single piston stop tube design is common to all cylinders except cushion rod end air cylinders. A stop tube will increase the overall length of the cylinder and will alter the mounting dimensions on most models by the length of the stop tube.

The second stop tube design is the double piston stop tube. This stop tube is primarily used for cushion rod end air cylinders. Unlike the single piston stop tube design, the double piston stop tube provides additional strength for excessive side loading and adds additional bearing area to the cylinder.

To determine if a stop tube is necessary for a cylinder application, the value of “K” has to be determined (refer to Figure 1). If the required cylinder has a “K” value in excess of 40,” a stop tube is required. For each 10” increment or fraction thereof in excess of 40”, one inch of stop tube is recommended.

Figure 1 – STROKE TO MOUNTING RELATIONSHIP

When mounting long stroke cylinders, care should be taken to assure cylinder alignment over the entire length of stroke. The use of external guides or swivel bushings is recommended to reduce side load conditions and prolong the cylinder’s service life.
Air Cylinder Force and Speed

**AIR CYLINDER FORCE**

An air cylinder must be oversized to move a load. As illustrated, a 4" bore air cylinder will balance a 1000 pound load with 80 psi of air pressure. To move this load at a slow rate of speed, the cylinder must be oversized.

The designer should remember that when calculating cylinder force on the return (pull) stroke, the rod area must be deducted from the piston area. When a double rod end cylinder is used, deduct for both directions of stroke when calculating the thrust force.

**AIR CYLINDER SPEED**

The exact speed of an air cylinder cannot be calculated. Air cylinder sizing depends on the degree of overpowering required to move the load at the desired speed, valving, piping, and other factors which usually are unknown and cannot be measured.

When a fast speed is required, the bore size and line pressure should be twice that which is needed to balance the load resistance. The lines to the valve and cylinder should be as short as possible. When selecting the directional valve to be used in an air application, the orifice of the valve should be equal to the cylinder port size. The air cylinder speed chart shows the proper port size under average conditions.

Note: This Air Cylinder Speed Chart is based on average conditions. Conditions where the cylinder is operating at twice the thrust force required and a line pressure of 80 to 100 psi.

**AIR CYLINDER SPEED CHART**

<table>
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<tr>
<th>ACTUAL VALVE ORIFICE SIZE</th>
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</tr>
<tr>
<td>1½</td>
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<tr>
<td>2</td>
</tr>
<tr>
<td>2½</td>
</tr>
<tr>
<td>3¼</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
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<td>6</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>12</td>
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Above figures are in inches per second.
HYDRAULIC CYLINDER FORCE

Table 3 on page 31 or 67 shows the thrust force developed by various bore diameters when working at various pressures. These figures do not include a factor covering a reduction in force due to seal or packing friction in the cylinder. This type of friction is estimated to affect the cylinder thrust force by 10%. Additional pressure must be developed by the pump, not only to overcome frictional loss, but also flow losses in the circuitry. The engineer should realize that the usable pressure in the cylinder may be from 10% to 25% less than the pump and relief valve gauge reading.

HYDRAULIC CYLINDER SPEED

Hydraulic Cylinder Force and Speed

This type of friction is estimated to affect the cylinder thrust force by 10%. Additional pressure must be developed by the pump, not only to overcome frictional loss, but also flow losses in the circuitry. The engineer should realize that the usable pressure in the cylinder may be from 10% to 25% less than the pump and relief valve gauge reading.

### HYDRAULIC CYLINDER SPEED

Figures shown in the body of this chart are cylinder rod travel speeds in inches per minute. The extension speeds represent the net piston area for the various rod diameters shown.

<table>
<thead>
<tr>
<th>PISTON DIA</th>
<th>ROD DIA</th>
<th>1 GPM</th>
<th>3 GPM</th>
<th>5 GPM</th>
<th>8 GPM</th>
<th>12 GPM</th>
<th>15 GPM</th>
<th>20 GPM</th>
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<th>75 GPM</th>
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<td>182</td>
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<td>365</td>
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<td>111</td>
<td>135</td>
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<td>205</td>
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<td>455</td>
<td>555</td>
<td>675</td>
<td>815</td>
<td>975</td>
<td>1175</td>
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<tr>
<td>1¼</td>
<td>251</td>
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<td>111</td>
<td>146</td>
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<td>750</td>
<td>975</td>
<td>1245</td>
<td>1625</td>
<td>2075</td>
<td>2700</td>
</tr>
</tbody>
</table>
FLUIDS

Hydraulic fluid heats, cools, lubricates, and sometimes corrodes mechanical components, picks up and releases gases, and sweeps sludge into supposedly free clearances. The fluid is just as important as any other part of the hydraulic system. In fact, a major portion of hydraulic problems stem from the use of improper types of fluids or fluids containing dirt and other contaminants.

To understand the fluids used in today’s industry, you have to divide them into two general areas: petroleum fluids and fire resistant fluids. These in turn break down into a number of different types with different properties. Not all fluids are compatible with the standard seal combinations offered by cylinder manufacturers.

In the chart below is a small sample of the fluids available and the seals with which they are compatible. Specific information on seal compatibility is available from either the fluid supplier or the component manufacturer.

SEALS

BUNA N SEAL  This type of seal is excellent with petroleum products. The seal is rated for a temperature range from -20°F to +200°F, but when used for low temperatures, it is necessary to sacrifice some low temperature resistance. It is a superior material for compression set, cold flow, tear and abrasion resistance. This seal is generally recommended for petroleum, water, diester and water-glycol.

POLYURETHANE SEAL  The polyurethane seal provides excellent mechanical and physical properties. Polyurethane does not provide a good low pressure seal, due to its poor compression and permanent set properties. This seal is generally recommended for petroleum, water/oil, and phosphate ester.

ETHYLENE PROPYLENE  This seal is excellent when used with Skydrol 500 and Phosphate Ester Fluids. The seal is rated for a temperature range from -65° F to +350° F. This seal is generally recommended for phosphate ester, steam (to 400° F), water, and ketones.

VITON SEAL  Viton seals are compatible with a wide range of fluids. This seal is rated for a temperature range from -15° F to +350°F. This seal is generally recommended for petroleum, silicate ester, diester, halogenated hydrocarbons, and most phosphate esters.

### SEAL COMPATIBILITY with COMMON FLUIDS

<table>
<thead>
<tr>
<th>FLUID NAME</th>
<th>MILITARY SPECIFICATION</th>
<th>TRADE NAME/NUMBER</th>
<th>BUNA-N</th>
<th>POLYURETHANE</th>
<th>EP</th>
<th>VITON FLUOROCARBON</th>
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<tbody>
<tr>
<td><strong>Water Glycol</strong></td>
<td>MIL-H22072</td>
<td>Houghto-Safe 600 Series</td>
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<td></td>
<td></td>
<td>Houghto-Safe 500 Series</td>
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<td></td>
<td>Houghto-Safe 271 Series</td>
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<tr>
<td></td>
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<td>Skydrol 500 Type 2</td>
<td>Unsatisfactory</td>
<td>Insufficient data</td>
<td>Recommended</td>
<td>Unsatisfactory</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Skydrol 7000 Type 2</td>
<td>Unsatisfactory</td>
<td>Insufficient data</td>
<td>Recommended</td>
<td>Unsatisfactory</td>
</tr>
<tr>
<td><strong>Diester</strong></td>
<td>MIL-H-7808</td>
<td>Lube Oil Aircraft</td>
<td>Satisfactory</td>
<td>Unsatisfactory</td>
<td>Unsatisfactory</td>
<td>Satisfactory</td>
</tr>
<tr>
<td><strong>Silicate Ester</strong></td>
<td>MIL-H-8446B</td>
<td>Brayco 846</td>
<td>Satisfactory</td>
<td>Recommended</td>
<td>Unsatisfactory</td>
<td>Recommended</td>
</tr>
<tr>
<td><strong>Kerosene</strong></td>
<td>MIL-J-5624</td>
<td>JP-3, 4, 5 (RP-1)</td>
<td>Recommended</td>
<td>Satisfactory</td>
<td>Unsatisfactory</td>
<td>Recommended</td>
</tr>
<tr>
<td><strong>Jet Fuel</strong></td>
<td></td>
<td></td>
<td>Recommended</td>
<td>Marginal</td>
<td>Unsatisfactory</td>
<td>Recommended</td>
</tr>
<tr>
<td><strong>Diesel Fuel</strong></td>
<td></td>
<td></td>
<td>Recommended</td>
<td>Satisfactory</td>
<td>Unsatisfactory</td>
<td>Recommended</td>
</tr>
<tr>
<td><strong>Gasoline</strong></td>
<td></td>
<td></td>
<td>Recommended</td>
<td>Satisfactory</td>
<td>Unsatisfactory</td>
<td>Recommended</td>
</tr>
<tr>
<td><strong>Petroleum Base</strong></td>
<td>MIL-H-6383</td>
<td>Preservative Oil</td>
<td>Recommended</td>
<td>Recommended</td>
<td>Unsatisfactory</td>
<td>Recommended</td>
</tr>
<tr>
<td></td>
<td>MIL-H-5606</td>
<td>Aircraft Hyd. Fluid</td>
<td>Recommended</td>
<td>Satisfactory</td>
<td>Unsatisfactory</td>
<td>Recommended</td>
</tr>
</tbody>
</table>

Note: This chart is for general information and should not be taken as warranty or representation for which legal responsibility is assumed. The chart and the information on this page is offered only for your convenience, consideration, investigation and verification.
SOLID STATE END OF STROKE LIMIT SWITCHES

**FEATURES:**
- End of stroke indication for all sizes of cylinders
- Pneumatic or hydraulic operation (3000 psi)
- Choice of rod end, cap end or both ends
- Cushioned or non-cushioned cylinders available
- Switches are permanently set at factory – no adjustments necessary
- No special filtration required – any cylinder operating fluid acceptable
- Operating point repeatable to .002”
- Quick Response
- Operating temperature range of -4°F to +158°F
- Sensing range .08”
- Short circuit protected
- Immunity to weld field noise
- Typical switching range: 20 to 250 volts AC/DC

**OPTIONS:**
- Low profile, 1¾" high above surface (for certain cylinder sizes)
- Mini or micro connections
- Reduced switching voltage available to 10 vdc
- Supplied with or without switches

COMBINED MOUNTINGS

Milwaukee Cylinder offers the designer the ability to combine standard mountings to meet special design requirements. Some examples of this are:

- An MF1 mount constructed with an MS2 mount blind end cap.
- An MP1 mount constructed with an MS4 mount rod end cap.

These and other combinations can be readily made from standard parts. If you are unsure of a possible combination or its suitability to your application, consult your local Milwaukee Cylinder Distributor or the factory.

OTHER STYLES AND CONFIGURATIONS OF CYLINDERS MODIFIED FOR EMBEDDED OR EXTERNAL TRANSDUCERS ARE AVAILABLE. CONTACT YOUR LOCAL MILWAUKEE CYLINDER DISTRIBUTOR OR THE FACTORY.
Rod Boot Data

Standard Material:
Neoprene Nylon

Special Material:
Consult Factory

**ROD BOOTS**
When cylinders are used in areas of high contamination or where contaminants have an air hardening property, the exposed piston rod should be covered with a rod boot to protect the rod bearing and seals. A rod boot is simply a collapsible cover. It is of sewn construction made from a neoprene coated fabric. The rod boots are impervious to oil, grease and water. They will operate effectively from 0°F to +200°F without cracking.

### ROD BOOT DATA CHART

<table>
<thead>
<tr>
<th>ROD DIA. (in)</th>
<th>COVER I.D</th>
<th>COVER O.D</th>
<th>ROD BOOT STYLE</th>
<th>MINIMUM LENGTH FACTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>⅝</td>
<td>¾</td>
<td>3</td>
<td>RA-15</td>
<td>.07</td>
</tr>
<tr>
<td>⅞</td>
<td>¾</td>
<td>3⅛</td>
<td>RB-15</td>
<td>.07</td>
</tr>
<tr>
<td>1</td>
<td>1⅛</td>
<td>3⅛</td>
<td>RC-15</td>
<td>.07</td>
</tr>
<tr>
<td>1⅜</td>
<td>1⅛</td>
<td>4⅛</td>
<td>RD-15</td>
<td>.07</td>
</tr>
<tr>
<td>1⅝</td>
<td>2⅛</td>
<td>4⅛</td>
<td>RE-15</td>
<td>.07</td>
</tr>
<tr>
<td>2</td>
<td>2⅛</td>
<td>5⅛</td>
<td>RF-15</td>
<td>.07</td>
</tr>
<tr>
<td>⅝</td>
<td>3⅛</td>
<td>7</td>
<td>Consult Factory</td>
<td></td>
</tr>
<tr>
<td>⅞</td>
<td>3⅛</td>
<td>7⅜</td>
<td>Consult Factory</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>4⅞</td>
<td>8⅜</td>
<td>Consult Factory</td>
<td></td>
</tr>
<tr>
<td>1⅛</td>
<td>5⅛</td>
<td>9</td>
<td>Consult Factory</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>5⅛</td>
<td>9⅛</td>
<td>Consult Factory</td>
<td></td>
</tr>
</tbody>
</table>

**NOTE:** ROD EXTENSION MUST BE INCREASED TO ACCOMMODATE BOOT

To Compute: 

\[ W = (\text{Stroke} \times \text{Min. Length Factor}) + 1\frac{1}{8}'' \]

Round up to the nearest ⅛”

Example: 
A61, 3½" bore x 12" stroke x 1" rod
\[ W = (12 \times 0.07) + 1.375 = (0.84) + 1.375 = 2.22'' \]

Round up to the nearest ⅛”

\[ W = 2.25'' \]
**Non-Rotating Cylinder Design**

**FEATURES:**
- All cylinder series
- Cushioned or non-cushioned cylinders
- All bore and rod combinations except ⅜" diameter rod
- Spline shaft and mating sleeve prevent natural rotation of piston rod during stroke
- Mounting styles 11, 21, 31, 35, 41, 42, 43, 71, 72, 73, 74. Consult factory for other mounting styles
- Engineering dimensional drawing provided with each cylinder ordered

**NOTE:** Not available in double rod end cylinders or with stroke lengths over 45 inches. Rotational limits or torsional load information must be supplied to factory.

---

**GUIDE ROD**

**FEATURES:**
- All cylinder series
- Cushioned or non-cushioned cylinders
- All mounting styles
- Double rod end cylinders
- All bore and rod combinations 8-inch bore and larger
- Guide rod design through piston prevents natural rotation of piston rod
- Engineering dimensional drawing provided with each cylinder ordered

**NOTE:** Rotational limits or torsional load information must be supplied to factory.

---

**BORE DIA.** | **ROD DIA.** | **AVAILABILITY**
--- | --- | ---
1½ | ⅝ | N/A
1 | ⅝ | N/A
1¼ | ⅝ | N/A
1¼ | 1 | N/A
1⅜ | 1 | N/A
2 | 1 | N/A
2½ | 1 | Yes
3½ | 1 | N/A
3½ | 1½ | N/A
3½ | 2 | N/A
4 | 1½ | Yes
1¾ | 1½ | Yes
1¾ | 2 | Yes
4 | 2½ | Yes
5 | 1 | Yes
1¾ | 1¾ | Yes
1¾ | 2½ | Yes
2½ | 3 | Yes
3½ | 3½ | N/A
3½ | 3 | N/A
6 | 1⅜ | Yes
1¾ | 1⅜ | Yes
1⅜ | 2 | Yes
2½ | 2½ | Yes
3½ | 4 | Yes
3½ | 4 | Yes
4½ | 4½ | Yes
5 | 5 | N/A
Custom Products

Contact Milwaukee Cylinder for all your Custom Cylinder needs.

Milwaukee Cylinder has two basic identities as a cylinder producer. The first is a supplier of standard Hydraulic and Air Cylinders. The second is as a specialist in the design and manufacture of totally unique cylinders. For information on what data is required to develop a design to suit your needs, contact either your local Milwaukee Cylinder representative, or the factory.

■ ADJUSTABLE STROKE CYLINDER

In this application, the extend cycle of the cylinder had to be adjustable for different lengths. Milwaukee Cylinder attached a special, welded stop around one of the double rod ends. The rod end going through the stop has an easily adjustable nut that will precisely set the length of the extend cycle.

■ ADJUSTABLE STOP CYLINDER

Like the cylinder above, this one does not require special valving to achieve an adjustable stroke length. But unlike the other cylinder, the length of the stroke had to be adjustable in both directions. In this case, the blind end flange had an extension added through which one of the double rod ends passed. Around the rod were attached two, threaded, locking collars for quick and easy adjustment of the rod travel in either direction.

■ NOSE MOUNTED CYLINDER

Quite often, cylinders designed and manufactured overseas do not conform to NFPA specifications. Milwaukee Cylinder is able to design a replacement non-NFPA cylinder. This particular cylinder was designed to replace a cylinder built in Europe. A special threaded nozzle was required for mounting purposes.
Whether you require a different material, seals, mounting, other modification or a completely unique custom product, Milwaukee Cylinder has the resources to meet your needs. We also offer mechanical locking, position sensing, non-rotating and other specialty cylinder types.

■ HEAVY-DUTY CYLINDER
The Series HD cylinder is a heavy-duty, non-tie rod design rated for continuous 5,000-psi operation. It has been designed specifically for punching and piercing operations in thick metal requiring tonnage ratings from 17-1/2 to 100 tons.

■ CONTROLLED ROTATING CYLINDER
Sand shell cores for casting turbine rotors required a large cam roll and three men to turn the cope. Due to the curved blades on the rotor, the cope of the pattern had to be rotated as it was being removed. Milwaukee Cylinder engineered a precision cylinder in which the rod would rotate during the first two inches of upward travel and then travel straight up for eleven more inches. This controlled rotation released the blades in the pattern from the sand core without incurring breakage.

■ TILT SYSTEM CYLINDER
Milwaukee Cylinder was chosen to design and manufacture a custom hydraulic cylinder functioning as the tilting mechanism. We developed a cylinder that could extend and retract a precise distance, allowing a specific degree of tilt in either direction.
Power Units: Gear and Vane Info

Hydraulic Power Units from Milwaukee Cylinder are available in Gear Pump and Vane Pump designs.

HOW A VANE PUMP WORKS
The MCVEV series uses a vane style pump element that has both volume adjustment and maximum pressure adjustment. The output flow and pressure are determined by the position of the cam ring and the vane rotor.

HOW A GEAR PUMP WORKS
The MCVEG series uses a gear style pump element. The driven gear is coupled to the motor. The idler gear is driven by the rotation of the driven gear. Oil is pulled into the suction port, carried in the gap between the gear teeth, and comes out of the pressure port. Adjustment of the system pressure requires a relief valve in the circuit.

A. To adjust the volume output, the position of the cam ring is moved to reduce the clearance between the vane rotor and the cam ring.

B. To adjust the maximum output pressure, the spring adjustment is set so the internal pressure in the cam ring centers the cam ring around the rotor.

Calculating System Requirements

- Cylinder Area \((\text{in})^2 = \pi r^2\)
- Cylinder Volume = \((\text{in}^3) = \text{Cylinder Area} \times \text{Stroke}\)
- Flow Requirement (gpm) = \(\frac{\text{Cylinder Volume} \times \# \text{of Cylinders} \times (60/\text{Speed Required**)}}{231 \text{ in}^3 \text{ per gal}}\)

* Alternate formula: \((\text{Bore Diameter})^2 \times 0.7854\)
** In seconds

Example:

Cylinder Bore: 4.00" Stroke Length: 12"
Number of Cylinders: 4 Speed Required = 6 sec.

Cylinder Radius \((r) = 4^\prime \text{ bore diameter} \div 2 = 2^\prime \text{ radius}\)

Cylinder Area = \(\pi \times 2^\prime \times 2^\prime = 3.14 \times 4 \text{ in}^2 = 12.56 \text{ in}^2\)

Cylinder Volume = 12.56 in\(^2\) \times 12\" = 150.72 in\(^3\)

Flow Requirement = \(\frac{150.72 \text{ in}^3 \times 4 \times (60 \div 6 \text{ sec})}{231 \text{ in}^3 \text{ per gal}}\)

= \(\frac{602.88 \text{ in}^3}{231 \text{ in}^3 \text{ per gal}}\)

= 26 gpm

Calculating Reservoir Size

The oil capacity of the reservoir used in a hydraulic power unit (HPU) provides the oil volume required to operate the cylinders and other devices in a system, and also absorbs and radiates the heat produced during the operation of the HPU. Using a small reservoir may result in an overheated system. The guideline for sizing the reservoir is 3 to 4 times the flow rate of the pump (gpm).

For example, a 5 gpm HPU should use a 15-20 gallon reservoir. Further reduction of heat buildup in the reservoir may require the use of a heat exchanger. A low oil level and high temperature switch in the reservoir can be used to shut the system down if the oil level in the reservoir falls below a usable level or if the oil temperature rises to an unsafe temperature.
D03 AND D05 DIRECTIONAL VALVES
Spool type valves are typically used with a hydraulic power unit (HPU) where the system provides continuous flow. This helps to compensate for losses due to internal leakage in the valves. Milwaukee Cylinder offers spool valves in two industry standard sizes:
D03: Flow rates of 12-17 gpm
D05: Flow rates of 25 gpm
The operation of a valve is described by the flow paths to the circuit ("way"), the number of valve operating positions ("position") and the type of flow path in the center position ("center"). Other characteristics used in describing a valve describe the type of operator used: solenoid, manual lever, cam, air, and operator options such as spring centered and detented.
Common valve configurations are:

**4 way /3 position /TANDEM Center**
CENTER POSITION: Pessure to Tank
USES: Idles pump in the center position

**4 way /3 position /OPEN Center**
CENTER POSITION: All ports to Tank
USES: Idles pump in the center position

**4 way /3 position /CLOSED Center**
CENTER POSITION: All ports blocked
USES: Used in system with multiple valves

**4 way /3 position /FLOAT Center**
CENTER POSITION: A & B to to Tank, P blocked
USES: Used in system with multiple valves with pilot operated check valves

**4 way /2 position**
NO CENTER POSITION
USES: Used in systems where cylinders are always either advanced or retracted

ACCESSORY VALVES
In many circuits, accessory valves are used with the directional valve to provide additional control of the flow in the system:

**Holding:**
Check valve on the pressure port

**Dual pilot operated check valves on "A" and "B"**

Control of flow rate:

Control of pressure (on pressure port)

Manifolds
Manifolds are available for D03 and D05 size valves as either pump mounted or remote mounted. They are available in single and multiple valve models. For systems operating up to 3000 psi, choose an aluminum manifold. The pump mounted manifolds used on the Milwaukee Cylinder power units are aluminum, as these units operate at 3000 psi or below.
For applications using higher pressure power units, up to 5000 psi, select the remote mount ductile iron manifolds.

Porting:
D03:
P and T: #10 SAE
A and B: #8 SAE

D05:
P and T: #12 SAE
A and B: #8 SAE
### Fluid Power Formulas

#### FLUID PRESSURE (pounds per square inch)

<table>
<thead>
<tr>
<th>FORMULA</th>
<th>WORD FORMULA</th>
<th>LETTER FORMULA</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRESSURE</td>
<td>force (pounds) / unit area (square inches)</td>
<td>$P = \frac{F}{A}$ or $psi = \frac{F}{A}$</td>
</tr>
</tbody>
</table>

#### CYLINDER AREA (square inches)

<table>
<thead>
<tr>
<th>FORMULA</th>
<th>WORD FORMULA</th>
<th>LETTER FORMULA</th>
</tr>
</thead>
<tbody>
<tr>
<td>AREA</td>
<td>$\pi \times \text{radius}^2$ (inches)</td>
<td>$A = \pi r^2$</td>
</tr>
<tr>
<td></td>
<td>$\pi/4 \times \text{diameter}^2$ (inches)</td>
<td>$A = \frac{\pi d^2}{4}$ or $A = .785d^2$</td>
</tr>
</tbody>
</table>

#### CYLINDER FORCE (pounds, push or pull)

<table>
<thead>
<tr>
<th>FORMULA</th>
<th>WORD FORMULA</th>
<th>LETTER FORMULA</th>
</tr>
</thead>
<tbody>
<tr>
<td>FORCE</td>
<td>pressure (psi) x net area (square inches)</td>
<td>$F = \psi A$ or $F = PA$</td>
</tr>
</tbody>
</table>

#### CYLINDER VELOCITY or SPEED (feet per second)

<table>
<thead>
<tr>
<th>FORMULA</th>
<th>WORD FORMULA</th>
<th>LETTER FORMULA</th>
</tr>
</thead>
<tbody>
<tr>
<td>VELOCITY</td>
<td>$\frac{231 \times \text{flow rate (GPM)}}{12 \times 60 \times \text{net area (square inches)}}$</td>
<td>$v = \frac{231Q}{231}$ or $v = \frac{.3208Q}{A}$</td>
</tr>
</tbody>
</table>

#### CYLINDER VOLUME or CAPACITY (gallons of fluid)

<table>
<thead>
<tr>
<th>FORMULA</th>
<th>WORD FORMULA</th>
<th>LETTER FORMULA</th>
</tr>
</thead>
<tbody>
<tr>
<td>VOLUME</td>
<td>$\pi \times \text{radius}^2 \times \text{stroke (inches)}$</td>
<td>$v = \pi r^2L$</td>
</tr>
<tr>
<td></td>
<td>$\pi \times \frac{(\text{diameter})^2}{4} \times \text{stroke (inches)}$</td>
<td>$v = \pi \frac{d^2}{4}L$</td>
</tr>
</tbody>
</table>

#### CYLINDER FLOW RATE (GPM)

<table>
<thead>
<tr>
<th>FORMULA</th>
<th>WORD FORMULA</th>
<th>LETTER FORMULA</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLOW RATE</td>
<td>$12 \times 60 \times \text{velocity (feet/second)} \times \text{net area (square inches)}$</td>
<td>$Q = \frac{720vA}{231}$ or $Q = \frac{3.117vA}{231}$</td>
</tr>
</tbody>
</table>

#### FLUID MOTOR TORQUE (inch pounds)

<table>
<thead>
<tr>
<th>FORMULA</th>
<th>WORD FORMULA</th>
<th>LETTER FORMULA</th>
</tr>
</thead>
<tbody>
<tr>
<td>TORQUE</td>
<td>pressure (psi) x f.m. displacement (cu. in./rev)</td>
<td>$T = \psi \frac{d}{2\pi}$ or $T = \frac{Pd}{2\pi}$</td>
</tr>
<tr>
<td></td>
<td>horsepower x 63025 rpm</td>
<td>$T = 63025 \frac{HP}{n}$</td>
</tr>
<tr>
<td></td>
<td>flow rate (gpm) x pressure (psi) x 36.77 rpm</td>
<td>$T = \frac{36.77OP}{n}$ or $T = \frac{36.77psi \times \text{flow rate}}{n}$</td>
</tr>
</tbody>
</table>

#### FLUID MOTOR TORQUE /100 psi (inch pounds)

<table>
<thead>
<tr>
<th>FORMULA</th>
<th>WORD FORMULA</th>
<th>LETTER FORMULA</th>
</tr>
</thead>
<tbody>
<tr>
<td>TORQUE</td>
<td>f.m. displacement (cu. in./rev)</td>
<td>$T_{\text{100psi}} = \frac{d}{.0628}$</td>
</tr>
</tbody>
</table>

#### FLUID MOTOR SPEED (revolutions per minute)

<table>
<thead>
<tr>
<th>FORMULA</th>
<th>WORD FORMULA</th>
<th>LETTER FORMULA</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPEED</td>
<td>$231 \times \text{flow rate (gpm)} \times \text{f.m. displacement}$</td>
<td>$n = \frac{231Q}{d}$</td>
</tr>
</tbody>
</table>

#### FLUID MOTOR POWER (horsepower output)

<table>
<thead>
<tr>
<th>FORMULA</th>
<th>WORD FORMULA</th>
<th>LETTER FORMULA</th>
</tr>
</thead>
<tbody>
<tr>
<td>HORSEPOWER</td>
<td>torque output (inch pounds) x rpm</td>
<td>$HP = \frac{Tn}{63025}$</td>
</tr>
</tbody>
</table>

#### PUMP OUTLET FLOW (gallons per minute)

<table>
<thead>
<tr>
<th>FORMULA</th>
<th>WORD FORMULA</th>
<th>LETTER FORMULA</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLOW</td>
<td>rpm x pump displacement (cu. in./rev.)</td>
<td>$Q = \frac{nD}{231}$</td>
</tr>
</tbody>
</table>

#### PUMP INPUT POWER (horsepower required)

<table>
<thead>
<tr>
<th>FORMULA</th>
<th>WORD FORMULA</th>
<th>LETTER FORMULA</th>
</tr>
</thead>
<tbody>
<tr>
<td>HORSEPOWER INPUT</td>
<td>flow rate output (gpm) x pressure (psi)</td>
<td>$HP_{\text{in}} = \frac{Q \times \psi}{1714 \times \text{efficiency \ (overall)}}$</td>
</tr>
</tbody>
</table>

#### FLOW RATE through PIPING (additional required oil to reach pressure)

<table>
<thead>
<tr>
<th>FORMULA</th>
<th>WORD FORMULA</th>
<th>LETTER FORMULA</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADDITIONAL VOLUME</td>
<td>pressure (psi) x volume of oil under pressure</td>
<td>$V_A = \frac{PV}{250,000}$</td>
</tr>
</tbody>
</table>

#### GAS LAWS for ACCUMULATOR SIZING:

Where $P^n = \text{psia (absolute)} = \text{psig (gauge pressure)} + 14.7 \text{psi}$

<table>
<thead>
<tr>
<th>FORMULA</th>
<th>WORD FORMULA</th>
<th>LETTER FORMULA</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRESSURE or VOLUME (W/Constant “T”) Temperature</td>
<td>Original Pressure x Original Volume = Final Pressure x Final Volume</td>
<td>$P_{1V} = \frac{P_{2V}}{P_{1V}}$ [isothermic]</td>
</tr>
<tr>
<td>PRESSURE or TEMPERATURE (W/Constant “T”) Volume</td>
<td>Original Pressure x Final Temperature = Final Pressure x Original Temperature</td>
<td>$P_{1T} = \frac{P_{2T}}{P_{1T}}$ [isochoric]</td>
</tr>
<tr>
<td>VOLUME or TEMPERATURE (W/Constant “P”) Pressure</td>
<td>Original Volume x Final Temperature = Final Volume x Original Temperature</td>
<td>$V_{1T} = \frac{V_{2T}}{V_{1T}}$ [isobaric]</td>
</tr>
<tr>
<td>PRESSURE or VOLUME (W/Temperature change due to heat of compression)</td>
<td>Original Temperature x Final Volume $^{n}$ = Final Pressure x Final Volume $^{n}$</td>
<td>$P_{1V}^{n} = \frac{P_{2V}^{n}}{P_{1V}^{n}}$</td>
</tr>
</tbody>
</table>

For Nitrogen in the exponent: $n$ = 1.4 For full adiabatic conditions i.e., the “FULL HEATING” theoretical condition

$n$ = 1.3 For rapid cycling (most heating normally experienced)

$n$ = 1.1 For “NORMAL” cycling

$n$ = 1.0 Where gas time to return to normal temperature before discharge or recharge
A

ACCUMULATOR a container in which fluid is stored under pressure as a source of fluid power.

AIR, COMPRESSED air at any pressure greater than atmospheric pressure.

B

BLEEDER, AIR a device for the removal of air from an oil system.

BREATHER, AIR a device permitting air movement between the atmosphere and the component in which it is installed, while preventing contaminations from entering the component.

C

CAP, BLIND END a cylinder end closure which completely covers the bore area.

CAP, ROD END the cylinder and enclosure which covers the differential area between the bore area and the piston rod area.

CAVITATION a localized gaseous condition within a liquid stream which occurs when the pressure is reduced to the vapor pressure.

CLEVIS a “U” shaped mounting device which contains a common pin hole at right angle or normal to the axis of symmetry through each extension.

COMPRESSIBILITY the change in volume of a unit of volume of a fluid when subjected to a unit change of pressure.

CUSHION a device which provides controlled resistance to motion.

CUSHION, CYLINDER a cushion built into the cylinder to restrict flow at the outlet port, thereby arresting the motion of the piston rod.

CYCLE a single complete operation consisting of progressive phases, starting and ending at the neutral position.

CYLINDER a device which converts fluid power into linear mechanical force and motion.

CYLINDER, ADJUSTABLE STROKE a cylinder in which fluid force can be applied to the moveable element in either direction.

CYLINDER, NON-ROTATING a cylinder in which the relative rotation of the cylinder housing and the piston and piston rod, plunger or ram, is fixed.

CYLINDER, SINGLE ACTING a cylinder in which the fluid force can be applied to the moveable element in only one direction.

CYLINDER, TANDEM two or more cylinders with interconnected piston assemblies.

D

DUROMETER HARDNESS a measure of elastomer hardness by use of a durometer.

FILTER a device whose primary function is the retention by porous media of insoluble contaminans from a liquid.

FITTING a connector or closure for fluid power lines and passages.

FLOW, LAMINAR a flow situation in which fluid moves in parallel laminar or layers. Flow Rate – the volume, mass, or weight of a fluid passing through any conductor, per unit of time.

FLOW, TURBULENT a flow situation in which fluid particles move in a random manner.

FLUID FRICTION friction due to the viscosity of fluids.

FLUID STABILITY resistance of a fluid to permanent changes in properties.

G

GAGE an instrument or device for measuring, indicating, or comparing a physical characteristic, such as pressure or volume.

HYDRAULIC PUMP a device which converts mechanical force and motion into fluid power.

INTENSIFIER a device which converts low pressure fluid power into high pressure fluid power; also called a booster.

L

LUBRICATOR a device which adds controlled or metered amounts of lubricant into an air system.

MANIFOLD a conductor which provides multiple connection ports.

MUFFLER a device for reducing gas flow noise.

PACKING a sealing device consisting of bulk deformable material or one or more mating deformable elements, reshaped by manually adjustable compression to obtain and maintain effectiveness. It usually uses axial compression to obtain radial sealing.

PORT an internal or external terminus of a passage in a component.

PORT BLEED a port which provides a passage for the purging of gas from a system or component.

PORT, CYLINDER a port which provides a passage to or from an actuator.

PORT, EXHAUST a port which provides a passage to the atmosphere.

PRESSURE force per unit area, usually expressed in pounds per square inch.

PRESSURE, BURST the pressure which creates loss of fluid thru the component envelope, resulting from failure.

PRESSURE, CRACKING the pressure at which a pressure operated valve begins to pass fluid.

PRESSURE, OPERATING the pressure at which a system is operated.

PRESSURE, PEAK the maximum pressure encountered in the operation of a component.

PRESSURE, RATED the qualified operating pressure which is recommended for a component or a system by the manufacturer.

PRESSURE, SHOCK the pressure existing in a wave moving at sonic velocity.

PRESSURE, STATIC the pressure in a fluid at rest.

PRESSURE, SURGE the pressure existing from surge conditions.

PRESSURE, WORKING the pressure at which the working device normally operates.

PRESSURE VESSEL a container which holds fluid under pressure.

RESERVOIR a container for the storage of liquid in a fluid power system.

RESTRICTOR a device which reduces the cross-sectional flow area.

REYN the standard unit of absolute viscosity in the English system. It is expressed in pound-seconds per square inch.

SERVOVALVE a valve which modulates output as a function of an input command. Silencer – a device for reducing gas flow noise. Noise is decreased by tuned resonant control of gas expansion.

SUBPLATE an auxiliary ported plate for mounting components.

SURGE a transient rise of pressure or flow.

T

TUBE a line whose size is its outside diameter. Tube is available in varied wall thicknesses.

ValVE a device which controls fluid flow direction, pressure, or flow rate.

VALVE, DIRECTIONAL CONTROL a valve whose primary function is to direct or prevent flow through selected passages.

VALVE, FLOW CONTROL a valve whose primary function is to control flow rate.

VALVE, SEQUENCE a valve whose primary function is to direct flow in a predetermined sequence.

VALVE POSITION, DETENT a predetermined position maintained by a holding device, acting on the flow-directing elements of a directional control valve.

VALVE POSITION, NORMAL the valve position when signal or actuating force is not being applied.

VISCOSITY a measure of internal friction or the resistance of a fluid to flow.

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Seller warrants the goods sold hereunder to be free from defects in material and workmanship for a period of twelve months after the date of shipment from Seller’s plant. If the goods are in accordance with or in reference to an engineering drawing specified by or furnished to the customer, the specifications and information on the drawing shall be applicable in determining such correct use, operation and application.

When claiming a breach of the above warranty, Buyer must notify Seller promptly in writing, whereupon Seller will either examine the goods at their site or issue shipping instructions for return to Seller.

When any goods sold hereunder are proved not as warranted, Seller’s sole obligation under this warranty shall be to repair or replace the goods, not including installation or any other charges, at its option, without charge to Buyer.

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