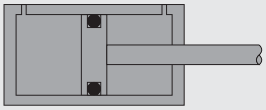
milwaukee Cylinder

Design Engineering Guide

Cylinder Basics

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.

FORCE = PRESSURE x AREA or 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 πr^2, where "r" is the radius. In the case of a 4" diameter piston, the area equals 12.57 square inches (πr^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.

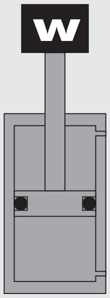
When calculating the pull force of a cylinder, the area covered by the piston rod must be subtracted from the total area of the piston. The pressure does not act on the area covered by the piston rod.

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

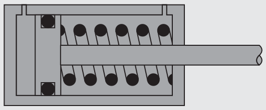
Standard cylinders have been designed to meet the wide range of applications. The following types of cylinders provide an overview of what is available.

■ SINGLE-ACTING CYLINDER



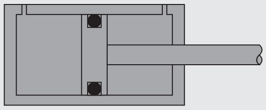
The single-acting cylinder is pressurized at one end only, with the opposite end vented to atmosphere through a breather filter (air cylinder) or vented to a reservoir (hydraulic cylinder). The return stroke of the cylinder is accomplished by some external means.

■ SPRING RETURN CYLINDER



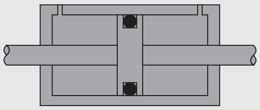
The spring return cylinder is normally considered a single acting cylinder. The operation of this type of cylinder is the same as a single acting cylinder, except that a spring is used to accomplish the return stroke.

■ DOUBLE-ACTING CYLINDER



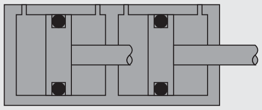
The most familiar double acting cylinder is the single rod end. This type of cylinder provides power in both directions, with a pressure port at either end. Single rod end cylinders exert greater forces when extending than when retracting, since the piston area on the blind end is larger than the piston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

■ DOUBLE ROD END CYLINDER



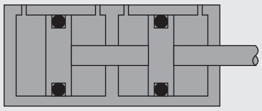
The double rod end cylinder is used when it is necessary for the cylinder to exert equal force and operate at equal speed in both directions. It also can be used to operate limit valves or switches.

■ 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

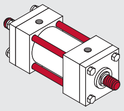


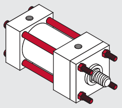
A tandem cylinder consists of two cylinders mounted in line with the pistons, connected by a common piston rod. The main advantage of this cylinder is the multiplication of force, during the entire stroke, without requiring higher operating pressures or larger bores.

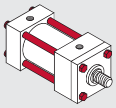
Standard NFPA Mountings

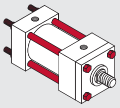
DESIGN INFORMATION

TIE ROD MOUNT


NFPA MX1

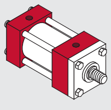

NFPA MX3

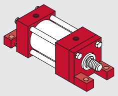

NFPA MX *no mount*

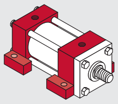

NFPA MX2

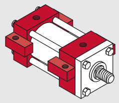
When using tie rods extended on the rod end, the best application is a tension load. For a thrust load application, the tie rods should be extended on the blind end of the cylinder. Tie rod mounts are suited for many applications, but it should be noted that they are not as rigid as flange mounted cylinders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

SIDE AND LUG MOUNTS


NFPA MS4 *side mount*

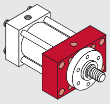

NFPA MS7

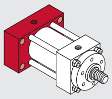

NFPA MS2


NFPA MT3

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.

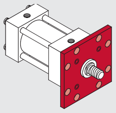
SOLID FLANGE MOUNT

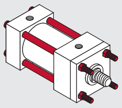

NFPA ME5

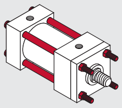

NFPA ME6

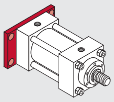
The solid flange mount is the strongest, most rigid method of mounting a cylinder. Industry standards for this type of mounting only cover 1½" through 8" bore cylinders. *Milwaukee Cylinder,* however, offers this mount on cylinders up to 12" bore.

FLANGE MOUNT


NFPA MF5

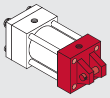

NFPA MF1

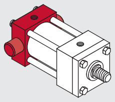

NFPA MF6

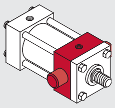

NFPA MF2

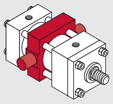
The flange mount is one of the strongest, most rigid methods of mounting. With this type of mount, there is little allowance for misalignment. When long strokes are required, the free end opposite the mounting should be supported to prevent sagging and possible binding of the cylinder. When the cylinder 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


NFPA MP1 *pin mount*

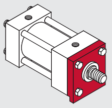

NFPA MT2


NFPA MT1

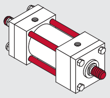

NFPA MT4

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.

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.


NFPA MDX

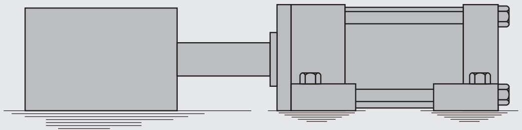
DOUBLE ROD END CYLINDERS

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.

Cylinder Loading

MOVING LOAD

■ SLIDING LOAD

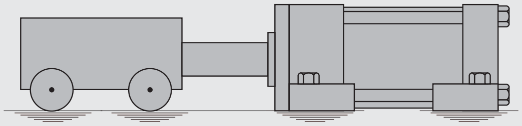


Cylinders perform a wide variety of applications and are often used in place of larger, more expensive mechanical systems. One such application is when a cylinder is used to move a high friction sliding load. Some examples of this are: machine slides, pallet shuttle systems on automated machinery, milling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



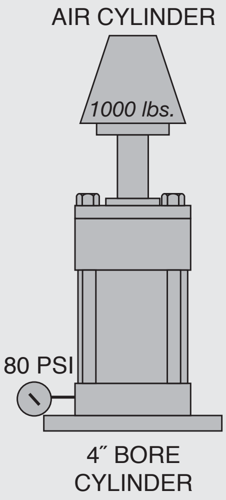
Cylinders can be used to move rolling loads or loads which are moved on low friction bearings. For this type of application, the cylinder should have a thrust force capable of moving a load equal to 10% of the actual load. When using a cylinder to move a rolling load, some means of deceleration at the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

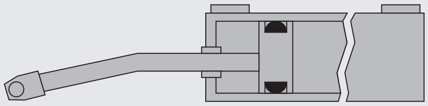


The exact speed of an air cylinder cannot be calculated. Air cylinder sizing depends on the degree of overpowering to move the load, valving, piping, and other factors which usually are unknown and cannot be measured. For further information on air cylinder sizing and speed, refer to page 100.

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.

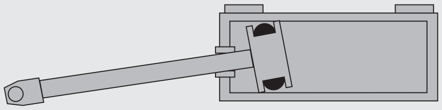
ROD SIZE

■ 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

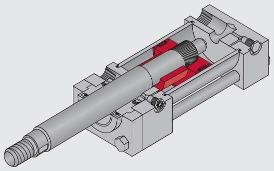
Side load is the most common cause of rod bearing failure. *Milwaukee Cylinder* has designed its standard line of cylinders to operate with a minimum amount of side load. When mounting a cylinder, it is critical that the alignment is checked both in the extended and the retracted positions. When the 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.

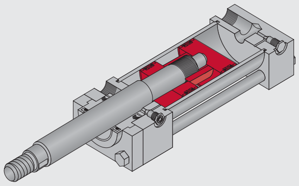
■ STOP TUBE

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.



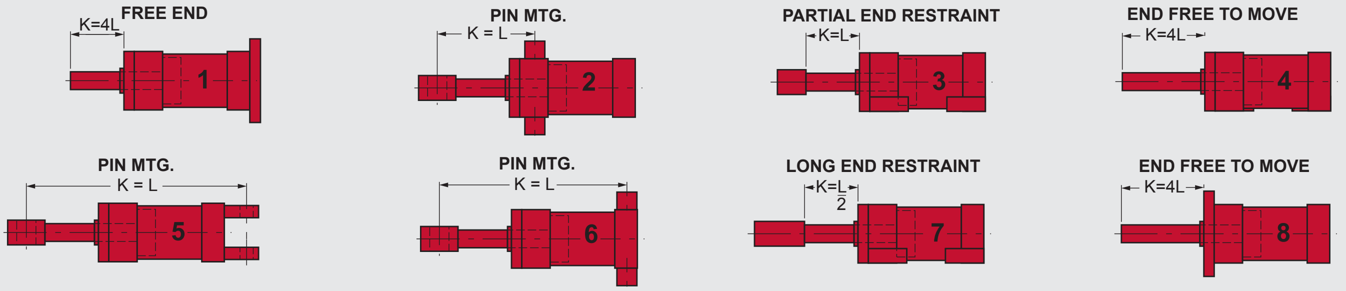
At *Milwaukee Cylinder,* we offer two stop tube designs. The single piston stop tube design is common to all cylinders except cushion rod end air cylinders. A stop tube will increase the overall length of the cylinder and will alter the mounting dimensions on most models by the length of the stop tube.



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

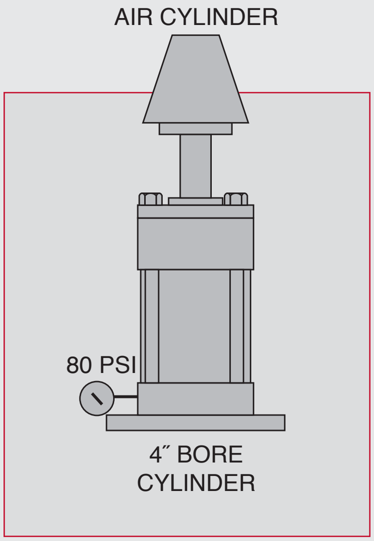


When mounting long stroke cylinders, care should be taken to assure cylinder alignment over the entire length of stroke. The use of external guides or swivel bushings is recommended to reduce side load conditions and prolong the cylinder's service life.

■ AIR CYLINDER FORCE

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

	ACTUAL VALVE ORIFICE SIZE							
BORE DIA	1⁄32	1⁄16	1⁄8	1⁄4	3⁄8	1⁄2	3⁄4	1
1⅛	5	12	28	85	–	–	–	–
1½	3	7	16	50	125	–	–	–
2	1	4	9	28	70	112	–	–
2½	–	2	6	18	45	72	155	–
3¼	–	–	3	9	22	36	78	165
4	–	–	2	7	17	28	60	130
5	–	–	1	4	11	18	40	82
6	–	–	–	3	7	12	26	55
8	–	–	–	1	4	7	15	32
4	–	–	–	–	2	4	9	20
12	–	–	–	–	1	3	6	14

Above figures are in inches per second.

Hydraulic Cylinder Force and Speed

■ 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.

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■ 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.

HYDRAULIC CYLINDER SPEEDS (inches per minute)

PISTON DIA	ROD DIA	1 GPM	3 GPM	5 GPM	8 GPM	12 GPM	15 GPM	20 GPM	25 GPM	30 GPM	40 GPM	50 GPM	75 GPM
1½	none	130	392	654	1034	–	–	–	–	–	–	–	–
	⅝	158	476	792	1265	–	–	–	–	–	–	–	–
	1	235	706	1176	1880	–	–	–	–	–	–	–	–
2	none	73	221	368	588	883	1120	–	–	–	–	–	–
	1	97	294	490	782	1175	1465	–	–	–	–	–	–
	1⅜	139	418	697	1115	1673	2090	–	–	–	–	–	–
2½	none	47	131	235	376	565	675	940	1175	–	–	–	–
	1	56	168	280	448	672	840	1120	1400	–	–	–	–
	1⅜	67	203	339	542	813	1015	1355	1695	–	–	–	–
	1¾	92	277	463	740	1110	1385	1850	2310	–	–	–	–
3¼	none	28	83	139	223	334	417	557	696	836	1115	–	–
	1⅜	34	102	170	271	407	510	680	850	1020	1360	–	–
	1¾	39	118	196	313	472	588	784	980	1176	1568	–	–
	2	44	134	224	358	537	672	896	1120	1344	1792	–	–
4	none	18	55	92	147	220	276	368	460	552	736	920	–
	1¾	22	68	113	182	273	339	452	565	678	904	1130	–
	2	24	73	122	196	294	366	488	610	732	976	1220	–
	2½	30	90	150	241	362	450	600	750	900	1200	1500	–
5	none	12	35	58	94	141	174	232	290	348	464	580	870
	2	14	42	70	112	168	210	280	350	420	560	700	1050
	2½	16	47	78	125	188	235	315	390	470	630	780	1170
	3	18	55	92	147	220	275	365	460	550	730	920	1380
	3½	22	66	111	178	266	333	444	555	665	888	1110	1665
6	none	8	24	41	65	98	123	162	202	245	320	405	606
	2½	10	30	50	79	118	150	200	250	300	400	495	750
	3	11	33	54	87	130	165	206	270	325	435	545	810
	3½	12	37	62	99	148	185	245	310	370	495	615	830
	4	15	44	73	117	176	220	295	365	440	585	735	1095
7	none	6	18	30	48	72	90	120	150	180	240	300	450
	3	7	22	37	59	88	110	145	185	220	295	365	555
	3½	8	24	40	64	96	120	160	200	240	320	400	600
	4	9	27	45	71	107	135	180	225	270	360	445	675
	4½	10	31	51	82	122	153	205	255	305	410	515	765
	5	12	37	61	98	147	185	245	305	370	490	615	915
8	none	4	14	23	36	55	69	92	115	135	185	230	345
	3½	5½	17	28	45	68	85	115	140	170	230	285	420
	4	6	18	30	49	73	90	122	150	180	240	305	450
	4½	6½	20	33	53	80	100	135	165	200	265	335	495
	5	7½	22	38	60	90	114	150	185	225	300	375	555
	5½	8½	26	43	70	104	129	172	215	255	345	430	645
10	none	3	9	15	23	35	44	60	73	88	115	145	220
	4½	3½	11	18	29	44	55	75	92	111	150	185	275
	5	4	12	20	31	47	60	80	100	120	155	195	300
	5½	4½	13	21	34	50	63	84	105	132	165	210	315
	7	5½	17	29	46	69	87	115	145	174	230	285	435

Fluids and Seals

■ 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

FLUID NAME	MILITARY SPECIFICATION	TRADE NAME/NUMBER	BUNA-N	POLYURETHANE	EP	VITON FLUROCARBON
Water Glycol	MIL-H22072	Houghto-Safe 600 Series	Recommended	Unsatisfactory	Recommended	Satisfactory
		Houghto-Safe 500 Series	Recommended	Unsatisfactory	Recommended	Insufficient data
		Houghto-Safe 271 Series	Recommended	Unsatisfactory	Recommended	Satisfactory
		Ucon Hydrolube	Recommended	Unsatisfactory	Recommended	Recommended
		Celluguard	Recommended	Unsatisfactory	Recommended	Recommended
Water Oil/Emulsion		Houghto-Safe 5040 Series	Recommended	Unsatisfactory	Unsatisfactory	Recommended
		Gulf FR	Recommended	Recommended	Unsatisfactory	Recommended
Water Soluble Oil			Recommended	Insufficient data	Recommended	Insufficient data
Water, Fresh			Recommended	Unsatisfactory	Recommended	Satisfactory
Water, Salt			Recommended	Unsatisfactory	Recommended	Satisfactory
Phosphate Ester	MIL-19547B	Houghto-Safe 1000 Series	Unsatisfactory	Insufficient data	Recommended	Recommended
		Houghto-Safe 1120 Series	Unsatisfactory	Unsatisfactory	Recommended	Recommended
		Pyrogard 42, 43, 53, 55	Unsatisfactory	Unsatisfactory	Recommended	Recommended
		Skydrol 500 Type 2	Unsatisfactory	Unsatisfactory	Recommended	Unsatisfactory
		Skydrol 7000 Type 2	Unsatisfactory	Unsatisfactory	Recommended	Unsatisfactory
Diester	MIL-H-7808	Lube Oil Aircraft	Satisfactory	Unsatisfactory	Unsatisfactory	Satisfactory
Silicate Ester	MIL-H-8446B	Brayco 846	Satisfactory	Recommended	Unsatisfactory	Recommended
Kerosene			Recommended	Recommended	Unsatisfactory	Recommended
Jet Fuel	MIL-J-5624	JP-3, 4, 5 (RP-1)	Recommended	Satisfactory	Unsatisfactory	Recommended
Diesel Fuel			Recommended	Marginal	Unsatisfactory	Recommended
Gasoline			Recommended	Satisfactory	Unsatisfactory	Recommended
Petroleum Base	MIL-H-6383	Preservative Oil	Recommended	Recommended	Unsatisfactory	Recommended
	MIL-H-5606	Aircraft Hyd. Fluid	Recommended	Satisfactory	Unsatisfactory	Recommended

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.

Mounting Modifications/Accessories

MOUNTING MODIFICATIONS

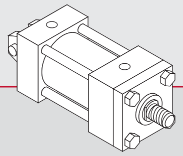
SPECIAL CYLINDER MOUNTINGS

The standard NFPA (National Fuid Power Association) mountings satisfy a wide range of mounting applications and can be easily modified to suit specific design requirements. As a machine or equipment designer, you may encounter various situations where a standard or a modified standard mounting will not satisfy your design requirements. *Milwaukee Cylinder* specializes in meeting your needs in this area by providing cylinders custom designed to suit your specific applications.

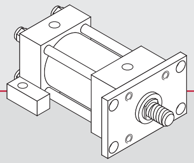
For information on what data is required by *Milwaukee Cylinder* to develop a design to suit your specific requirements, contact either your local *Milwaukee Cylinder* Distributor or the factory.

COMBINED MOUNTINGS

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



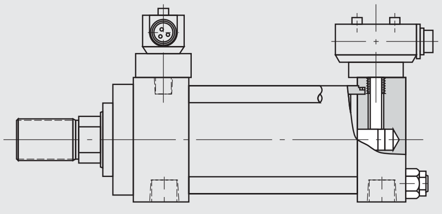
An MF1 mount constructed with an MS2 mount blind end cap.



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.

SOLID STATE END OF STROKE LIMIT SWITCHES



Design compatible with major brands.

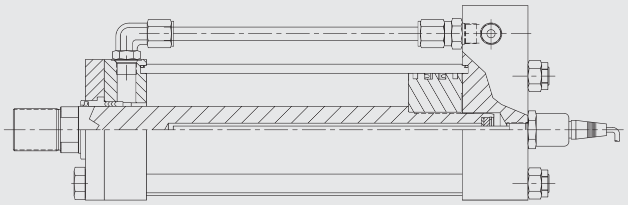
FEATURES:

- 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, 13/8" high above surface (for certain cylinder sizes)
- Mini or micro connections
- Reduced switching voltage available to 10 vdc
- Supplied with or without switches

TRANSDUCERS



FEATURES:

- High immunity to shock and vibration
- Non-contacting design, no wear
- 3000 psi operating pressure
- 24 VDC operating voltage
- Analog or digital output
- Strokes up to 200 inches

Rod Boot Data

Standard Material:
Neoprene Nylon

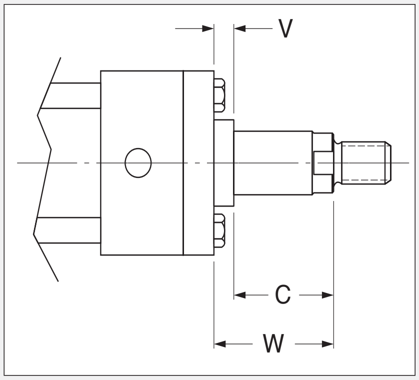
Special Material:
Consult Factory

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

ROD DIA. (in)	COVER I.D	COVER O.D	ROD BOOT STYLE	MINIMUM LENGTH FACTOR
⅝	¾	3	RA-15	.07
1	1⅛	3⅜	RB-15	.07
1⅜	1½	3¾	RC-15	.07
1¾	1⅞	4⅛	RD-15	.07
2	2⅜	4⅝	RE-15	.07
2½	2⅞	5⅛	RF-15	.07
3	3⅜	7	Consult Factory	
3½	3⅞	7½	Consult Factory	
4	4½	8¼	Consult Factory	
4½	5	8⅜	Consult Factory	
5	5¼	9	Consult Factory	
5½	5¾	9½	Consult Factory	

Note: Rod extension must be increased to accommodate boot



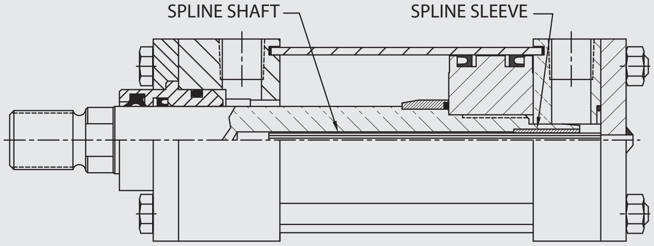
To Compute: W = (Stroke x Min. Length Factor) + 1⅜"
Round up to the nearest ⅛"

Example: A61, 3¼" bore x 12" stroke x 1" rod
W = (12 x 0.07) + 1.375 = (.84) + 1.375 = 2.22"
Round up to the nearest ⅛"

W = 2.25"

Non-Rotating Cylinder Design

SPLINE SHAFT

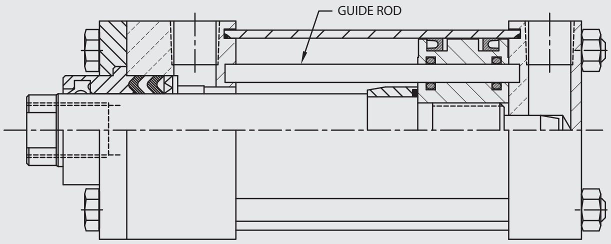


FEATURES:

- All cylinder series
- Cushioned or non-cushioned cylinders
- All bore and rod combinations except ⅝" 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:

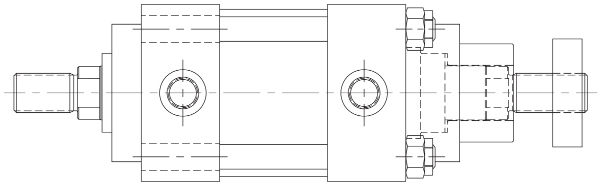
- All cylinder series
- Cushioned or non-cushioned cylinders
- All mounting styles
- Double rod end cylinders
- All bore and rod combinations 8-inch bore and larger
- Guide rod design through piston prevents natural rotation of piston rod
- Engineering dimensional drawing provided with each cylinder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

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

BORE DIA.	ROD DIA.	AVAILABILITY
1½	⅝	N/A
	1	N/A
2	⅝	N/A
	1	N/A
	1⅜	N/A
2½	⅝	Yes
	1	N/A
	1⅜	N/A
	1¾	N/A
3½	1	Yes
	1⅜	N/A
	1¾	N/A
	2	N/A
4	1	Yes
	1⅜	Yes
	1¾	Yes
	2	N/A
	2½	N/A
5	1	Yes
	1⅜	Yes
	1¾	Yes
	2	Yes
	2½	Yes
	3	N/A
	3½	N/A
6	1⅜	Yes
	1¾	Yes
	2	Yes
	2½	Yes
	3	Yes
	3½	Yes
	4	N/A
7	3	Yes
	3½	Yes
	4	Yes
	4½	Yes
	5	N/A

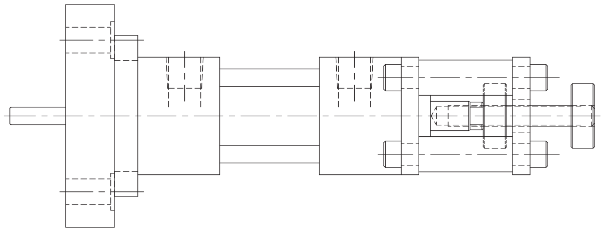
Contact Milwaukee Cylinder for all your Custom Cylinder needs.

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.*



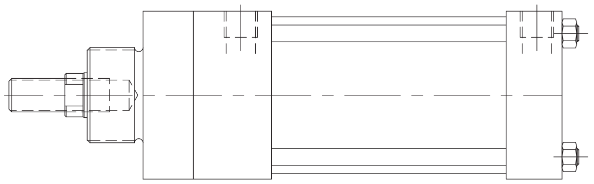
■ ADJUSTABLE STROKE CYLINDER

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.

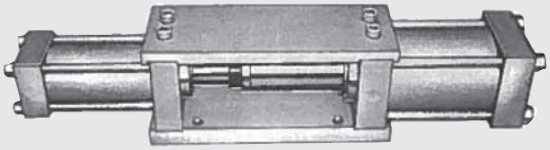


■ NOSE MOUNTED CYLINDER

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.

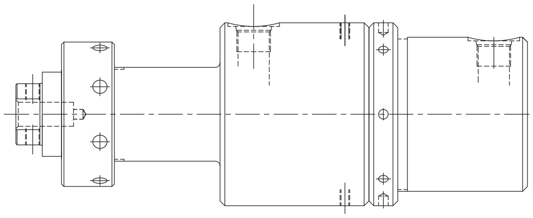
Custom Products

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.*



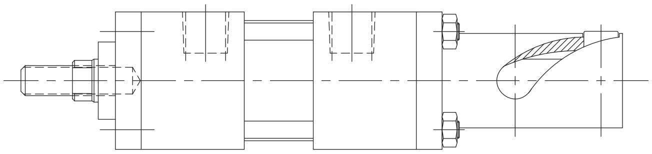
HEAVY-DUTY CYLINDER

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.



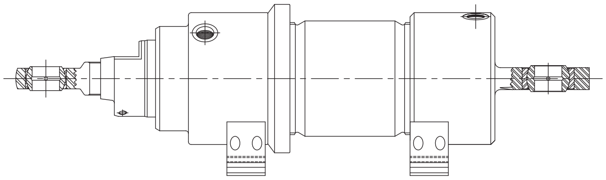
CONTROLLED ROTATING CYLINDER

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.

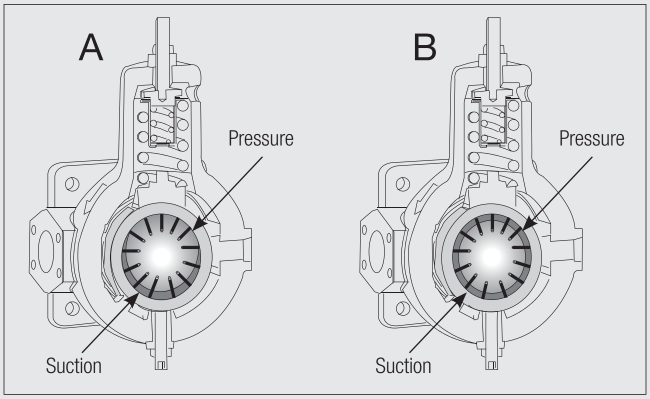


Power Units: Gear and Vane Info

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.

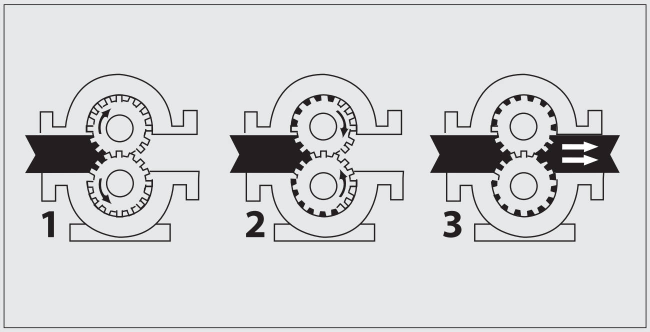


A. To adjust the volume output, the position of the cam ring is moved to reduce the clearance between the vane rotor and the cam ring.

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.

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.



Calculating System Requirements

- Cylinder Area (in)* $= \pi r^2$
- Cylinder Volume = (in^3) = Cylinder Area x Stroke
- Flow Requirement (gpm) =

$$\frac{\text{Cylinder Volume x \# of Cylinders x (60÷Speed Required**)}}{231 \text{ in}^3 \text{ per gal}}$$

* 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" bore diameter ÷ 2 = 2" radius

Cylinder Area $= \pi \times 2'' \times 2'' = 3.14 \times 4 \text{ in}^2 = 12.56 \text{ in}^2$

Cylinder Volume $= 12.56 \text{ in}^2 \times 12'' = 150.72 \text{ in}^3$

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

$$= \frac{602.88 \text{ in}^3 \times 10}{231 \text{ in}^3 \text{ per gal}} = \frac{6028.8 \text{ in}^3}{231 \text{ in}^3 \text{ per gal}}$$

$$= 26 \text{ gpm}$$

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 a 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

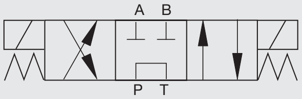
The operation of a valve is described by the flow paths to the circuit ("way"), the number of valve operating positions ("position") and the type of flow path in the center position ("center"). Other characteristics used in describing a valve describe the type of operator used: solenoid, manual lever, 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

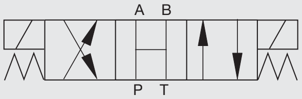
USES: Idles pump in the center position



4 way / 3 position / OPEN Center

CENTER POSITION: All ports to Tank

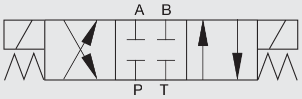
USES: Idles pump in the center position
commonly used with pilot operated check valve



4 way / 3 position / CLOSED Center

CENTER POSITION: All ports blocked

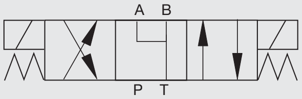
USES: Used in system with multiple valves



4 way / 3 position / FLOAT Center

CENTER POSITION: A & B to to Tank, P blocked

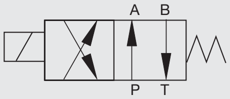
USES: Used in system with mulitple valves with pilot
operated check valves



4 way / 2 position

NO CENTER POSITION

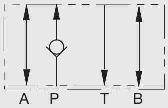
USES: Used in systems where cylinders are always
either advanced or retracted



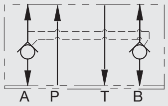
ACCESSORY VALVES

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

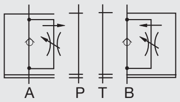
Holding:
Check valve on the pressure port



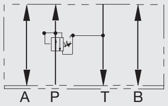
Dual pilot operated check valves on "A" and "B"



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

FORMULA	WORD FORMULA	LETTER FORMULA
FLUID PRESSURE *(pounds per square inch)*	PRESSURE $= \dfrac{\text{force } \textit{(pounds)}}{\text{unit area } \textit{(square inches)}}$	$P = \dfrac{F}{A}$ *or* $psi = \dfrac{F}{A}$
CYLINDER AREA *(square inches)*	AREA $= \pi \times \text{radius}^2 \; \textit{(inches)}$	$A = \pi r^2$
	$= \pi/4 \times \text{diameter}^2 \; \textit{(inches)}$	$A = \dfrac{\pi D^2}{4}$ *or* $A = .785d^2$
CYLINDER FORCE *(pounds, push or pull)*	FORCE $= \text{pressure } \textit{(psi)} \times \text{net area } \textit{(square inches)}$	$F = psi \times A$ *or* $F = PA$
CYLINDER VELOCITY or SPEED *(feet per second)*	VELOCITY $= \dfrac{231 \times \text{flow rate } \textit{(GPM)}}{12 \times 60 \times \text{net area } \textit{(square inches)}}$	$v = \dfrac{231Q}{720A}$ *or* $v = \dfrac{.3208Q}{A}$
CYLINDER VOLUME CAPACITY *(gallons of fluid)*	VOLUME $= \dfrac{\pi \times \text{radius}^2 \textit{ (inches)} \times \text{stroke } \textit{(inches)}}{231}$	$v = \dfrac{\pi r^2 L}{231}$
	$= \dfrac{\text{net area } \textit{(inches)} \times \text{stroke } \textit{(inches)}}{231}$	$v = \dfrac{AL}{231}$ L = *length of stroke*
CYLINDER FLOW RATE *(GPM)*	FLOW RATE $= \dfrac{12 \times 60 \times \text{velocity } \textit{(feet/second)} \times \text{net area } \textit{(square inches)}}{231}$	$Q = \dfrac{720vA}{231}$ *or* $Q = 3.117vA$
FLUID MOTOR TORQUE *(inch pounds)*	TORQUE $= \dfrac{\text{pressure } \textit{(psi)} \times \text{f.m. displacement } \textit{(cu. in./rev.)}}{2\pi}$	$T = \dfrac{psi\, d}{2\pi}$ *or* $T = \dfrac{Pd}{2\pi}$
	$= \dfrac{\text{horsepower} \times 63025}{\text{rpm}}$	$T = \dfrac{63025\, HP}{n}$
	$= \dfrac{\text{flow rate } \textit{(gpm)} \times \text{pressure } \textit{(psi)} \times 36.77}{\text{rpm}}$	$T = \dfrac{36.77QP}{n}$ *or* $T = \dfrac{36.77psi}{n}$
FLUID MOTOR TORQUE /100 psi *(inch pounds)*	TORQUE $= \dfrac{\text{f.m. displacement } \textit{(cu. in./rev.)}}{.0628 \textit{ (cu. in./rev.)}}$	$T_{100psi} = \dfrac{d}{.0628}$
FLUID MOTOR SPEED *(revolutions per minute)*	SPEED $= \dfrac{231 \times \text{flow rate } \textit{(gpm)}}{\text{f.m. displacement}}$	$n = \dfrac{231Q}{d}$
FLUID MOTOR POWER *(horsepower output)*	HORSEPOWER $= \dfrac{\text{torque output } \textit{(inch pounds)} \times \text{rpm}}{63025}$	$HP = \dfrac{Tn}{63025}$
PUMP OUTLET FLOW *(gallons per minute)*	FLOW $= \dfrac{\text{rpm} \times \text{pump displacement } \textit{(cu. in./rev.)}}{231}$	$Q = \dfrac{nD}{231}$
PUMP INPUT POWER *(horsepower required)*	HORSEPOWER INPUT $= \dfrac{\text{flow rate output } \textit{(gpm)} \times \text{pressure } \textit{(psi)}}{1714 \times \text{efficiency } \textit{(overall)}}$	$HP_{IN} = \dfrac{QP}{1714Eff}$ *or* $\dfrac{GPM \times psi}{1714Eff}$
FLOW RATE through PIPING *(additional required oil to reach pressure)*	ADDITIONAL VOLUME $= \dfrac{\text{pressure } \textit{(psi)} \times \text{volume of oil under pressure}}{250{,}000}$	$V_A = \dfrac{PV}{250{,}000}$ *Approx. ½% per 1000 psi*

GAS LAWS for ACCUMULATOR SIZING: Where “P” = **psia** (absolute) = **psig** (gauge pressure) + **14.7 psi**

FORMULA	WORD FORMULA	LETTER FORMULA
PRESSURE or VOLUME *(W/Constant “T”) Temperature*	Original Pressure x Original Volume = Final Pressure x Final Volume	P1V1 = P2V2 [isothermic]
PRESSURE or TEMPERATURE *(W/Constant “V”) Volume*	Original Pressure x Final Temperature = Final Pressure x Original Temperature	P1T2 = P2V1 [isochoric]
VOLUME or TEMPERATURE *(W/Constant “P”) Pressure*	Original Volume x Final Temperature = Final Volume x Original Temperature	V1T2 = V2T1 [isobaric]
PRESSURE or VOLUME *(W/Temperature change due to heat of compression*	Original Temperature x Final Volume ^{n} = Final Pressure x Final Volume ^{n}	$P1V1^n = P2V2^n$
	$\dfrac{\text{Final Temperature}}{\text{Original Temperature}} = \left(\dfrac{\text{Original Volume}}{\text{Final Volume}}\right)^{n-1} = \left(\dfrac{\text{Final Pressure}}{\text{Original Pressure}}\right)^{n-1/n}$	$\dfrac{T2}{T1} = \left(\dfrac{V1}{V2}\right)^{n-1} = \left(\dfrac{P2}{V1}\right)^{n-1/n}$

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

Fluid Power Glossary

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 where 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.

F

FILTER a device whose primary function is the retention by porous media of insoluble contaminants 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.

H

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

I

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.

M

MANIFOLD a conductor which provides multiple connection ports.

MUFFLER a device for reducing gas flow noise.

P

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.

R

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.

S

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.

V

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.

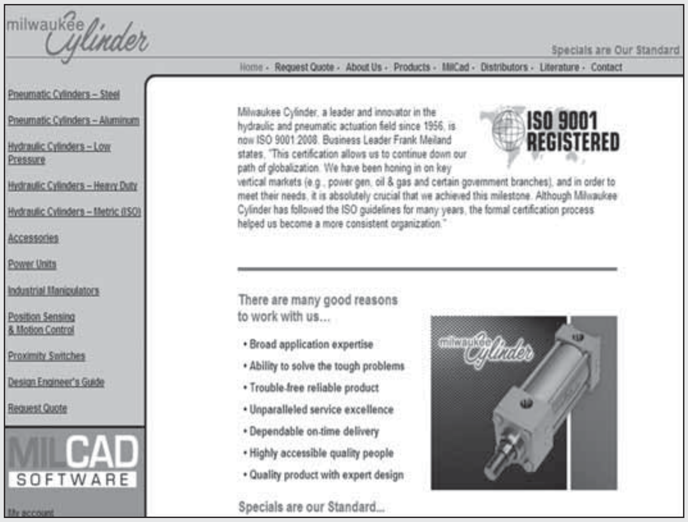
VALVE, SEQUENCE a valve whose primary function is to direct flow in a predetermined sequence.

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.

Terms and definitions are extracted from ANSI Glossary of Terms for Fluid Power with permission of the publisher, National Fluid Power Association, Milwaukee, Wisconsin 53222.



milwaukee Cylinder

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ISO 9001 REGISTERED

Milwaukee Cylinder, a leader and innovator in the hydraulic and pneumatic actuation field since 1956, is now ISO 9001:2008. Business Leader Frank Meiland states, "This certification allows us to continue down our path of globalization. We have been honing in on key vertical markets (e.g., power gen, oil & gas and certain government branches), and in order to meet their needs, it is absolutely crucial that we achieved this milestone. Although Milwaukee Cylinder has followed the ISO guidelines for many years, the formal certification process helped us become a more consistent organization."

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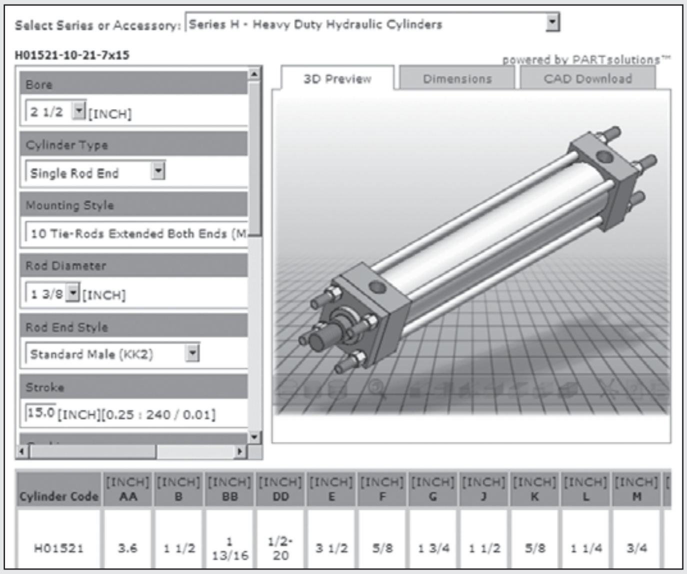

Select Series or Accessory: Series H - Heavy Duty Hydraulic Cylinders

H01521-10-21-7x15

Bore: 2 1/2 [INCH]

Cylinder Type: Single Rod End

Mounting Style: 10 Tie-Rods Extended Both Ends (M

Rod Diameter: 1 3/8 [INCH]

Rod End Style: Standard Male (KK2)

Stroke: 15.0 [INCH][0.25 : 240 / 0.01]

Cylinder Code	[INCH] AA	[INCH] B	[INCH] BB	[INCH] DD	[INCH] E	[INCH] F	[INCH] G	[INCH] J	[INCH] K	[INCH] L	[INCH] M
H01521	3.6	1 1/2	1 13/16	1/2-20	3 1/2	5/8	1 3/4	1 1/2	5/8	1 1/4	3/4

WARRANTY

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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Notes