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CYLINDERS

Function

Cylinders convert hydraulic power into linear motion and force. For this reason, cylinders are often referred to as linear actuators.

Sizing

The linear force generated by a hydraulic cylinder is a product of pressure and effective area, minus inefficiencies (losses). When sizing a cylinder for a specific application the relationships between pressure, area, displacement volume, flow, speed, and the influence of inefficiencies must be considered.

System pressure

The first variable to consider is maximum available system pressure. If modifications are being made to an existing system the maximum working pressure may be constrained by existing components, such as the pump, valving, the power of the prime mover, or other system design considerations. In a new application, the maximum system pressure can be determined at the outset. Factors to consider are cost, component size and weight, duty cycle, reliability and service life. Components for high-pressure systems (3600-6000 psi / 250-400 bar) are generally more expensive than those for normal pressure systems (2100-3500 psi /150-250 bar).

Once nominal system operating pressure has been determined, assuming that the cylinder force and stroke speed required for the application are known, the logical starting point for the calculations is the cylinder's effective area.

Effective area

The force produced by a hydraulic cylinder is a product of its effective area and the differential pressure (Δp) across its ports. It is important to consider that the pressure at the outlet port of a cylinder, such as charge pressure in semi-closed loop circuits, or pressure drop caused by valves, filters, coolers and plumbing in open loop circuits, reduces the effective working pressure and therefore available force. As Δp decreases, output force decreases, assuming effective area remains constant. The effective area required to achieve the desired cylinder force can be calculated using the following formula:

$$A = \frac{F}{\Delta p \times \eta hm}$$

Where

A	=	effective area (in²)
F	=	cylinder force (Ib)
Δp	=	pressure difference across cylinder ports (psi)
ηhm	=	cylinder hydraulic/mechanical efficiency (0.85 – 0.95)

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In metric units

$$A = \frac{F}{\Delta p \times 10 \times \eta hm}$$

Where

A	=	effective area (cm²)
F	=	cylinder force (N)
Δp	=	pressure difference across cylinder ports (bar)
ηhm	=	cylinder hydraulic/mechanical efficiency (0.85 – 0.95)

Cylinder Diameter

Once the effective area has been determined, the required cylinder diameter can be calculated. If the desired force is required from the cylinder in extension i.e. effective area equals piston area, the following formula is used to calculate the piston diameter:

$$D_p = \sqrt{(A \div 0.785)}$$

Where

D_p	=	piston diameter (in)
A	=	effective area (in²)

In metric units

$$D_p = \sqrt{(A \div 0.00785)}$$

Where

D_p	=	piston diameter (mm)
A	=	effective area (cm²)

For double-acting cylinders, if the desired force is required from the cylinder in retraction, i.e. effective area equals annulus area (piston area minus piston rod area), the following formula can be used to calculate the piston diameter:

$$D_p = \sqrt{[(A \div 0.785) + D_r^2]}$$

Where

D_p	=	piston diameter (in)
A	=	effective area (in²)
D_r	=	piston rod diameter (in)

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In metric units

$$D_p = \sqrt{[(A \div 0.00785) + D_r^2]}$$

Where

D_p = piston diameter (mm)
A = effective area (cm²)
D_r = piston rod diameter (mm)

For double-acting cylinders where the primary force is required in extension and the cylinder diameter is selected accordingly, the force available in retraction can be calculated using the following formula:

$$F_z = \Delta p \times (D_p^2 - D_r^2) \times 0.785$$

Where

F_z = retraction force (lbf)
Δp = pressure difference across cylinder ports (psi)
D_p = piston diameter (in)
D_r = piston rod diameter (in)

In metric units

$$F_z = \Delta p \times (D_p^2 - D_r^2) \times 0.0785$$

Where

F_z = retraction force (N)
Δp = pressure difference across cylinder ports (bar)
D_p = piston diameter (mm)
D_r = piston rod diameter (mm)

Before confirming cylinder selection, check that the required force is developed within the manufacturer's maximum permissible working pressure.

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Cylinder speed and flow rate

Once the cylinder's piston and rod diameter have been determined, in relation to the required force and available pressure, the required cylinder stroke speed will determine the flow rate required. The maximum recommended stroke speed for most applications is 1.65 ft/sec (0.5 m/s). Stroke speed can be calculated using the following formula:

$$v = L \div t$$

Where

v	=	stroke speed (in/sec)
L	=	cylinder stroke length (in)
t	=	time allowed to stroke cylinder (seconds)

In metric units

$$v = L \div t$$

Where

v	=	stroke speed (m/sec)
L	=	cylinder stroke length (m)
t	=	time allowed to stroke cylinder (seconds)

Once the stroke speed has been determined, the flow rate required to achieve the desired stroke speed can be calculated using the following formula:

$$Q = A \times v \times 0.2597 \div \eta vol$$

Where

Q	=	flow rate required (USgpm)
A	=	effective area (in²)
v	=	stroke speed (in/sec)
ηvol	=	cylinder volumetric efficiency (0.95)

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In metric units

$Q = A \times v \times 6 \div \eta vol$

Where

Q	=	flow rate required (litres/min)
A	=	effective area (cm²)
v	=	stroke speed (m/sec)
ηvol	=	cylinder volumetric efficiency (0.95)

Effective force

In applications where cylinder thrust is at an angle of less than 90° to the load, effective cylinder force is less than nominal force and can be calculated using the following formula:

$F_e = F_n \times \sin \propto$

Where

F_e	=	effective force in pounds or Newtons
F_n	=	nominal force in pounds or Newtons
$\propto$	=	minimum acute working angle

Rod diameter selection

A cylinder operating in extension is subjected to inflection forces as the cylinder rod is compressed. The maximum force a cylinder rod can sustain without bending is influenced by stroke length, rod material and diameter, and cylinder mounting arrangement.

The nomogram on the next page can be used to find the maximum length (L_m) for steel rods for a known cylinder force and rod diameter. Note that the maximum rod length read off the nomogram must be adjusted by a factor that takes into account the mounting arrangement of the cylinder according to the table on the following page.

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Mounting Arrangement			**Permissible Length**
Dead (rear) end	**Gland (front) end**	**Rod end**	
eye or clevis		eye or clevis	$L_m \times 0.3$
rigid	rigid	eye or clevis	$L_m \times 0.8$
rigid	rigid	rigid	L_m
	rigid	eye or clevis	$L_m \times 0.8$
	rigid	rigid	L_m
rigid		eye or clevis	$L_m \times 0.4$
rigid		rigid	$L_m \times 0.8$
trunnion		eye or clevis	$L_m \times 0.3$
	trunnion	eye or clevis	$L_m \times 0.6$
	trunnion	rigid	$L_m \times 0.8$

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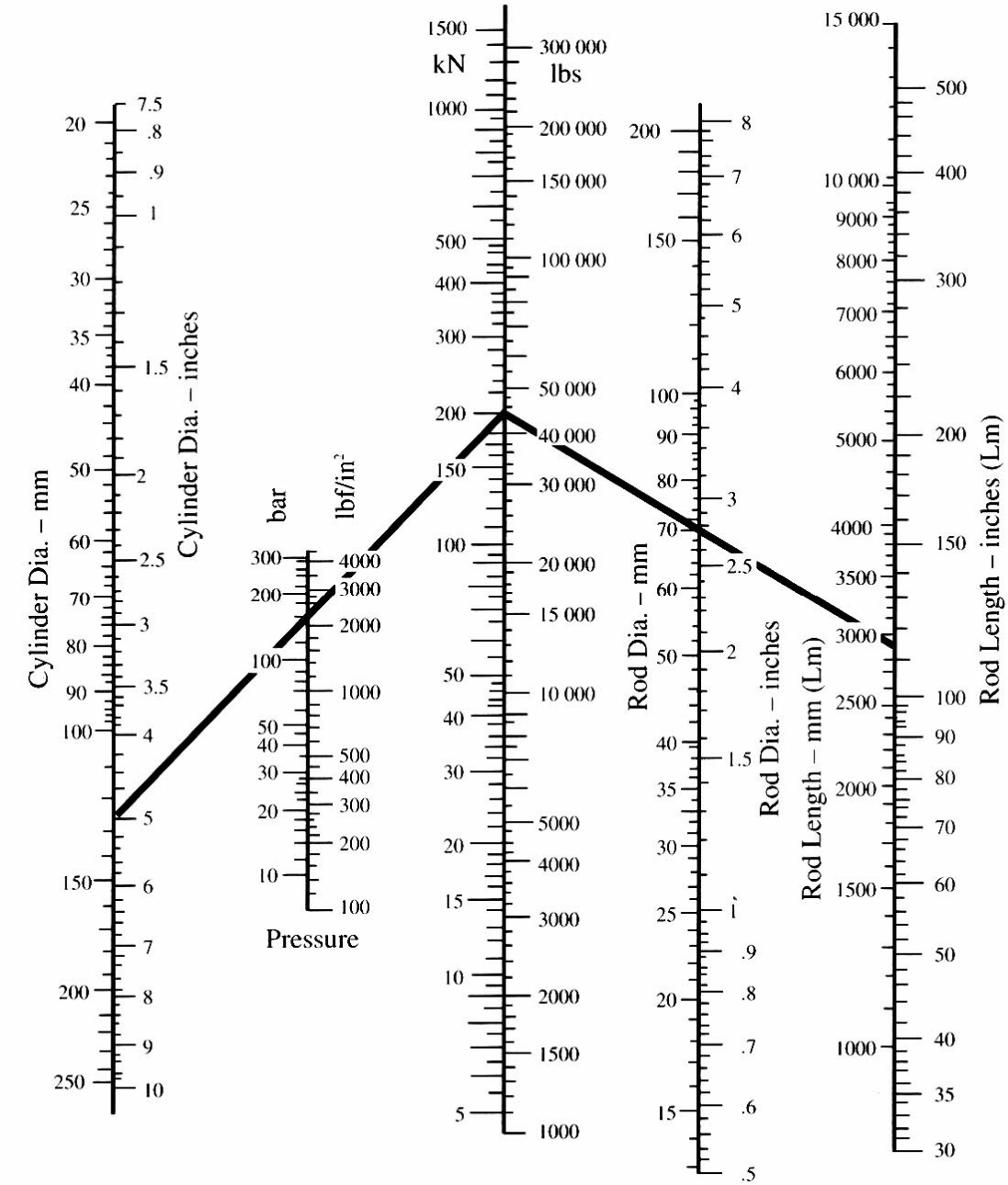

Cylinder output force and maximum rod length

(Note: Rod length read off nomogram must be adjusted by a factor that takes into account the mounting arrangement of the cylinder. Refer to the table on the previous page).

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