

Air Preparation Units

| Symbol | Description |
|--------|--------------------------------------------------------------------|
| | Filter / Separator with manual drain |
| | Filter / Separator with automatic drain |
| | Oil Removal Filter |
| | Automatic Drain |
| | Lubricator less drain |
| | Lubricator with manual drain |
| | Lubricator with automatic filling |
| | Air Line Pressure Regulator adjustable, relieving |
| | Air Line Pressure Regulator pilot controlled, relieving |
| | Filter / Regulator (piggyback) manual drain relieving (with gauge) |
| | Filter / Regulator (piggyback) auto drain relieving |
| | Air Line Combo F-R-L simplified |

Pneumatic Valves

| Symbol | Description |
|--------|----------------------------|
| | Check |
| | Flow Control |
| | Relief Valve |
| | 2-Position, 2-Way |
| | 2-Position, 3-Way |
| | 2-Position, 4-Way |
| | 2-Position, 4-Way 5-Ported |

Pneumatic Valves

| Symbol | Description |
|--------|----------------------------------------------------------------------------------|
| | 3-Position, 4-Way, APB ports closed, center pos. |
| | 3-Position, 4-Way, CE 5-Ported cylinder ports open to exhaust in center position |
| | 3-Position, 4-Way, PC 5-Ported pressure ports open to exhaust in center position |
| | Quick Exhaust |
| | Shuttle |

Valve Actuators

| Symbol | Description |
|--------|--------------------------------------------------------------------|
| | Manual general symbol |
| | Push Button |
| | Lever |
| | Pedal or Treadle |
| | Mechanical cam, toggle, etc. |
| | Spring |
| | Detent line indicates which detent is in use |
| | Piezo |
| | Solenoid |
| | Internal Pilot Supply |
| | Remote Pilot Supply |
| | And / Or Composite solenoid and pilot or manual override |
| | And / Or Composite solenoid and pilot or manual override and pilot |

Cylinders

| Symbol | Description |
|--------|------------------------|
| | Standard double acting |
| | Single Acting |
| | Double Rod |
| | Spring Return |
| | Ram Type |
| | Telescope |
| | Tandem |
| | Duplex |

Lines and Functions

| Symbol | Description |
|--------|--------------------------------------------------------|
| | Solid Line - Main Line |
| | Dashed Line - Pilot Line |
| | Dotted Line - Exhaust or Drain Line |
| | Center Line - Enclosure Outline |
| | Lines Crossing (90° intersection not necessary) |
| | Lines Joining (90° intersection not necessary) |
| | Lines Joining |
| | Flow Direction hydraulic medium |
| | Flow Direction gaseous medium |
| | Energy Source |
| | Line with Fixed Restriction |
| | Line with Adjustable Restriction |
| | Flexible Line |
| | Plugged Port, Test Station, Power Take-off |
| | connected/disconnected Quick Disconnect Without Checks |
| | connected/disconnected Quick Disconnect With Checks |
| | connected/disconnected Quick Disconnect With One Check |

Design Torque

Design torque represents the maximum torque that an actuator must supply in an application. This maximum is the greater of the Demand Torque or the Cushion Torque. If the demand torque exceeds what the actuator can supply, the actuator will either move too slowly or stall. If the cushion torque is too high, the actuator may be damaged by excessive pressure. Demand torque and cushion torque are defined below in terms of load, friction, and acceleration torque.

Equations for calculating demand torque and cushion torque for some general applications are provided on the following pages.

T - Torque

The amount of turning effort exerted by a rotary actuator.

TD - Demand Torque

This is the torque required from the actuator to do the job and is the sum of the load torque, friction torque, and acceleration torque, multiplied by an appropriate design factor. Design factors vary with the applications and the designers' knowledge.

$$\text{Equation 4-3) } TD = Ta + Tf + TL$$

TL - Load torque

This is the torque required to equal the weight or force of the load. For example, in Fig. 4-8a, the load torque is 563 Nm (5000 lb-in.); in Fig. 4-8b the load torque is zero; in Fig. 4-8c the load torque is 563 Nm (5000 lb-in.). The load torque term is intended to encompass all torque components that aren't included in the friction or acceleration terms.

Tf - Friction torque

This is the torque required to overcome friction between any moving parts, especially bearing surfaces. In Fig. 4-8a, the friction torque is zero for the hanging load; in Fig. 4-8b the friction torque is 775 Nm (6880 lb-in) for the sliding load; in Fig. 4-8c the friction torque is zero for the clamp.

$$\text{Equation 4-4) } Tf = mWr$$

Ta - Acceleration Torque

This is the torque required to overcome the inertia of the load in order to provide a required acceleration or deceleration. In Fig. 4-8a the load is suspended motionless so there is no acceleration. In Fig. 4-8b, the load is accelerated from 0 to some specified angular velocity. If the mass moment of inertia about the axis of rotation is I and the angular acceleration is a, the acceleration torque is equal to Ia. In Fig. 4-8c there is no acceleration.

Some values for mass moment of inertia are given in Table 4. Some useful equations for determining a are listed in Table 5. Equation 5 below shows the general equation for acceleration torque.

$$\text{Equation 4-5) } Ta = Ia$$

TC - Cushion Torque

This is the torque that the actuator must apply to provide a required deceleration. This torque is generated by restricting the flow out of the actuator (meter-out) so as to create a back pressure which decelerates the load. This back pressure (deceleration) often must overcome both the inertia of the load and the driving pressure (system pressure) from the pump. See applications.

$$\text{Equation 4-6) } Tc = Ta + \frac{PrV}{\theta} - Tf \pm TL$$

The friction torque Tf reduces the torque the actuator must apply to stop the load. The load torque TL may add to, or subtract from the torque required from the actuator, depending upon the orientation of the load torque. For example, a weight being swung upward would result in a load torque that is subtracted.

Warning: Rapid deceleration can cause high pressure intensification at the outlet of the actuator. Always insure that cushion pressure does not exceed the manufacturer's pressure rating for the actuator.

KE - Kinetic Energy (1/2 Jmω²)

This is the amount of energy that a rotating load has. The rotator must be able to stop the load. All products have kinetic energy rating tables. Choose the appropriate deceleration option (i.e., bumper, cushions, shock absorbers, etc.) that meets or exceeds the kinetic energy of the load.

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Rotary Actuator Torque Requirements
Demand Torque Examples

A) Example of load torque

The load is held motionless as shown.

$$T_D = T_\alpha + T_f + T_L$$

$$T_\alpha = 0$$

$$T_f = 0$$

$$T_L = (500 \text{ lb})(10 \text{ in}) = 5,000 \text{ lb-in}$$

$$T_D = 5,000 \text{ lb-in}$$

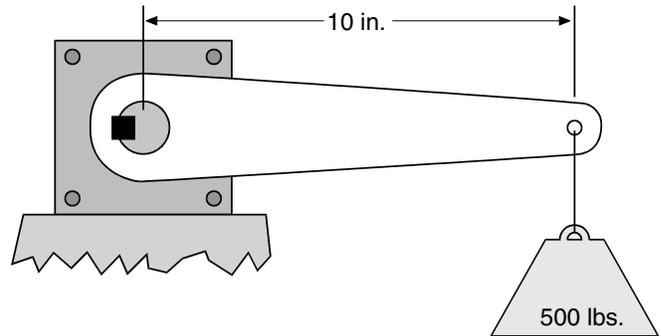


Figure 4-8a

B) Due to friction and acceleration

The 500 lb rotating index table is supported by bearings with a coefficient of friction of 0.25. The table's acceleration a is 2 rad/sec². The table's mass moment of inertia I is 2,330 lb-in-sec².

$$T_D = T_\alpha + T_f + T_L$$

$$T_\alpha = I\alpha = (2,330 \text{ lb-in-sec}^2)(2/\text{sec}^2) = 4,660 \text{ lb-in}$$

$$T_f = \mu W r_b = 0.25 (500 \text{ lb})(55 \text{ in}) = 6,880 \text{ lb-in}$$

$$T_L = 0$$

$$T_D = 4,660 \text{ lb-in} + 6,880 \text{ lb-in} = 11,540 \text{ lb-in}$$

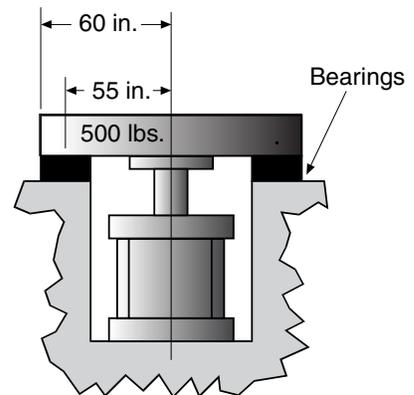


Figure 4-8b

C) Load torque example

$$T_D = T_\alpha + T_f + T_L$$

$$T_\alpha = 0$$

$$T_f = 0$$

$$T_L = (500 \text{ lb})(10 \text{ in}) = 5,000 \text{ lb-in}$$

$$T_D = 5,000 \text{ lb-in}$$

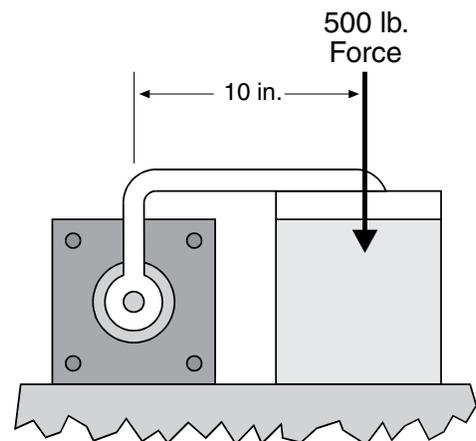


Figure 4-8c

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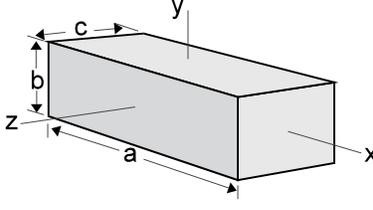
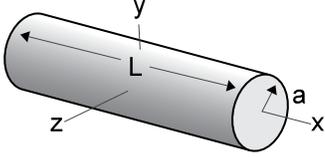
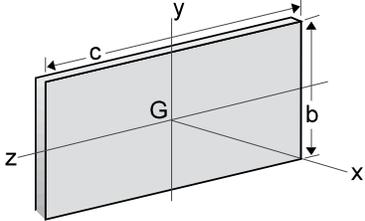
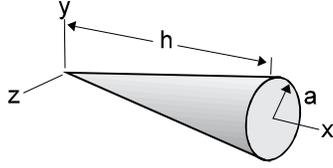
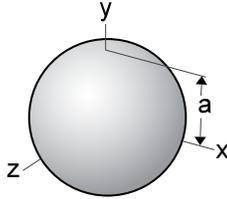
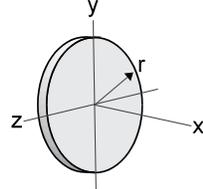
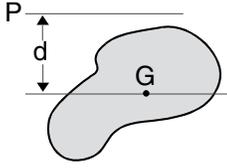
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Rotary Actuator Moments of Inertia
Table 4: Mass Moments of Inertia

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|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>Rectangular prism</p> $I_x = \frac{1}{12}m(b^2 + c^2)$ $I_y = \frac{1}{12}m(c^2 + a^2)$ $I_z = \frac{1}{12}m(a^2 + b^2)$  | <p>Circular cylinder</p> $I_x = \frac{1}{2}ma^2$ $I_y = I_z = \frac{1}{12}m(3a^2 + L^2)$  |
| <p>Thin rectangular plate</p> $I_x = \frac{1}{12}m(b^2 + c^2)$ $I_y = \frac{1}{12}mc^2$ $I_z = \frac{1}{12}mb^2$  | <p>Circular cone</p> $I_x = \frac{3}{10}ma^2$ $I_y = I_z = \frac{3}{5}m\left(\frac{1}{4}a^2 + h^2\right)$  |
| <p>Sphere</p> $I_x = I_y = I_z = \frac{2}{5}ma^2$  | <p>Thin disk</p> $I_x = \frac{1}{2}mr^2$ $I_y = I_z = \frac{1}{4}mr^2$  |
| <p>Parallel Axis Theorem:</p> $I_p = I + md^2$  | <p>I_p = Mass moment of inertia about an axis parallel to a centroidal axis I = Mass moment of inertia about a centroidal axis m = Mass d = Distance between axes</p> |
| <p>When acceleration is constant:</p> $\theta = \omega_0 t + \frac{1}{2} \alpha t^2$ $\alpha = \frac{2\theta}{t^2}$ $\theta = \omega_0 t + \frac{1}{2} \omega_t t$ $\alpha = \frac{(\omega_t - \omega_0)^2}{2\theta}$ $\omega = \omega_0 + \alpha t$ $\alpha = \frac{(\omega_t - \omega_0)}{t}$ $\omega = (\omega_0^2 + 2\alpha\theta)^{1/2}$ | <p>When velocity is constant:</p> $\theta = \omega t$ <p>t = time θ = angular position ω_t = angular velocity at time = t ω_0 = angular velocity at time = 0 α = angular acceleration</p> |

Rotary Actuator Basic Equations
Basic Velocity, Acceleration, Kinetic Energy And Torque Equations

Equations below are based on triangular velocity profile.

$$\omega_{\max} = .035 \times \frac{\Theta}{t}$$

$$\alpha = \frac{\omega_{\max}^2}{\left(\frac{\Theta}{57.3}\right)}$$

$$\alpha = \frac{\omega_{\max}}{(t/2)}$$

$$K.E. = 1/2 J_m \omega^2$$

$$T_a = \alpha \times J_m$$

$$T_f = W \times U_s \times \left(\text{Distance from pivot point to center of external bearings} \right)$$

$$T_L = \left(\text{Torque arm length to C.G. of load} \right) \times WL \times \cos(\phi)$$

Where ϕ = Angle between torque arm and horizontal plane

Where:

Θ = Angle of Rotation (Degrees)

t = Time to rotate through Θ (sec)

ω = Angular velocity, radians/sec

α = Angular accelerations (radians/sec²)

WL = Weight of load (lbf)

T_a = Torque to accelerate load (lb-in)

U_s = Coefficient of static friction

J_m* = Rotational mass moment of inertia (lb-in-sec²)

T_f = Torque to overcome friction (lb-in)

T_L = Torque to overcome effects of gravity

*Use "I" values from Table 4.

Coefficients of Friction

| Material* | μ_s | μ_k |
|-----------------------------|---------|---------|
| Steel on Steel | 0.80 | 0.40 |
| Steel on Steel (lubricated) | 0.16 | 0.03 |
| Aluminum on Steel | 0.45 | 0.30 |
| Copper on Steel | 0.22 | 0.22 |
| Brass on Steel | 0.35 | 0.19 |
| Teflon on Steel | 0.04 | 0.04 |

*dry contact unless noted

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Selecting the proper vacuum cup

CAUTION:
 Selecting the type of vacuum cup, material, and size suitable for an application is important to the overall vacuum system. Calculating the forces involved for each application is recommended to determine the vacuum cup size. It should be noted that these calculations are basic theoretical guidelines and each application must be tested for actual results. With all vacuum applications, certain practical assumptions concerning cup materials, environmental conditions, and product characteristics to name a few, may not be consistent with the performance. Again, the user should determine the efficiency, performance, and safety factor of the cup selection.

Calculating pad diameter and forces

Mass
 The term mass is a quantity of matter and its ability to resist motion when acted on by an external force. The magnitude of an object is represented as a certain number of kilograms (kg) and is symbolized as “m”. The easiest way to determine the mass of an object is to measure the weight with a scale within the earth’s gravitational field ($a_g = 9.81\text{m/sec}^2$). Likewise, outside of any gravitational field, a mass could potentially be weightless.

Forces
 For vacuum applications, force is a vector quantity in a defined direction either horizontal or vertical. The standard international unit of force is measured in Newtons (N) which is the equivalent of (kgm/sec^2). The force can be calculated by measuring the effect of a change in acceleration on a mass.

Newton’s Law: $F(N) = \text{mass}(\text{kg}) \times a_g(\text{m/sec}^2)$
 Consider an object with a mass of 10kg. The gravitational force on this object would be:
 $F(N) = 10\text{kg} \times 9.81\text{m/sec}^2 = 98.1 \text{ N}$

Acceleration
 Acceleration is the change in velocity of a moving object. Acceleration is a vector, a directional quantity expressed in units of meters per second squared (m/sec^2) and symbolized as “a”. To explain the magnitude of acceleration consider an object with a change in velocity of 2 meters per second (m/sec) over a 4 second time frame. The acceleration can be calculated with:

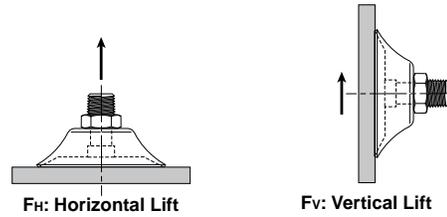
$$a = \frac{\Delta \text{ velocity}}{\text{time}} \quad a = \frac{6\text{m/sec}}{2 \text{ sec}} \quad a = 3\text{m/sec}^2$$

This is considered an average acceleration.

Coefficient of friction
 Certain values for coefficient of friction should be taken into consideration when calculating the combined forces in motion. Actual values between suction cups and surfaces are difficult to determine. Therefore, coefficient of friction values from published charts, should be used as a reference to adjust the safety factors accordingly.

Lifting forces

When calculating lifting forces, safety factors of 2 for horizontal lifts and 4 for vertical lifts are minimum values. Applications with irregular shapes, difficult surfaces, and backward motions will require increased safety factors.



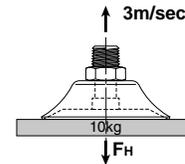
Horizontal lifting force

Apply Newton’s Law to calculate the force on a 10kg mass with a change in acceleration of 3m/sec^2 and a safety factor of 2.

$$F_H(N) = \text{mass}(\text{kg}) \times (a_g + a) \times \text{Sf}$$

$$F_H(N) = 10\text{kg} \times (9.81\text{m/sec}^2 + 3\text{m/sec}^2) \times 2$$

$$F_H = 256.2 \text{ N}$$



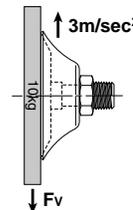
Vertical lifting force

Apply Newton’s Law to calculate the force on a 10kg mass with a dry surface, a change in acceleration of 3m/sec^2 and a safety factor of 4.

$$F_V(N) = \text{mass}(\text{kg}) \times (a_g + a) \times \text{Sf}$$

$$F_V(N) = 10\text{kg} \times (9.81\text{m/sec}^2 + 3\text{m/sec}^2) \times 4$$

$$F_V = 512.4 \text{ N}$$



Combined vertical lift and horizontal motion

Calculate the force on a 10kg mass with a dry surface, a change in acceleration of 3m/sec^2 , and a change in travel acceleration of 2m/sec^2 .

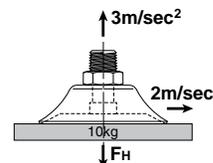
$$F_M(N) = \sqrt{F_V^2 + F_H^2}$$

$$F_M(N) = \sqrt{[(10\text{kg} \times 2\text{m/sec}^2) \times 4]^2 + [10\text{kg} \times (9.81\text{m/sec}^2 + 3\text{m/sec}^2) \times 2]^2}$$

$$F_M(N) = \sqrt{(80\text{kgm/sec}^2)^2 + [256\text{kgm/sec}^2]^2}$$

$$F_M(N) = \sqrt{6400\text{kgm/sec}^2 + 65,536\text{kgm/sec}^2}$$

$$F_M = 268.2 \text{ N}$$



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Analyze the forces

Using the previous examples, consider an application where 4 cups have been selected to transfer the product.

Take the Horizontal Lifting Force (FH) of 256.2 N and divide by the number of cups (4) to obtain the individual force for each cup.

$$\frac{256.2 \text{ (N)}}{4} = 64.05 \text{ N / Cup}$$

Referring to the chart below, at 60% vacuum, select a force greater than 64.05 N. The appropriate selection is a 40mm diameter cup which has a theoretical lifting force of 76.9 N.

The same calculation can be applied to the Vertical Lifting Force and the Forces in Motion examples to determine the cup diameter.

To convert Pounds (lbf) to Newton (N), multiply lbf x 4.4.

Theoretical lifting force per cup lbf (N)

| Cup | | Vacuum level | | | | | | | | |
|-------------|----------------------|---------------|---------------|---------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Diameter mm | Area cm ² | 3 inHg | 6 inHg | 9 inHg | 12 inHg | 15 inHg | 18 inHg | 21 inHg | 24 inHg | 27 inHg |
| | | -1.5 PSIG | -3 PSIG | -4.5 PSIG | -6 PSIG | -7.5 PSIG | -9 PSIG | -10.5 PSIG | -12 PSIG | -13.5 PSIG |
| | | 10.2 kPa | 20.3 kPa | 30.5 kPa | 40.6 kPa | 50.8 kPa | 61 kPa | 71.1 kPa | 81.3 kPa | 91.4 kPa |
| | | 10% | 20% | 30% | 40% | 50% | 60% | 70% | 80% | 90% |
| 1.5 | 0.01 | 0.004 (0.02) | 0.008 (0.04) | 0.008 (0.04) | 0.014 (0.06) | 0.018 (0.08) | 0.022 (0.10) | 0.026 (0.12) | 0.032 (0.14) | 0.032 (0.14) |
| 2 | 0.03 | 0.007 (0.03) | 0.013 (0.06) | 0.022 (0.10) | 0.029 (0.13) | 0.036 (0.16) | 0.043 (0.19) | 0.049 (0.22) | 0.056 (0.25) | 0.063 (0.28) |
| 3.5 | 0.10 | 0.022 (0.10) | 0.045 (0.20) | 0.065 (0.29) | 0.088 (0.39) | 0.110 (0.49) | 0.133 (0.59) | 0.155 (0.69) | 0.175 (0.78) | 0.198 (0.88) |
| 5 | 0.20 | 0.045 (0.20) | 0.090 (0.40) | 0.135 (0.60) | 0.180 (0.80) | 0.225 (1.00) | 0.270 (1.20) | 0.315 (1.40) | 0.360 (1.60) | 0.405 (1.80) |
| 6 | 0.28 | 0.065 (0.29) | 0.130 (0.58) | 0.196 (0.87) | 0.270 (1.20) | 0.315 (1.40) | 0.382 (1.70) | 0.450 (2.00) | 0.517 (2.30) | 0.585 (2.60) |
| 7 | 0.39 | 0.088 (0.39) | 0.175 (0.78) | 0.265 (1.18) | 0.360 (1.60) | 0.450 (2.00) | 0.540 (2.40) | 0.607 (2.70) | 0.697 (3.10) | 0.787 (3.50) |
| 8 | 0.50 | 0.117 (0.52) | 0.229 (1.02) | 0.346 (1.54) | 0.450 (2.00) | 0.585 (2.60) | 0.697 (3.10) | 0.809 (3.60) | 0.922 (4.10) | 1.034 (4.60) |
| 10 | 0.79 | 0.180 (0.80) | 0.360 (1.60) | 0.540 (2.40) | 0.719 (3.20) | 0.899 (4.00) | 1.079 (4.80) | 1.259 (5.60) | 1.439 (6.40) | 1.619 (7.20) |
| 15 | 1.77 | 0.404 (1.80) | 0.809 (3.60) | 1.216 (5.41) | 1.619 (7.20) | 2.023 (9.00) | 2.428 (10.8) | 2.833 (12.6) | 2.237 (14.4) | 3.642 (16.2) |
| 18 | 2.55 | 0.585 (2.60) | 1.169 (5.20) | 1.751 (7.79) | 2.338 (10.4) | 2.923 (13.0) | 3.507 (15.6) | 4.069 (18.1) | 4.676 (20.8) | 5.238 (23.3) |
| 20 | 3.14 | 0.719 (3.20) | 1.439 (6.40) | 2.158 (9.60) | 2.878 (12.8) | 3.597 (16.0) | 4.316 (19.2) | 5.036 (22.4) | 5.755 (25.6) | 6.474 (28.8) |
| 25 | 4.91 | 1.124 (5.00) | 2.248 (10.0) | 3.372 (15.0) | 4.496 (20.0) | 5.620 (25.0) | 6.744 (30.0) | 7.868 (35.0) | 8.992 (40.0) | 10.116 (45.0) |
| 30 | 7.07 | 1.619 (7.20) | 3.237 (14.4) | 4.856 (21.6) | 6.474 (28.8) | 8.093 (36.0) | 9.712 (43.2) | 11.330 (50.4) | 12.949 (57.6) | 14.568 (64.8) |
| 35 | 9.62 | 2.203 (9.80) | 4.406 (19.6) | 5.598 (29.4) | 8.813 (39.2) | 11.016 (49.0) | 13.241 (58.9) | 15.422 (68.6) | 17.648 (78.5) | 19.828 (88.2) |
| 40 | 12.6 | 2.900 (12.9) | 5.755 (25.6) | 8.655 (38.5) | 11.510 (51.2) | 14.388 (64.0) | 17.288 (76.9) | 20.143 (89.6) | 23.155 (103) | 25.853 (115) |
| 50 | 19.6 | 4.519 (20.1) | 8.992 (40.0) | 13.511 (60.1) | 17.985 (80.0) | 22.481 (100) | 26.977 (120) | 31.473 (140) | 35.969 (160) | 40.466 (180) |
| 60 | 28.3 | 6.497 (28.9) | 12.949 (57.6) | 19.446 (86.5) | 25.853 (115) | 32.372 (144) | 38.892 (173) | 45.411 (202) | 51.931 (231) | 58.226 (259) |
| 75 | 44.2 | 10.161 (45.2) | 20.233 (90.0) | 30.349 (135) | 40.466 (180) | 50.582 (225) | 60.698 (270) | 70.815 (315) | 80.931 (360) | 91.048 (405) |
| 80 | 50.3 | 11.555 (51.4) | 22.931 (102) | 34.621 (154) | 46.086 (205) | 57.551 (256) | 69.241 (308) | 80.706 (359) | 92.172 (410) | 103.637 (461) |
| 90 | 63.6 | 14.635 (65.1) | 29.225 (130) | 43.838 (195) | 58.226 (259) | 72.838 (324) | 87.451 (389) | 102.063 (454) | 116.676 (519) | 131.064 (583) |
| 95 | 70.9 | 16.299 (72.5) | 32.372 (144) | 48.784 (217) | 64.970 (289) | 81.156 (361) | 97.567 (434) | 113.753 (506) | 129.940 (578) | 146.126 (650) |
| 110 | 95.0 | 21.851 (97.2) | 43.613 (194) | 65.419 (291) | 87.001 (387) | 108.808 (484) | 130.614 (581) | 152.421 (678) | 174.227 (775) | 195.809 (871) |
| 120 | 113.1 | 26.078 (116) | 51.706 (230) | 77.784 (346) | 103.637 (461) | 129.490 (576) | 155.568 (692) | 181.421 (807) | 207.274 (922) | 233.127 (1037) |
| 150 | 176.7 | 40.690 (181) | 80.931 (360) | 121.622 (541) | 161.862 (720) | 202.328 (900) | 243.019 (1081) | 283.259 (1260) | 323.950 (1441) | 364.191 (1620) |
| 200 | 314.2 | 72.164 (321) | 143.878 (640) | 216.041 (961) | 287.531 (1279) | 359.919 (1601) | 432.083 (1922) | 503.797 (2241) | 575.961 (2562) | 647.449 (2880) |

Calculate the diameter of the cup

Calculate the cup diameter for horizontal lift at 60% of full vacuum using the information from the previous page.

$$D = 35.7 \sqrt{\frac{m (a_g + a) \times S}{P_v \times n}}$$

D (mm) = Diameter of Cup
m (kg) = Mass

$a_g = 9.81 \text{ m/sec}^2$

a = Motion Acceleration

S = Safety Factor

P_v (kPa) = Operating Vacuum Pressure

n = number of Cups

$$D = 35.7 \sqrt{\frac{10 (9.81 + 3) \times 2}{61 \times 4}}$$

D = 36.58 mm

Referring to the chart below, at 60% vacuum, select a cup diameter equal to or greater than 37mm. The appropriate selection is a 40mm diameter cup which has a theoretical lifting force of 76.9 N.

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Selecting a generator size

The choice of Generator Series depends on the system requirements for components and overall performance for the application. Inline Generators offer the basic function for creating vacuum flow. Adding integrated components such as automatic blow off Controls, Vacuum and Blow-off Solenoids, Pressure Sensors, Check Valves and Filters are options that can reduce overall mounting space, reduce cycle time and can offer air conservation functions as well as emergency stop modes. For guidelines on selecting Vacuum Generators by features, consult the highlight features in the Generator Index section for each Series Section.

A vacuum source can only achieve and hold a degree of vacuum that sustains the amount of leakage into the vacuum system. In most cases, it is the leakage through the product and by of the cup seal that limits the system degree of vacuum. Products with high product leakage are Porous Applications. The degree of vacuum that can be obtained with this type of product can vary and tends to be below 10 inHg. Products with low or no leakage are called Non-Porous Applications. It can be assumed that the maximum degree of vacuum of the system is the maximum degree of the vacuum generator. Due to design cycle time and safety requirements, a lower degree of vacuum is generally chosen other than the maximum obtainable degree of vacuum. Chart 1 lists different units of measure for vacuum with typical application levels. The system degree of vacuum must be determined by product testing.

Evacuation time

The size of the generator generally refers to either the Evacuation Time or the Vacuum Flow Rates of the generator and varies by the size of the nozzle / diffuser.

Evacuation Time is the time required to evacuate the air out of a vacuum system to specific degree of vacuum. Typically, this degree of vacuum is a value where it is safe to move a product in a pick and place application and is determined by the design engineer. Evacuation Time can also be considered response time of the system.

A typical Evacuation Time chart for a generator series is shown in Chart 2. The time to achieve a given degree of vacuum in a 1 cubic foot volume is listed in seconds for each Generator.

Chart 1: Basic vacuum pressure measurements units

| Negative gauge pressure PSIG | Absolute pressure PSIA | Inches of mercury inHg |
|-------------------------------------------------|------------------------|------------------------|
| 0 | 14.7 | 0 |
| Atmospheric pressure at sea level | | |
| -1.5 | 13.2 | 3 |
| -3.0 | 11.7 | 6 |
| -4.5 | 10.2 | 9 |
| Typical porous vacuum level | | |
| -6.0 | 8.7 | 12 |
| -7.5 | 7.2 | 15 |
| -9.0 | 5.7 | 18 |
| -10.5 | 4.2 | 21 |
| Typical non-porous vacuum level | | |
| -12.0 | 2.7 | 24 |
| -13.5 | 1.2 | 27 |
| -14.7 | 0 | 29.92 |
| Perfect vacuum (zero reference pressure) | | |

Example: A pick and place application requires a 0.25 secs for creation of 18 inHg of vacuum in the vacuum system. The vacuum system volume, which includes tubing and cups, is 0.002 ft³.

The evacuation time charts are given for a 1 cubic foot (ft³) volume. To use these charts, convert the time requirement of the system to an equivalent time for a 1 cubic foot (ft³) volume. In this example, 1 cubic foot (ft³) is 500 times the system volume of 0.002 ft³. Multiply the system time requirement by 500 (500 x 0.25 secs = 125 seconds). Any generator with a evacuation time of less than 125 seconds to attain 18 inHg can be chosen for this application. A CV-15-HS will meet the requirements for this application. A (-) listed means the generator will not obtain a higher degree of vacuum than the level of the first (-).

Chart 2: evacuation time

| Series / nozzle diameter | Air supply pressure PSI | Air consumption SCFM | Evacuation time in sec / ft ³ * to reach different vacuum levels (inHg) | | | | | | | | |
|--------------------------|-------------------------|----------------------|------------------------------------------------------------------------------------|------|-------|-------|-------|-------|-------|-------|-------|
| | | | 3 | 6 | 9 | 12 | 15 | 18 | 21 | 24 | 27 |
| CV-05HS | 70 | 0.46 | 24.3 | 57.3 | 101.0 | 160.5 | 231.1 | 305.1 | 433.1 | 597.7 | — |
| CV-05LS | 70 | 0.46 | 11.0 | 23.4 | 40.0 | 64.4 | 110.2 | — | — | — | — |
| CV-10HS | 70 | 1.55 | 4.8 | 9.9 | 16.0 | 24.9 | 35.9 | 51.4 | 77.4 | 117.5 | 226.0 |
| CV-10LS | 70 | 1.55 | 3.7 | 7.6 | 13.0 | 20.3 | 33.1 | — | — | — | — |
| CV-15HS | 70 | 3.53 | 2.5 | 4.8 | 7.0 | 11.0 | 15.5 | 22.0 | 31.9 | 46.6 | 112.1 |
| CV-15LS | 70 | 3.53 | 2.0 | 3.1 | 5.0 | 7.6 | 12.1 | — | — | — | — |
| CV-20HS | 70 | 6.36 | 1.7 | 2.8 | 5.0 | 6.5 | 9.0 | 13.0 | 18.9 | 27.4 | 60.7 |
| CV-20LS | 70 | 6.36 | 1.3 | 2.5 | 4.0 | 5.9 | 11.3 | — | — | — | — |

* 1 ft³ = 28.31 liters

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Vacuum flow

A typical Vacuum Flow chart for a generator series is listed in Chart 3. The vacuum flow rate at given degree of vacuum is listed in SCFM for each Generator. This chart is generally used to determine the change of degree of vacuum given a change in vacuum flow rate of a generator.

Example. A CV-15HS can only obtain 9 inHg. The vacuum flow rate at 9 inHg is 1.50 SCFM. This means that the cup

seal and product leaks 1.50 SCFM of air. This generator can maintain the leak rate of 1.50 SCFM. Choosing a generator with more flow at 9 inHg will increase the degree of vacuum in the system because the generator can overcome more leakage. In this case, the vacuum flow rates are linear since this CV generator is a single stage venturi generator. Replacing a CV-15HS with CV-20HS will increase the degree of vacuum in the system to approximately 16.2 inHg. The CV-20HS now maintains 16.2 inHg at a flow rate of 1.50 SCFM.

Chart 3: Vacuum flow (SCFM)

| Nozzle diameter | inHg | | | | | | | | | | |
|-----------------|------|------|------|------|------|------|------|-----|-----|-----|----|
| | 0 | 3 | 6 | 9 | 12 | 15 | 18 | 21 | 24 | 27 | 30 |
| CV-05HS | .21 | .19 | .17 | .15 | .13 | .11 | .09 | .07 | .05 | .03 | — |
| CV-05LS | .32 | .27 | .22 | .17 | .12 | .06 | — | — | — | — | — |
| CV-10HS | .95 | .85 | .75 | .65 | .55 | .45 | .35 | .25 | .15 | .05 | — |
| CV-10LS | 1.27 | 1.05 | .83 | .59 | .38 | .17 | — | — | — | — | — |
| CV-15HS | 2.22 | 1.98 | 1.74 | 1.5 | 1.26 | 1.01 | .76 | .51 | .25 | .10 | — |
| CV-15LS | 3.35 | 2.79 | 2.23 | 1.67 | 1.10 | .53 | — | — | — | — | — |
| CV-20HS | 3.88 | 3.45 | 3.02 | 2.59 | 2.16 | 1.73 | 1.30 | .87 | .44 | .25 | — |
| CV-20LS | 5.85 | 5.09 | 4.03 | 2.97 | 1.91 | .85 | — | — | — | — | — |

Tubing reference

| Tubing ID | | Tubing length (L) | |
|-----------------|------|-------------------|------|
| SAE | mm | In. | M |
| 5/64 | 2 | 18 | .457 |
| 3/32 | 2.38 | 24 | .610 |
| 1/8 | 3.17 | 30 | .762 |
| 5/32 | 4 | 36 | .914 |
| 3/16 | 4.76 | 42 | 1.07 |
| 1/4 | 6.35 | 48 | 1.22 |
| 5/16 | 8 | 54 | 1.37 |
| 3/8 | 9.52 | 60 | 1.52 |
| 7/16 | 11.1 | 66 | 1.67 |
| SAE x 25.4 = mm | | In. x 25.4 = M | |

Pad volume reference (pv)

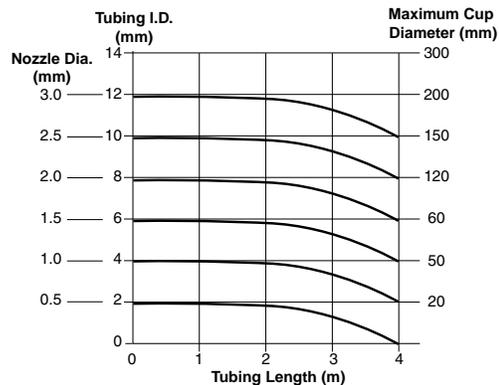
| PFG | | | PBG | | | PCG | | |
|-----|--------|----------|-----|--------|-------|-----|--------|--------|
| Ø | Cu in. | L | Ø | Cu in. | L | Ø | Cu in. | L |
| 2 | .00004 | .0000006 | 10 | .013 | .0002 | 5 | .002 | .00003 |
| 3.5 | .0001 | .000002 | 15 | .045 | .0007 | 7 | .003 | .00004 |
| 5 | .0003 | .000005 | 20 | .070 | .001 | 10 | .010 | .0001 |
| 6 | .00048 | .000008 | 30 | .28 | .004 | 15 | .060 | .0009 |
| 8 | .002 | .00003 | 40 | .56 | .009 | 18 | .082 | .001 |
| 10 | .004 | .00007 | 50 | 1.60 | .026 | 20 | .123 | .002 |
| 15 | .012 | .0002 | 75 | 4.63 | .076 | 30 | .595 | .009 |
| 20 | .03 | .0005 | 110 | 6.77 | .111 | 40 | 1.15 | .018 |
| 25 | .067 | .0011 | 150 | 15.86 | .26 | 60 | 4.40 | .072 |
| 30 | .067 | .0011 | | | | 90 | 10.00 | .1639 |
| 35 | .14 | .0023 | | | | | | |
| 40 | .18 | .003 | | | | | | |
| 50 | .25 | .0042 | | | | | | |
| 60 | .57 | .0094 | | | | | | |
| 80 | 1.28 | .021 | | | | | | |
| 95 | 1.95 | .032 | | | | | | |
| 110 | 5.00 | .082 | | | | | | |
| 150 | 10.80 | .177 | | | | | | |
| 200 | 23.24 | .381 | | | | | | |

1 ft³ = 28.31 liters
1 ft³ = 1728 in³

Nozzle diameter to tubing diameter to cup diameter reference

For each application, the size of the nozzle diameter, vacuum tubing I.D., and maximum cup diameter must be practical in relationship to each other. The chart to the right is a quick reference to aid in selecting the vacuum tubing I.D. and nozzle diameter given the maximum cup diameter.

As an example, one 60mm cup with 2 meters in tubing length would require a minimum 6mm I.D. vacuum tube and a 1.5mm nozzle. The same 60mm cup with 3.5 meters in tubing length would require a minimum 8mm I.D. vacuum tube and a 2.0mm nozzle to achieve an equivalent performance.



Saving Money and Space by Sizing Your Valves Properly

This catalog gives you a flow rating (Cv) for each valve in the Parker Hannifin line. You can “plug” your requirements into the following simple formula, and determine the Cv needed to do the job. By not oversizing, you’ll save space and money, and you’ll ensure the valve you select will do the job.

Converting the Job Requirements Into Cv

(Capacity Co-efficient).

$$Cv = \frac{\text{Cylinder Area (Sq. In.)} \times \text{Cylinder Stroke (In.)} \times \text{Compression Factor (Table 2)} \times \text{“A” (Table 2)}}{\text{Stroke Time (sec.)} \times 28.8}$$

Let’s work through an example:

We want to extend a 3-1/4" bore cylinder which has a 12" stroke in one second, and we have a supply pressure of 80 PSI to do the work. Here’s what we know:

- Cylinder Area for a 3-1/4" Bore, from Table 18.30 sq. in.
- Cylinder Stroke 12 in.
- Stroke Time Required in Seconds..... 1 sec.
- Compression Factor at 80 PSI, from Table 2..... 6.4
- “A” Constant for 80 PSI, from Table 2..... .048

Substituting in the formula, we have:

$$Cv = \frac{8.30 \times 12 \times 6.4 \times .048}{1 \times 28.8} = 1.06$$

Any valve, therefore, which has a Cv of at least 1.06, will extend our cylinder the specified distance in the required time.

Choosing the Valve “Series”

Your next step is to choose a basic valve design to do the job. For a quick guide to valve designs, see Table 3.

Having selected the basic valve design, consult the Capacity Co-efficient (Cv) tables which describe the individual valve capacities.

Selecting the Valve Model, Options and Accessories

Having determined Cv, series, port size, flow-path configuration (pre-determined by circuit design), and actuation method, you’re ready to choose the exact valve model number.

Read the pertinent catalog pages; note the exact model numbers, options and accessories you want. Then phone or write your Parker Hannifin air valve distributor. They will give you prompt, accurate service.

Note: Need circuit design help? Contact your local Parker Hannifin distributor. They are backed up by our regional Sales Engineers and offices. Between them, you’ll find answers to all of your questions.

Table 1

Effective Square-Inch Areas for Standard-Bore-Size Cylinders

| Bore Size | Cylinder Area (Sq. In.) | Bore Size | Cylinder Area (Sq. In.) |
|-----------|-------------------------|-----------|-------------------------|
| 3/4" | .44 | 4" | 12.57 |
| 1" | .79 | 4-1/2" | 15.90 |
| 1-1/8" | .99 | 5" | 19.64 |
| 1-1/4" | 1.23 | 6" | 28.27 |
| 1-1/2" | 1.77 | 7" | 38.48 |
| 1-3/4" | 2.41 | 8" | 50.27 |
| 2" | 3.14 | 10" | 78.54 |
| 2-1/2" | 4.91 | 12" | 113.10 |
| 3-1/4" | 8.30 | 14" | 153.94 |
| 3-5/8" | 10.32 | | |

Table 2

Compression Factors and “A” Constants

| Inlet Pressure (PSIG) | Compression Factor | “A” Constants for Various Pressure Drop* | | |
|-----------------------|--------------------|------------------------------------------|----------|-----------|
| | | 2 PSI ΔP | 5 PSI ΔP | 10 PSI ΔP |
| 10 | 1.6 | .152 | .103 | |
| 20 | 2.3 | .126 | .084 | .065 |
| 30 | 3.0 | .111 | .073 | .055 |
| 40 | 3.7 | .100 | .065 | .048 |
| 50 | 4.4 | .091 | .059 | .044 |
| 60 | 5.1 | .085 | .055 | .040 |
| 70 | 5.7 | .079 | .051 | .037 |
| 80 | 6.4 | .075 | .048 | .035 |
| 90 | 7.1 | .071 | .046 | .033 |
| 100 | 7.8 | .068 | .044 | .032 |
| 110 | 8.5 | .065 | .042 | .030 |
| 120 | 9.2 | .063 | .040 | .029 |
| 130 | 9.9 | .061 | .039 | .028 |
| 140 | 10.6 | .058 | .037 | .027 |
| 150 | 11.2 | .057 | .036 | .026 |
| 160 | 11.9 | .055 | .035 | .025 |
| 170 | 12.6 | .053 | .034 | .024 |
| 180 | 13.3 | .052 | .033 | .024 |
| 190 | 14.0 | .051 | .032 | .023 |
| 200 | 14.7 | .050 | .032 | .023 |

Note: Use “A” constant at 5 PSI rP for most applications. On very critical applications, use “A” at 2 PSI rP. You will find in many cases, a 10 PSI rP is not detrimental, and can save money and mounting space.

* Tabulated values are the solution of $\frac{1}{22.48} \sqrt{\frac{GT}{(P_1 - P_2) P_2}}$ where T is for 68°F and G = 1 for Air.

Table 3

Characteristics of the Major Valve Designs

| | |
|----------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>A. Poppet 3-Way and 4-Way</p> | <ol style="list-style-type: none"> High flow capacities Minimum lubrication requirements Fast response Self-cleaning poppet seats Pressures of 15 to 150 PSIG (modifications for vacuum to 250 PSIG) |
| <p>B. Spool Valves (WCS) 3-Way and 4-Way</p> | <ol style="list-style-type: none"> Low friction Lower operating pressures Fast response Less wear Long Cycle Life - Under pressure, radial expansion of the seal occurs to maintain sealing contact with the valve bore Non-Lube Service - No lubrication required for continuous valve shifting Bi-Directional Spool Seals - Common spool used for any pressure, including vacuum |
| <p>C. Packed Bore 4-Way</p> | <ol style="list-style-type: none"> Wide range of flow capacities Wide range of flow-path configurations Pilot-operated models available Pressures of vacuum to 150 PSIG |
| <p>D. Rotary Or Reciprocating Disc 4-Way, manually operated</p> | <ol style="list-style-type: none"> Inexpensive Versatility in manual actuation |

Cv – Capacity Co-efficients (sometimes called Flow Factors). Each flow path through the valve has its own Cv value. All Cv ratings for each valve cataloged on this page are listed on the front side of this sheet.

$$Cv = \frac{Q}{22.48} \sqrt{\frac{GT}{(P_1 - P_2) P_2}}$$

Q = Flow in Standard Cubic Feet per minute (14.7 PSIA at 60°F)
 P₁ = Inlet Absolute Pressure (gauge pressure + 14.7)
 P₂ = Outlet Absolute Pressure (gauge pressure + 14.7)
 Note: P₂ must be greater than .53 x P₁
 G = Specific Gravity of flowing medium (Air, G = 1)
 T = Absolute Temperature of Air (460 + °F)

Cv = Q x “A” (Table 2)

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