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Sizing circuits

for performance and efficiency

Here are some tips for right-sizing pneumatic systems.

Pneumatics often holds advantages over other motion-control technologies. In this packaging operation, for example, air systems are rugged, reliable, and easy to clean and maintain.

In today's manufacturing environments, pneumatics often provides ideal solutions for motion-control applications. Pneumatic systems are well suited for applications involving linear or rotary speeds of 4 m/sec (13 ft/sec) with forces up to 20 kN (4,500 lb). Linear actuators can come in stroke lengths as large as 10 m (33 ft) and, when coupled with a closed-loop system with a servocontroller and proportional valve, they can provide multiple speed, force, and positioning capabilities.

With the advent of fieldbus networking, pneumatic components can be simply attached to a system with less wiring and with the added capability to create a centralized or decentralized valve system.

Given the role pneumatic systems play in many industries, the question then becomes: How can manufacturing companies optimize performance and reduce energy costs associated with compressed air. The following are some important factors to consider.

Flow capacity

Sizing an air cylinder for an application is usually a straightforward process. Knowing the force and stroke requirements, and the available air pressure, engineers can readily calculate the minimum piston diameter to get the job done. When sizing a cylinder, a good rule of thumb is to initially make it large enough to provide approximately twice the calculated required force to overcome internal friction, guide friction, and other external forces.

Selecting and sizing pneumatic valves for a circuit is a bit more involved. Initial selection criteria include the type of valve and the operations it must perform; how it's turned on and off; and whether it's a stand-alone unit or mounted on a manifold. Beyond these basic criteria, however, flow capacity is arguably one of the most important factors. Oversized valves often lead to bigger-than-necessary connectors, tubing, and actuators, which increase the cost of components as well as the energy costs of electricity and compressed air – while undersized valves hurt system performance.

One key to efficient pneumatic systems is sizing valves to match the actuators. Festo's CPX terminals offer modular valve mounting, as well as I/O capabilities, fieldbus and Ethernet connectivity, and built-in diagnostics.

Flow capacity indicates the amount of resistance a valve presents to a pneumatic circuit, and is typically measured as volume coefficient (C_v) or in liters per minute. All devices that conduct air resist flow to some degree, and pressure drop across a device will increase with flow.

In the past, common practice was to match the port size of the valve to the port size of the actuators. Experts no longer recommend this method because today's valves are smaller yet have greater flow capacity than their counterparts of a few years ago. Smaller valves tend to switch quicker, cost less, and consume less power.

Thus, the first step in selecting a valve is calculating the flow required to move an actuator within an allotted time. The following equation lets you calculate the flow coefficient required for the valve. Flow rated is defined as

$Q = VC_f/t$

for SI units and

$Q = VC_f/(28.8t)$

for U.S. units.

The compression factor C_f is defined as

$C_f = (P_1 + P_a)/P_a$.

Then determine the required C_v. For U.S. units,

$C_v = Q(TG/(\Delta P(P_2 + P_a))^{0.5}/22.48$

and for SI units,

$C_v = Q(TG/(\Delta P(P_2 + P_a))^{0.5}/114.5$.

As an example, consider a double-acting cylinder with a 25-mm bore and 100-mm stroke. Rod diameter is 10 mm, air pressure is 6 bar, and pressure drop across the valve is 0.25 bar. The application requires the cylinder to extend in 0.25 sec and return in 0.2 sec.

The goal is to determine the necessary valve C_v. First calculate areas and volumes on the extend side of the cylinder.

$A_e = \pi(d/2)^2 = 490.87\ mm^2$.

$V_e = A_eL = 49{,}087\ mm^3 = 0.049\ l$.

Areas and volumes on the retract side are:

$A_r = \pi((d/2)^2 - (d_r/2)^2) = 412.33\ mm^2$.

$V_r = A_rL = 41,233\ mm^3 = 0.041\ l$.

Second, calculate the compression factor,

$C_f = (6 + 1)/1 = 7$.

Third, calculate the flow rate required to extend and retract the cylinder.

$Q_e = (V_eC_f)/t_e = 1.372$ l/sec

$Q_r = (V_rC_f)/t_r = 1.439$ l/sec.

Finally, calculate the C_v necessary to extend

$C_v = Q_e((293 \times 1)/(0.25(5.75 + 1))^{0.5}/114.5 = 0.158$

and retract the cylinder

$C_v = Q_r((293 \times 1)/(0.25(5.75 + 1))^{0.5}/114.5 = 0.166$.

For this example, the valve must have at least a $C_v = 0.158$ for the extend stroke and $C_v = 0.166$ to retract within the system's time requirements. A valve with the exact specific flows for both the extend and retract most likely does not exist, so select a valve with a larger C_v. One with a $C_v = 0.200$ should suffice. A slightly larger valve also takes into account restrictions cause by fittings and tubing which can affect reaction time.

Note that any device, fitting, or tubing can affect the system flow rate. In time-critical applications, a few extra inches of tubing or the wrong fitting can mean the difference between a circuit that works and one that does not. For this reason, valve ratings alone cannot predict the flow rate through a system branch.

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NOMENCLATURE

d = Cylinder diameter, in. or mm
d_r = Rod diameter, in. or mm
G = Specific gravity (1.0 for air)
L = Stroke, in. or mm
P_a = Atmospheric pressure, 14.7 psi or 1 bar
P_1 = Inlet pressure, psi or bar
P_2 = Outlet pressure, psi or bar
Q = Flow rate, ft^3/min or liter/sec
T = Temperature, Rankine or Kelvin
t = Time, sec
t_e = Cylinder extend time, sec
t_r = Cylinder retract time, sec
V = Volume, $in.^3$ or liter
ΔP = Pressure drop across valve, psi or bar