Piping Design of Instrument Air Distribution Systems

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Design of instrument air distribution systems is not a clear science, and there are myriad of ways to approach it. Even most experienced piping system designers take the easy way out and over design, because doing so is rarely costly and instrument air delivery systems are rarely a major cost factor in the design or installation of the plant.

Standard Assumptions and Terms

- Pressure: Typical instrument air pressure in a chemical or manufacturing plant must be at 6 bar* (or about 90psi); maximum ratings are seldom over 8 bar (120 psi). There are other uses and facilities, such as hospitals, that may require instrument air pressure of up to 10 bar (150 psi) and have much tighter specifications for air quality.
- Volume and volumetric flowrate units –
    - nmch is *normal meters-cubed per hour*,
    - scfm is *standard cubic feet per minute*.
    - fpm is *feet per* minute.

  Normal and *Standard* both refer to a volume at their respective standard reference conditions.
- Air to Open (ATO) - air pressure (and the small volume to fill accompanying chambers) are required to open the valve;
- Air to Close (ATC) - air pressure must be applied to close it;
- Fail Open (FO) - when air pressure drops below the minimum required, the valve opens (this normally requires a spring return, and is not necessarily related to ATO or ATC).
- Fail Close (FC) – when air pressure drops, the valve closes (spring close)
- Normally Open (or Closed) – this is the position of the valve during normal operation (under some circumstances, it might be ATO, so it is FC).

Instrument air is often specified to have a maximum dew point of -40˚ C (-40˚ F), and is very seldom allowed any higher than -20˚ C (-4˚ F). Even in climates where ambient temperatures can never be so low, the expansion cooling effect of air leakage through a leak or in an equipment bleed can result in condensate and ice buildup. There are many good reasons for very dry air; even very dry air from a compressor system has some moisture in it, and therefore can, over time, allow buildup of condensate in the system. Moisture/condensate buildup will result in sluggish performance and even damage to internal parts of actuators and devices.

Background

Typical instrument air devices are pressure based, rarely flow based. However, each valve actuator, sensor, signal converter or other device requires some finite volume of air at pressure to operate. For instance, control valves always require some flow, unless fully closed (or fully open, depending on type), and signal conditioners (including devices commonly called *I to P converters*, for instance) have a normal and varying amount of air bleed. Some leakage or venting is inherent in many devices to assure pressure. There are also devices such as a "normally open/fail closed" valve, that require constant but finite flow availability during steady-state operation. Other uses of instrument quality air include pneumatic motors, pumps, chucks, and convenience outlets for tools and other irregularly used devices.

The following Table lists some common instrumentation and devices that use instrument air, and the pressure and flow requirements that might be expected. Please note that these data are used here for example only, as the pressure and flow or volume requirements of any device are a function of its design (manufacturer and/or type), size, operating range, process use, and other factors. Specialty air users or systems each have their own air consumption or bleed rates (including box folders, web tension controllers/dancers, air knives, punches, etc). This information is available from the supplier.

Table 1

Device type	Air required				notes
Signal Converter (I/P, P/I, E/P, etc.)	1.02	nmch	0.60	scfm	Mfr "A"
	0.59	nmch	0.35	scfm	Mfr "B", single acting
	0.93	nmch	0.55	scfm	Mfr "B", double acting
Ball Valve Actuator	0.0012	m^3/ operation	73	cu in/ operation	minimum*, FO or FC, w/out springs
Valve Positioner	1.21	nmch	0.71	scfm	steady bleed
	21.4	nmch	12.6	scfm	in operation, during position adjustment
solenoid	0.0002	m^3/ operation	12.6	cu in/ operation	at actuation (leaky solenoids can be much higher in static operation
diaphragm pump	85	mch	50	cfm	small pump - may be *much* higher
air motor mixer	34	mch	20	cfm	drum size unit

* as an actuator wears or must operate with greater back pressure, the listed volumes can increase dramatically

Typically the component supplier will state the minimum line size requirement to the component; most commonly, the requirement is for 6 mm or 12 mm tube.

Discussion

In a medium to large sized chemical process facility, there might be hundreds of devices, or there also may be control panels with banks of solenoids and distribution tubing. In either case, they will often be concentrated in several areas or near specific unit operations, but they can also be fairly uniformly distributed over a site of many hectares (or acres). In either case, the designer needs to get a count of the number, type and size of devices that might be actuated at any time or over a short span of time (a few seconds), and provide for some diversity. (Note that rarely does every device actuate at any one time; and that often when one valve pressurizes (to actuate), another may be spring loaded to reverse actuate, so that only one charge of air addresses the requirement of two valves.) Then, the total air demand can be determined (or at least properly estimated).

The needed flow could be several hundred normal cubic meters per hour (or hundreds of cubic feet per minute), but only for a very few seconds of time. In this situation, it is often not cost effective to run 75mm or 100 mm (3 or 4 inch) or larger pipe for such a short duration need. The usual approach is to use and install reservoir or surge tanks to hold the needed volume nearer to the use points and run smaller supply lines (such as 25 mm) to the tank, and as a short-run distribution header, dropping down to tubing (6mm or even less) to the point of use. By calculating the total possible air demand, either the supply header or the surge tank can be sized. If either is undersized, the process cannot function properly or safely.

Be aware that, although a larger pipe may often be considered to function as a surge tank, that when the air is needed, any significant delay in delivery of the volume and pressure of air can and often does cause process and control problems. A long run of 75mm (3 inch) pipe, although it may hold the correct volume of air, may not be able to “deliver” the air needed in a timely manner – there is after all, friction loss and response time of a “slug” of air traveling the length of the header pipe and down to the device. Other issues regarding line specification and design include:

- The pipe or tube must have adequate structural strength to support itself or be otherwise adequately supported;
- tubing “drops” to users should come off the top of the header to prevent any moisture or debris from blowing into the using device;
- support and design must account for sudden pressure swings and “slamming” that can occur with valve actuation;
- the line must be sufficiently large to deliver air fast enough to replenish any surge or reservoir tanks without impacting worst-case process or system demand. (This time period may be up to minutes, as compared to the two seconds or less that air must be delivered to the air using device.) Also,
- include a blow-down valve at the end of the line, with the valve installed on a drop off the bottom.

<u>Simple Examples</u>

Example 1: A 150 m long web coating line including rolls, dancers, wind/unwind air chucks, splicing arm, turret winders, and cutting knives, is estimated to require 12 m^3/ 10 cycles at 6 bar. The splicing and roll change process cycle lasts no more than 20 seconds, and in normal production occurs no more often than once in 2 hours. Also included is a chemical mixing, filtering and feed process. Two diaphragm feed pumps use 85 mch air each; two small air motor mixer are used continually, using 34 mch air each. There are also 2 each "convenience outlets" for connecting pneumatic tools, each consuming at least 80 mch.

This is a small user of compressed air. The line requires only 2 operators, so it is not possible to use multiple convenience outlets or pneumatic tools while operating the production line. If the process is down, only two pneumatic tools can be used, with a total maximum consumption of 160 mch. Assume that only one convenience outlet can be used while the process is running, so maximum total air flow is 318 mch, plus the small amount from each process cycle (1.2 m^3). Over a 20 second cycle, the total air consumption is no more than about 3.0 m^3.

The line is 150 m long, so at least two reservoir tanks should to be installed, one toward each end. Some diversity needs to be included to account for unknown or undocumented users, and especially for effects of age (be aware that any leaky valve or damaged line, or "stuck" solenoids, etc., lose a lot of air, and can be the cause of loss of 5-30 mch each) and improper operation, so assume at least 50% diversity. Each tank should be at least 2.25m^3.

Line size needs to be sufficient that the pumps and mixers aren't starved at any time. Assume a target maximum velocity of 30 m/s (6000 fpm); 40 m/s and more may be acceptable. Line diameter is calculated to be 80 mm, but 75 mm (3 inch) is closest standard size.

Example 2: A new process sub-system includes 25 control valves, each with a signal converter; 30 air actuated valves that will each have no more than 10 cycles per hour; 20 solenoid valves expected to actuate no more than 10 cycles per hour; and there are 2 air operated diaphragm pumps (used mostly to transfer waste and rain run-off) that use a maximum of 75 mch. What is the size of the distribution header for compressed air?

We have to make some assumptions and gather information on the devices, which are summarized below:

- 25 control valves (positioners) at 20 nmch during full-stroke position change, and 1.2 nmch steady bleed; at startup and shutdown (a crucial time for safety), all can be expected to be in full stroke position change
- 25 each signal converters at 1.02 nmch
- 30 pneumatically actuated valves at 0.015 m^3/operation, maximum 10 cycles/hr, cycle duration of 5 seconds; based on the P&ID information, no more than 12 valves are expected to actuate simultaneously
- 20 solenoid valves at 0.0005 ncm/cycle, maximum 10 cycles/hr, cycle duration of 1 second, no more than 10 expected to operate simultaneously
- 2 each air operated sump pump at 75 mch, operated on-demand (less than 2% of the time)

Normal maximum operating demand flow for this sub-system is perhaps less than 250 mch, but during instantaneous crucial seconds each hour, the rate exceeds 675 mch (525 mch excluding the two pumps). Assume a target velocity of 30 m/s (6000 fpm); the suppliers all require 6 mm "drops" to their devices (larger for the pumps). The calculated optimal header diameter is 90 mm (either reduce down to 75mm or up to 100mm).

Consider that the pumps can be scheduled to operate during periods of reduced load, as long as they are used to pump waste within a shift (8 hours). Is there any savings gained by doing so? This drops the optimal header diameter to 62mm.

* The basic units presented in this paper are standard metric in common use, not necessarily SI (with SAE units in parentheses). Equivalents are not given as precisely calculated values, but approximate values, since all values are approximate or estimates only.