3

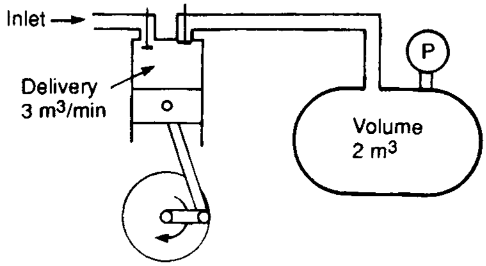
Air compressors, air treatment and pressure regulation

The vast majority of pneumatic systems use compressed atmospheric air as the operating medium (a small number of systems use nitrogen obtained commercially from liquid gas suppliers). Unlike hydraulic systems, a pneumatic system is 'open'; the fluid is obtained free, used and then vented back to atmosphere.

Pneumatic systems use a compressible gas; hydraulic systems an incompressible liquid, and this leads to some significant differences. The pressure of a liquid may be raised to a high level almost instantaneously, whereas pressure rise in a gas can be distinctly leisurely. In Figure 3.1a, a reservoir of volume two cubic metres is connected to a compressor which delivers three cubic metres of air (measured at atmospheric pressure) per minute. Using Boyle's law (expression 1.17) the pressure rise shown in Figure 3.1b can be found.

Pressure in a hydraulic system can be quickly and easily controlled by devices such as unloading and pressure regulating valves. Fluid is thus stored at atmospheric pressure and compressed to the required pressure as needed. The slow response of an air compressor, however, precludes such an approach in a pneumatic system and necessitates storage of compressed air at the required pressure in a receiver vessel. The volume of this vessel is chosen so there are minimal deviations in pressure arising from flow changes in loads and the compressor is then employed to replace the air used, averaged over an extended period of time (e.g. a few minutes).

Deviations in air pressure are smaller, and compressor control is easier if a large receiver feeds many loads. A large number of loads



(a) Components

t (min)	Volume (at NTP)	P Abs	P gauge
0	2	1	0
1	5	2.5	1.5
2	8	4	3
3	11	5.5	4.5

(b) Response

Figure 3.1 *Compressibility of a gas*

statistically results in a more even flow of air from the receiver, also helping to maintain a steady pressure. On many sites, therefore, compressed air is produced as a central service which is distributed around the site in a similar manner to electricity, gas and water.

Behaviour of a gas subjected to changes in pressure, volume and temperature is governed by the general gas equation given earlier as expression 1.19 and reproduced here:

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}. \qquad (3.1)$$

where pressures are given in absolute terms and temperatures are measured in degrees Kelvin.

A compressor increases air pressure by reducing its volume, and expression 3.1 predicts a resultant rise in temperature. A pneumatic system must therefore incorporate some method of removing this excess heat. For small systems, simple fins on the compressor (similar in construction to an air-cooled internal combustion engine) will suffice. For larger systems, a separate cooler (usually employing water as the heat-removing medium) is needed.

Atmospheric air contains water vapour, the actual amount varying from day to day according to humidity. The maximum amount of water vapour held in a given volume of air is determined by temperature, and any excess condenses out as liquid droplets (commonly experienced as condensation on cold windows). A similar effect occurs as compressed air is cooled, and if left the resultant water droplets would cause valves to jam and corrosion to form in pipes. An aftercooler must therefore be followed by a water separator. Often aftercoolers and separators are called, collectively, primary air treatment units.

Dry cool air is stored in the receiver, with a pressure switch used to start and stop the compressor motor, maintaining the required pressure.

Ideally, air in a system has a light oil mist to reduce chances of corrosion and to lubricate moving parts in valves, cylinders and so on. This oil mist cannot be added before the receiver as the mist would form oil droplets in the receiver's relatively still air, so the exit air from the receiver passes through a unit which provides the lubricating mist along with further filtration and water removal. This process is commonly called secondary air treatment.

Often, air in the receiver is held at a slightly higher pressure than needed to allow for pressure drops in the pipe lines. A local pressure regulation unit is then employed with the secondary air treatment close to the device using air. Composite devices called service units comprising water separation, lubricator and pressure regulation are available for direct line monitoring close to the valves and actuators of a pneumatic system.

Figure 3.2 thus represents the components used in the production of a reliable source of compressed air.

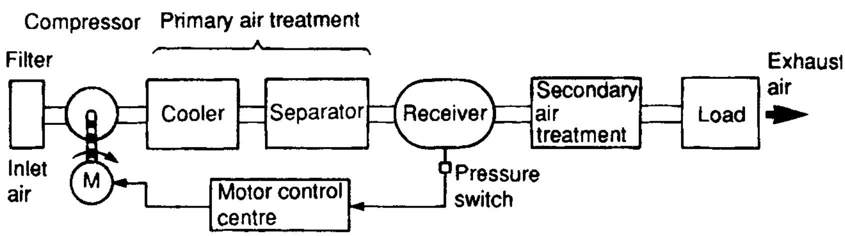


Figure 3.2 *Component parts of a pneumatic system*

Compressor types

Like hydraulic pumps, air compressors can be split into positive displacement devices (where a fixed volume of air is delivered on each rotation of the compressor shaft) and dynamic devices such as centrifugal or axial blowers. The vast majority of air compressors are of the positive displacement type.

A compressor is selected by the pressure it is required to work at and the volume of gas it is required to deliver. As explained in the previous section, pressure in the receiver is generally higher than that required at the operating position, with local pressure regulation being used. Pressure at the compressor outlet (which for practical purposes will be the same as that in the receiver) is called the working pressure and is used to specify the compressor. Pressure at the operating point is called, not surprisingly, the operating pressure and is used to specify valves, actuators and other operating devices.

Care should be taken in specifying the volume of gas a compressor is required to deliver. Expression 3.1 shows the volume of a given mass of gas to be highly dependent on pressure and temperature. Delivery volume of a compressor is defined in terms of gas at normal atmospheric conditions. Two standards known as *standard temperature and pressures* (STP) are commonly used, although differences between them are small for industrial users.

The *technical normal condition* is:

$$P = 0.98 \text{ bar absolute, } T = 20°C$$

and the *physical normal condition* is:

$$P = 1.01 \text{ bar absolute, } T = 0°C$$

The term *normal temperature and pressure* (NTP) is also used.

Required delivery volume of a compressor (in M^3 min^{-1} or ft^3 min^{-1}, according to the units used) may be calculated for the actuators at the various operating positions (with healthy safety margins to allow for leakage) but care must be taken to ensure this total volume is converted to STP condition before specifying the required compressor delivery volume.

A compressor delivery volume can be specified in terms of its theoretical volume (swept volume multiplied by rotational speed) or effective volume which includes losses. The ratio of these two volumes is the efficiency. Obviously the effective volume should be used in choosing a compressor (with, again, a safety margin for leakage). Required power of the motor driving the compressor is dependent on working pressure and delivery volume, and may be determined from expressions 2.2 and 2.5. Allowance must be made for the cyclic on/off operation of the compressor with the motor being sized for on load operation and not averaged over a period of time.

Piston compressors

Piston compressors are by far the most common type of compressor, and a basic single cylinder form is shown in Figure 3.3. As the piston descends during the inlet stroke (Figure 3.3a), the inlet valve opens and air is drawn into the cylinder. As the piston passes the bottom of the stroke, the inlet valve closes and the exhaust valve opens allowing air to be expelled as the piston rises (Figure 3.3b)

Figure 3.3 implies that the valves are similar to valves in an internal combustion engine. In practice, spring-loaded valves are used, which open and close under the action of air pressure across them. One common type uses a 'feather' of spring steel which moves above the inlet or output port, as shown in Figure 3.3c.

A single cylinder compressor gives significant pressure pulses at the outlet port. This can be overcome to some extent by the use of a large receiver, but more often a multicylinder compressor is used. These are usually classified as vertical or

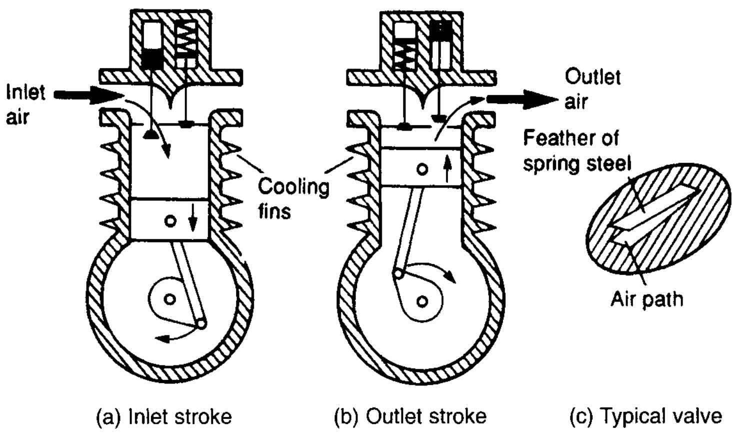


Figure 3.3 *Single cylinder compressor*

horizontal in-line arrangements and the more compact V, Y or W constructions.

A compressor which produces one pulse of air per piston stoke (of which the example of Figure 3.3 is typical) is called a single-acting compressor. A more even air supply can be obtained by the double acting action of the compressor in Figure 3.4, which uses two sets of valves and a crosshead to keep the piston rod square at all times. Double-acting compressors can be found in all configurations described earlier.

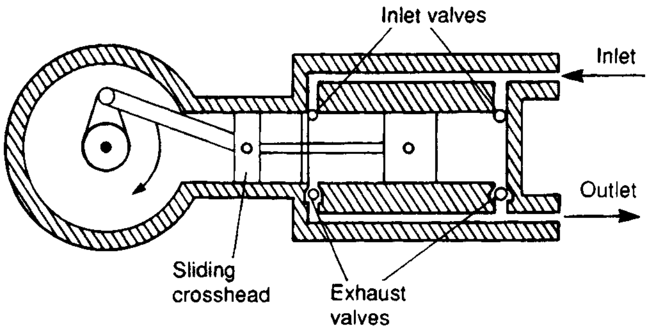


Figure 3.4 *Double-acting compressor*

Piston compressors described so far go direct from atmospheric to required pressure in a single operation. This is known as a single stage compressor. The general gas law (expression 1.19) showed compression of a gas to be accompanied by a significant rise in gas temperature. If the exit pressure is above about 5 bar in a single-acting compressor, the compressed air temperature can rise to over 200°C and the motor power needed to drive the compressor rises accordingly.

For pressures over a few bar it is far more economical to use a multistage compressor with cooling between stages. Figure 3.5 shows an example. As cooling (undertaken by a device called an intercooler) reduces the volume of the gas to be compressed at the second stage there is a large energy saving. Normally two stages are used for pneumatic pressures of 10 to 15 bar, but multistage compressors are available for pressures up to around 50 bar.

Multistage compressors can be manufactured with multicylinders as shown in Figure 3.5 or, more compactly, with a single cylinder and a double diameter piston as shown in Figure 3.6.

There is contact between pistons and air, in standard piston compressors, which may introduce small amounts of lubrication oil

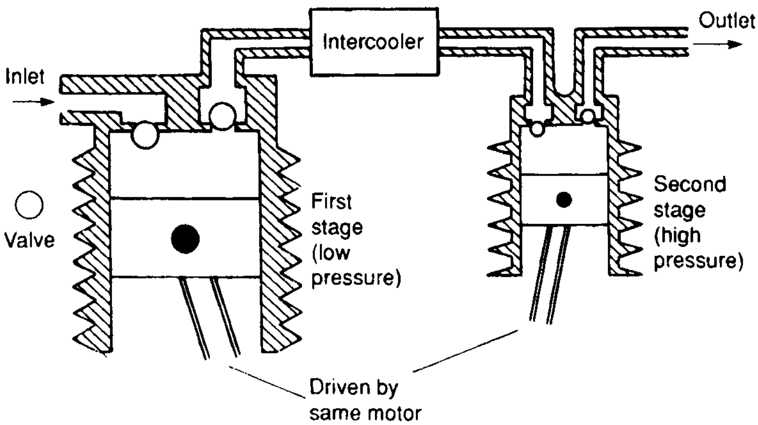


Figure 3.5 *Two-stage compressor*

from the piston walls into the air. This very small contamination may be undesirable in food and chemical industries. Figure 3.7 shows a common way of giving a totally clean supply by incorporating a flexible diaphragm between piston and air.

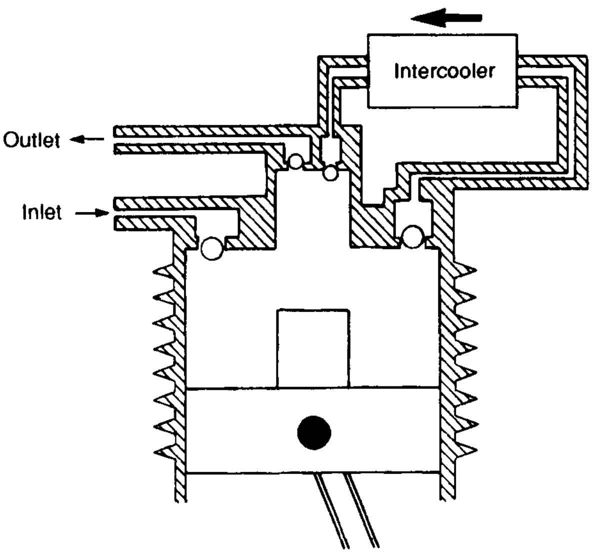


Figure 3.6 *Combined two-stage compressor*

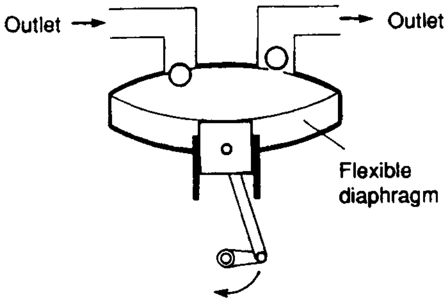


Figure 3.7 *Diaphragm compressor, used where air must not be contaminated*

Screw compressors

Piston compressors are used where high pressures (> 20 bar) and relatively low volumes (< 10,000 $m^3 hr^{-1}$) are needed, but are mechanically relatively complex with many moving parts. Many applications require only medium pressure (< 10 bar) and medium flows (around 10,000 $m^3 hr^{-1}$). For these applications, rotary compressors have the advantage of simplicity, with fewer moving parts rotating at a constant speed, and a steady delivery of air without pressure pulses.

One rotary compressor, known as the dry rotary screw compressor, is shown in Figure 3.8 and consists of two intermeshing rotating screws with minimal (around 0.05 mm) clearance. As the

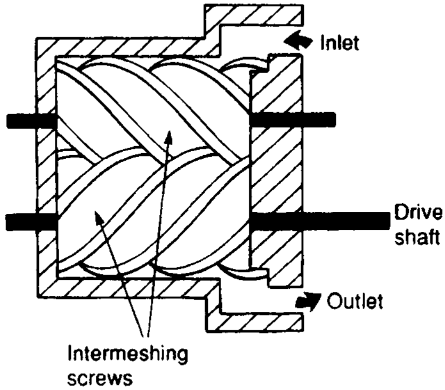


Figure 3.8 *Dry screw rotary compressor*

screws rotate, air is drawn into the housing, trapped between the screws and carried along to the discharge port, where it is delivered in a constant pulse-free stream.

Screws in this compressor can be synchronised by external timing gears. Alternatively one screw can be driven, the second screw rotated by contact with the drive screw. This approach requires oil lubrication to be sprayed into the inlet air to reduce friction between screws, and is consequently known as a wet rotary screw compressor. Wet screw construction though, obviously introduces oil contamination into the air which has to be removed by later oil separation units.

Rotary compressors

The vane compressor, shown in Figure 3.9 operates on similar principles to the hydraulic vane pump described in Chapter 2, although air compressors tend to be physically larger than hydraulic pumps. An unbalanced design is shown, balanced versions can also be constructed. Vanes can be forced out by springs or, more commonly, by centrifugal force.

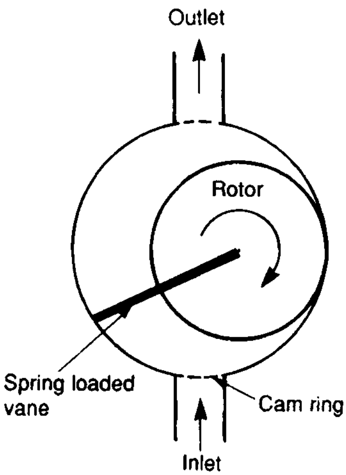


Figure 3.9 *Vane compressor*

A single stage vane compressor can deliver air at up to 3 bar, a much lower pressure than that available with a screw or piston compressor. A two-stage vane compressor with large low pressure and smaller high pressure sections linked by an intercooler allows pressures up to 10 bar to be obtained.

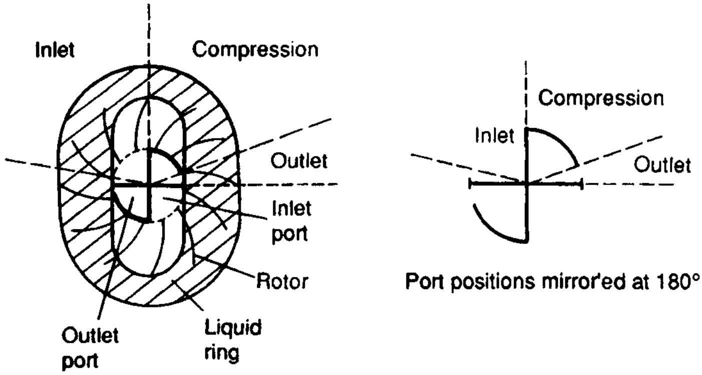


Figure 3.10 *Liquid ring compressor*

Figure 3.10 shows a variation on the vane compressor called a liquid ring compressor. The device uses many vanes rotating inside an eccentric housing and contains a liquid (usually water) which is flung out by centrifugal force to form a liquid ring which follows the contour of the housing to give a seal with no leakage and minimal friction. Rotational speed must be high (typically 3000 rpm) to create the ring. Delivery pressures are relatively low at around 5 bar.

The lobe compressor of Figure 3.11 (often called a Roots blower) is often used when a positive displacement compressor is needed with high delivery volume but low pressure (typically 1–2 bar). Operating pressure is mainly limited by leakage between rotors and housing. To operate efficiently, clearances must be very small, and wear leads to a rapid fall in efficiency.

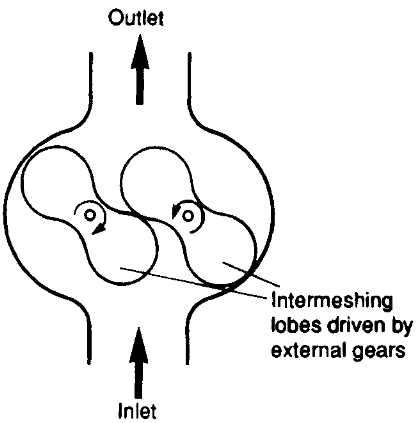


Figure 3.11 *Lobe compressor*

Dynamic compressors

A large volume of air (up to 5000 m^3 min^{-1}) is often required for applications such as pneumatic conveying (where powder is carried in an air stream), ventilation or where air itself is one component of a process (e.g. combustion air for gas/oil burners). Pressure in these applications is low (at most a few bar) and there is no need for a positive displacement compressor.

Large volume low pressure air is generally provided by dynamic compressors known as blowers. They can be subdivided into centrifugal or axial types, shown in Figure 3.12. Centrifugal blowers (Figure 3.12a) draw air in then fling it out by centrifugal force. A high shaft rotational speed is needed and the volume to input power ratio is lower than any other type of compressor.

An axial compressor comprises a set of rotating fan blades as shown in Figure 3.12b. These produce very large volumes of air, but at low pressure (less than one bar). They are primarily used for ventilation, combustion and process air.

Output pressures of both types of dynamic compressor can be lifted by multistage compressors with intercoolers between stages. Diffuser sections reduce air entry velocity to subsequent stages, thereby converting air kinetic energy to pressure energy.

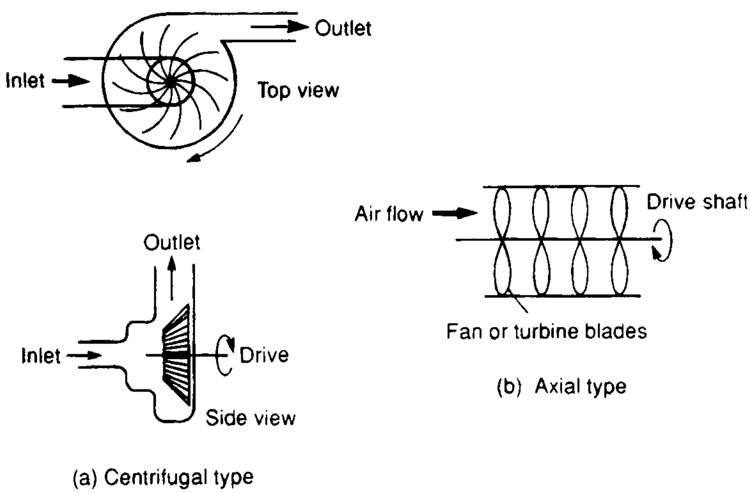


Figure 3.12 *Non-positive displacement compressors (Blowers)*

Positive displacement compressors use oil to lubricate the close machined parts and to maintain the air seal. Dynamic compressors have no such need, and consequently deliver very clean air.

Air receivers and compressor control

An air receiver is used to store high pressure air from the compressor. Its volume reduces pressure fluctuations arising from changes in load and from compressor switching.

Air coming from the compressor will be warm (if not actually hot!) and the large surface area of the receiver dissipates this heat to the surrounding atmosphere. Any moisture left in the air from the compressor will condense out in the receiver, so outgoing air should be taken from the receiver top.

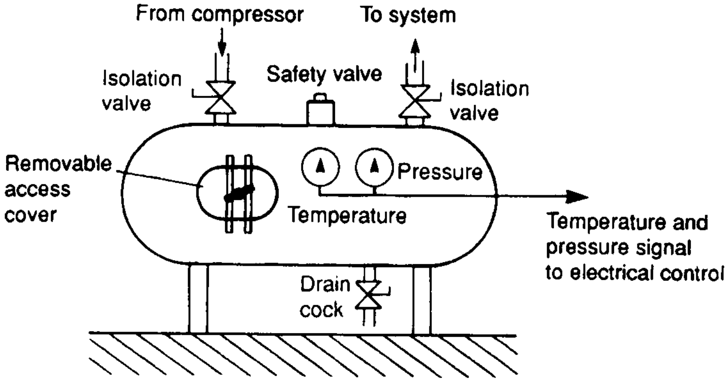


Figure 3.13 *Compressed air receiver*

Figure 3.13 shows essential features of a receiver. They are usually of cylindrical construction for strength, and have a safety relief valve to guard against high pressures arising from failure of the pressure control scheme. Pressure indication and, usually, temperature indication are provided, with pressure switches for control of pressure and high temperature switches for remote alarms.

A drain cock allows removal of condensed water, and access via a manhole allows cleaning. Obviously, removal of a manhole cover is hazardous with a pressurised receiver, and safety routines must be defined and followed to prevent accidents.

Control of the compressor is necessary to maintain pressure in the receiver. The simplest method of achieving this is to start the compressor when receiver pressure falls to some minimum pressure, and stop the compressor when pressure rises to a satisfactory level again, as illustrated in Figure 3.14. In theory two pressure switches are required (with the motor start pressure lower than the motor stop pressure) but, in practice, internal hysteresis in a typical switch allows one pressure switch to be used. The pressure in the receiver cycles between the start and stop pressure settings.

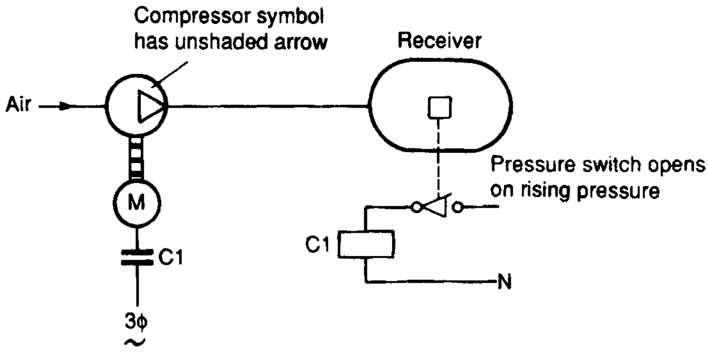


Figure 3.14 *Receiver pressure control via motor start/stop*

In Figure 3.15 another method of pressure control is shown, where the compressor runs continuously and an exhaust valve is fitted to the compressor outlet. This valve opens when the required pressure is reached. A non-return valve prevents air returning from the receiver. This technique is known as exhaust regulation.

Compressors can also be controlled on the inlet side. In the example of Figure 3.16, an inlet valve is held open to allow the compressor to operate, and is closed when the air receiver has

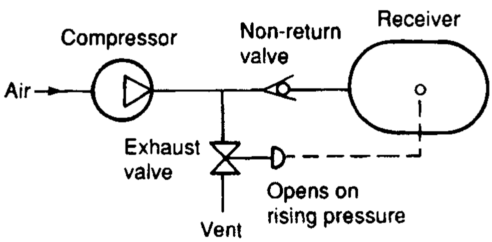


Figure 3.15 *Receiver pressure control using compressor outlet valve*

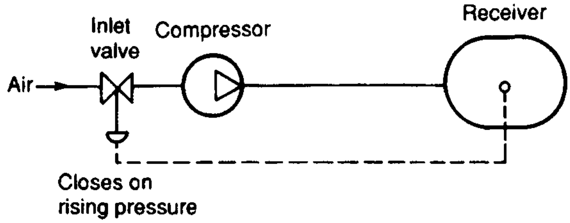


Figure 3.16 *Receiver pressure control using compressor inlet valve*

reached the desired pressure, (the compressor then forms a near vacuum on its inlet side).

The valves in Figure 3.15 and 3.16 can be electrically-operated solenoid valves controlled by pressure switches, or can be pneumatic valves controlled directly by receiver pressure.

The control method is largely determined by flow rates from receiver to the load(s) and the capacity of the compressor. If the compressor has significant spare capacity, for example, start/stop control is commonly used.

If compressor capacity and load requirements are closely matched, on the other hand, short start/stop cycling may cause premature wear in the electrical starter for the compressor motor. In this situation, exhaust or inlet regulation is preferred.

Air receiver size is determined by load requirements, compressor capacity, and allowable pressure deviations in the receiver. With the compressor stopped, Boyle's law (expression 1.17) gives the pressure decay for a given volume of air delivered from a given receiver at a known pressure. For example, if a receiver of 10 cubic metres volume and a working pressure of 8 bar delivers 25 cubic metres of air (at STP) to a load, pressure in the receiver falls to approximately 5.5 bar.

With the compressor started, air pressure rises at a rate again given by expression 1.17 (with the air mass in the receiver being *increased* by the difference between the air delivered by the compressor and that removed by the load).

These two calculations give the cycle time of the compressor when combined with settings of the cut-in and drop-out pressure switches. If this is unacceptably rapid, say less than a few minutes, then a larger receiver is required. Manufacturers of pneumatic equipment provide nomographs which simplify these calculations.

An air receiver is a pressure vessel and as such requires regular visual and volumetric pressure tests. Records should be kept of the tests.

Air treatment

Atmospheric air contains moisture in the form of water vapour. We perceive the amount of moisture in a given volume of air as the humidity and refer to days with a high amount of water vapour as 'humid' or 'sticky', and days with low amounts of water vapour as 'good drying days'. The amount of water vapour which can be held in a given volume depends on temperature but does *not* depend on pressure of air in that volume. One cubic metre at 20°C, for example, can hold 17 grams of water vapour. The amount of water vapour which can be held in a given volume of air rises with temperature as shown in Figure 3.17.

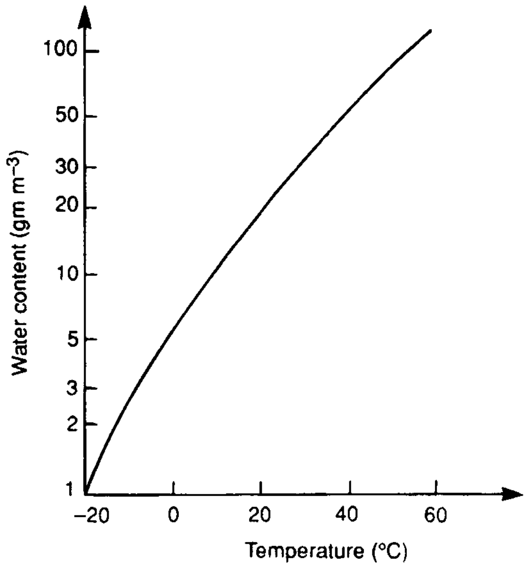


Figure 3. 17 *Moisture content curve*

If a given volume of air contains the maximum quantity of water vapour possible at the air temperature, the air is said to be *saturated* (and we would perceive it as sticky because sweat could not evaporate from the surface of the skin). From Figure 3.17, air containing 50 grams of water vapour per cubic metre at 40°C is saturated.

Moisture content of unsaturated air is referred to by relative humidity, which is defined as:

$$\text{Relative humidity} = \frac{\text{water content per cubic metre}}{\text{maximum water content per cubic metre}} \times 100\%. \quad (3.2)$$

Air containing 5 grams of water vapour per cubic metre of air at 20°C has, from Figure 3.17, a relative humidity of 30%.

Relative humidity is dependent on both temperature and pressure of the air. Suppose air at 30°C contains 20 grams of water vapour. From Figure 3.17 this corresponds to 67% humidity. If the air is allowed to cool to 20°C it can only hold 17 grams of water vapour and is now saturated (100% relative humidity). The excess 3 grams condenses out as liquid water. If the air is cooled further to 10°C, a further 8 grams condenses out.

The temperature at which air becomes saturated is referred to as the 'dew point'. Air with 17.3 grams of water vapour per cubic metre has, for example, a dew point of 20°C.

To see the effect of pressure on relative humidity, we must remember the amount of water vapour which can be held in a given volume is fixed (assuming a constant temperature). Suppose a cubic metre of air at atmospheric pressure (0 bar gauge or 1 bar absolute) at 20°C contains 6 grams of water vapour (corresponding to 34% relative humidity). If we wish to increase air pressure while maintaining its temperature at 20°C, we must compress it. When the pressure is 1 bar gauge (or 2 bar absolute) its volume is 0.5 cubic metres, which can hold 8.6 grams of water vapour, giving us 68% relative humidity. At 2 bar gauge (3 bar absolute) the volume is 0.33 cubic metres, which can hold 5.77 grams of water vapour. With 6 grams of water vapour in our air, we have reached saturation and condensation has started to occur.

It follows that relative humidity rises quickly with increasing pressure, and even low atmospheric relative humidity leads to saturated air and condensation at the pressures used in pneumatic systems (8–10 bar). Water droplets resulting from this condensation can cause many problems. Rust will form on unprotected steel surfaces, and the water may mix with oil (necessary for lubrication) to form a sticky white emulsion, which causes valves to jam and blocks the small piping used in pneumatic instrumentation systems. In extreme cases water traps can form in pipe loops.

When a compressed gas expands suddenly there is a fall of temperature (predicted by expression 1.19). If the compressed air has a high water content, a rapid expansion at exhaust ports can be accompanied by the formation of ice as the water condenses out and freezes.

Stages of air treatment

Air in a pneumatic system must be clean and dry to reduce wear and extend maintenance periods. Atmospheric air contains many harmful impurities (smoke, dust, water vapour) and needs treatment before it can be used.

In general, this treatment falls into three distinct stages, shown in Figure 3.18. First, inlet filtering removes particles which can damage the air compressor. Next, there is the need to dry the air to reduce humidity and lower the dew point. This is normally performed between the compressor and the receiver and is termed primary air treatment.

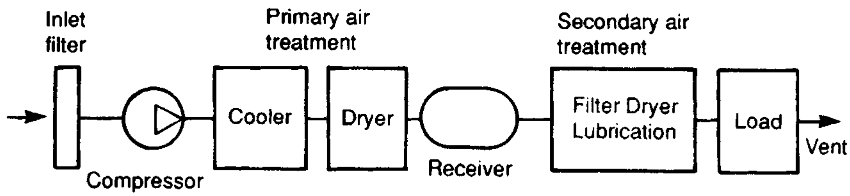


Figure 3.18 *Three stages of air treatment*

The final treatment is performed local to the duties to be performed, and consists of further steps to remove moisture and dirt and the introduction of a fine oil mist to aid lubrication. Not surprisingly this is generally termed secondary air treatment.

Filters

Inlet filters are used to remove dirt and smoke particles before they can cause damage to the air compressor, and are classified as dry filters with replaceable cartridges (similar to those found in motor car air filters) or wet filters where the incoming air is bubbled through an oil bath then passed through a wire mesh filter. Dirt particles became attached to oil droplets during the bubbling process and are consequently removed by the wire mesh.

Both types of filter require regular servicing: replacement of the cartridge element for the dry type; cleaning for the wet type. If a filter is to be cleaned, it is essential the correct detergent is used. Use of petrol or similar petrochemicals can turn an air compressor into an effective diesel engine – with severe consequences.

Filters are classified according to size of particles they will stop. Particle size is measured in SI units of micrometres (the older metric term *microns is* still common) one micrometre (1 μm) being 10^{-6} metre or 0.001 millimetre. Dust particles are generally larger than 10 μm, whereas smoke and oil particles are around 1 μm. A filter can have a nominal rating (where it will block 98% of particles of the specified size) or an absolute rating (where it blocks 100% of particles of the specified size).

Microfilters with removable cartridges passing air from the centre to the outside of the cartridge case will remove 99.9% of particles down to 0.01 μm, the limit of normal filtration. Coarse filters, constructed out of wire mesh and called strainers, are often used as inlet filters. These are usually specified in terms of the mesh size which approximates to particle size in micrometres as follows:

Mesh size	μm
325	30
550	10
750	6

Air dryers

An earlier section described how air humidity and dew point are raised by compression. Before air can be used, this excess moisture has to be removed to bring air humidity and dew point to reasonable levels.

In bulk air systems all that may be required is a simple aftercooler similar to the intercoolers described earlier, followed by a separator unit where the condensed water collects and can be drained off.

Figure 3.19a shows a typical water trap and separator. Air flow through the unit undergoes a sudden reversal of direction and a deflector cone swirls the air (Figure 3.19b). Both of these cause heavier water particles to be flung out to the walls of the separator and to collect in the trap bottom from where they can be drained. Water traps are usually represented on circuit diagrams by the symbol of Figure 3.19c.

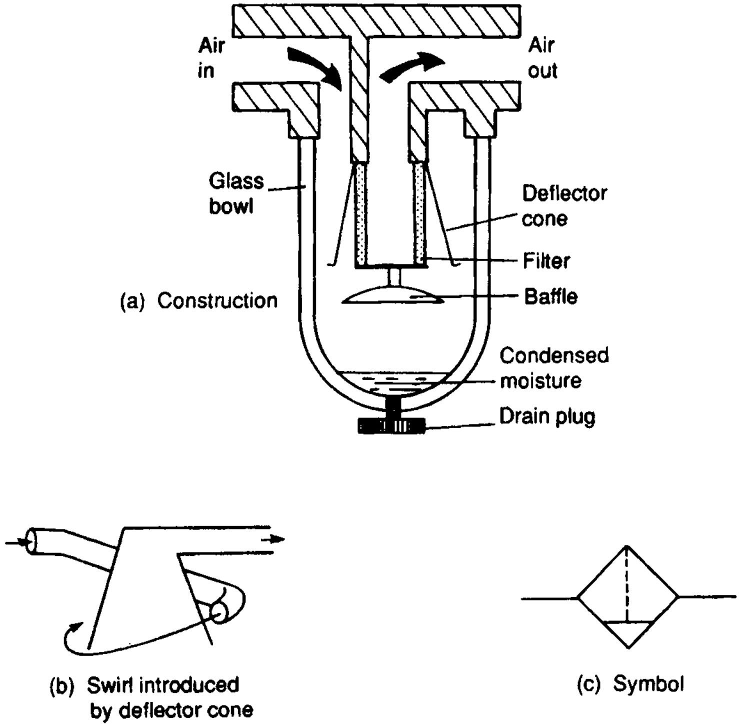


Figure 3.19 Air filter and water trap

Dew point can be lowered further with a refrigerated dryer, the layout of which is illustrated in Figure 3.20. This chills the air to just above 0°C condensing almost all the water out and collecting the condensate in the separator. Efficiency of the unit is improved with a second heat exchanger in which cold dry air leaving the dryer pre-chills incoming air. Air leaving the dryer has a dew point similar to the temperature in the main heat exchanger.

Refrigerated dryers give air with a dew point sufficiently low for most processes. Where absolutely dry air is needed, chemical dryers must be employed. Moisture can be removed chemically from air by two processes.

In a deliquescent dryer, the layout of which is shown in Figure 3.21, a chemical agent called a desiccant is used. This absorbs water vapour and slowly dissolves to form a liquid which collects at the bottom of the unit where it can be drained. The dessicant material is used up during this process and needs to be replaced at regular intervals. Often deliquescent dryers are referred to as absorbtion dryers. a term that should not be confused with the next type of dryer.

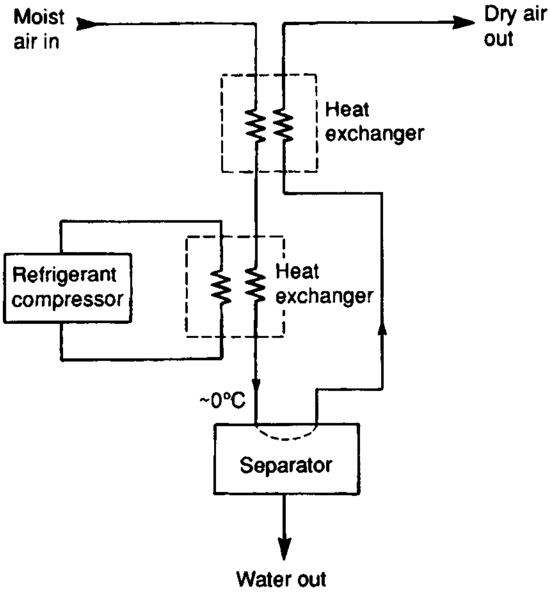


Figure 3.20 *Refrigerated dryer*

An adsorption dryer collects moisture on the sharp edges of a granular material such as silicon dioxide, or with materials which can exist in hydrated *and* de-hydrated states (the best known is copper sulphate but more efficient compounds are generally used). Figure 3.22 shows construction of a typical adsorption dryer. Moisture in the adsorption material can be released by heating, so

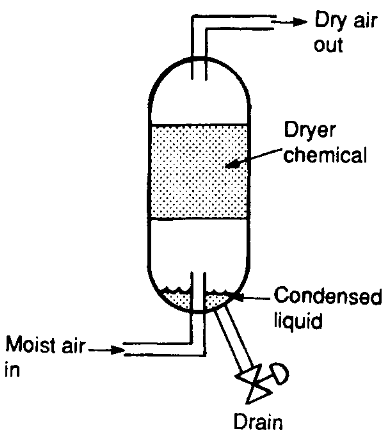


Figure 3.21 *Deliquescent dryer*

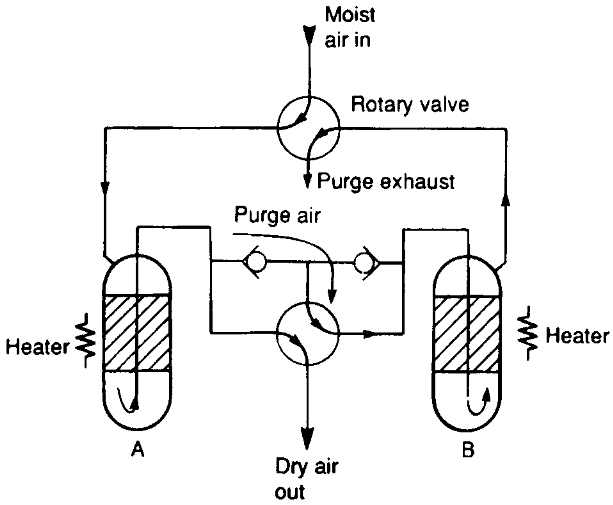


Figure 3.22 *Adsorption dryer*

two columns are used. At any time, one column is drying the air while the other is being regenerated by heating and the passage of a low purge air stream. As shown, column A dries the air and column B is being regenerated. The rotary valves are operated automatically at regular intervals by a time clock. For obvious reasons adsorption dryers are often referred to as regenerative dryers.

Lubricators

A carefully controlled amount of oil is often added to air immediately prior to use to lubricate moving parts (process control pneumatics are the exception as they usually require dry unlubricated air). This oil is introduced as a fine mist, but can only be added to thoroughly clean and dry air or a troublesome sticky emulsion forms. It is also difficult to keep the oil mist-laden air in a predictable state in an air receiver, so oil addition is generally performed as part of the secondary air treatment.

The construction of a typical lubricator is shown with its symbol in Figure 3.23. The operation is similar to the principle of the petrol air mixing in a motor car carburettor As air enters the lubricator its velocity is increased by a venturi ring causing a local reduction in pressure in the upper chamber. The pressure differential between lower and upper chambers causes oil to be drawn up a

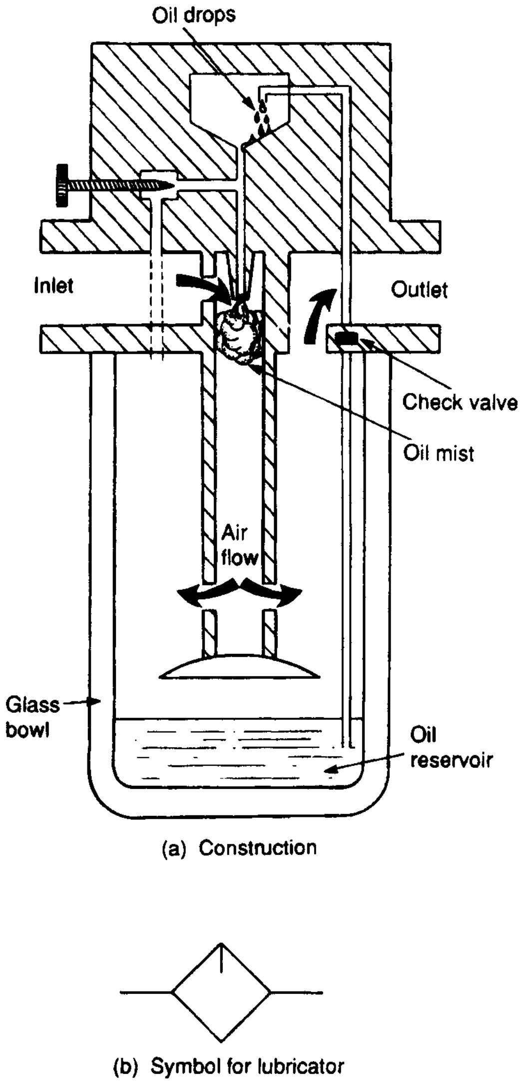


Figure 3.23 *Lubricator*

riser tube, emerging as a spray to mix with the air. The needle valve adjusts the pressure differential across the oil jet and hence the oil flow rate.

The air–oil mixture is forced to swirl as it leaves the central cylinder causing excessively large oil particles to be flung out of the air stream.

Pressure regulation

Flow velocities in pneumatic systems can be quite high, which can lead to significant flow-dependent pressure drops between the air receiver and the load.

Generally, therefore, air pressure in the receiver is set higher than the required load pressure and pressure regulation is performed local to loads to keep pressure constant regardless of flow. Control of air pressure in the receiver was described in an earlier section. This section describes various ways in which pressure is locally controlled.

There are essentially three methods of local pressure control, illustrated in Figure 3.24. Load A vents continuously to atmosphere. Air pressure is controlled by a pressure regulator which simply restricts air flow to the load. This type of regulator requires some minimum flow to operate. If used with a dead-end load which draws no air, the air pressure will rise to the main manifold pressure. Such regulators, in which air must pass through the load, are called non-relieving regulators.

Load B is a dead-end load, and uses a pressure regulator which vents air to atmosphere to reduce pressure. This type of regulator is called a three-port (for the three connections) or relieving regulator. Finally, load C is a large capacity load whose air volume requirements are beyond the capacity of a simple in-line regulator. Here a pressure control loop has been constructed com-

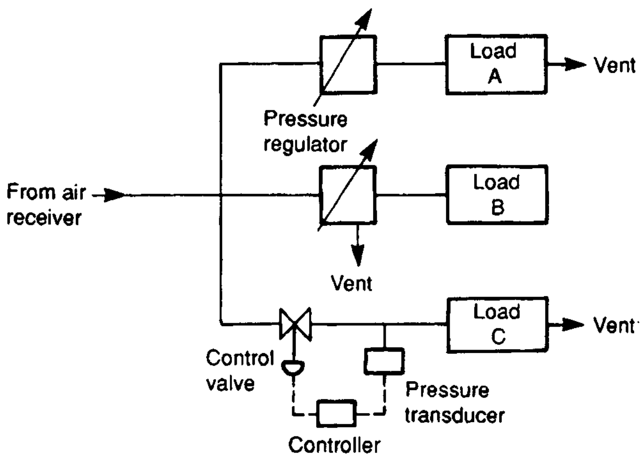


Figure 3.24 *Three types of pressure regulator*

prising pressure transducer, electronic controller and separate vent valve. This technique can also be used if the pressure regulating valve cannot be mounted locally to the point at which the pressure is to be controlled.

Relief valves

The simplest pressure regulating device is the relief valve shown in Figure 3.25. This is not, in fact, normally used to control pressure but is employed as a backup device should the main pressure control device fail. They are commonly fitted, for example, to air receivers.

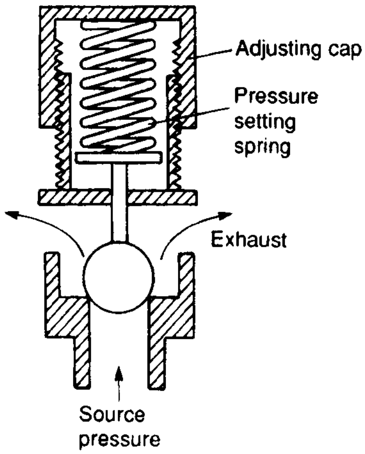


Figure 3.25 *Relief valve*

A ball valve is held closed by spring tension, adjustable to set the relief pressure. When the force due to air pressure exceeds the spring tension, the valve cracks open releasing air and reducing the pressure. Once cracked, flow rate is a function of excess pressure; an increase in pressure leading to an increase in flow. A relief valve is specified by operating pressure range, span of pressure between cracking and full flow, and full flow rate. Care is needed in specifying a relief valve because in a fault condition the valve may need to pass the entire compressor output.

A relief valve has a flow/pressure relationship and self-seals itself once the pressure falls below the cracking pressure. A pure safety valve operates differently. Once a safety valve cracks, it opens fully to discharge all the pressure in the line or receiver, and it does not automatically reclose, needing manual resetting before the system can be used again.

Non-relieving pressure regulators

Figure 3.26 shows construction of a typical non-relieving pressure regulator. Outlet pressure is sensed by a diaphragm which is pre-loaded by a pressure setting spring. If outlet pressure is too low, the spring forces the diaphragm and poppet down, opening the valve to admit more air and raise outlet pressure.

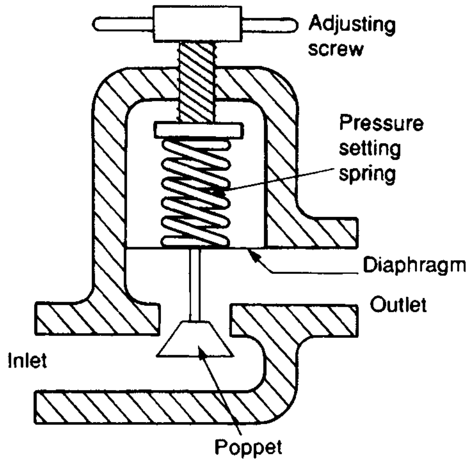


Figure 3.26 *Non-relieving pressure regulator*

If the outlet pressure is too high, air pressure forces the diaphragm up, reducing air flow and causing a reduction in air pressure as air vents away through the load. In a steady state the valve will balance with the force on the diaphragm from the outlet pressure just balancing the preset force on the spring.

Relieving pressure regulators

A relieving regulator is shown in Figure 3.27. Outlet pressure is sensed by a diaphragm preloaded with an adjustable pressure

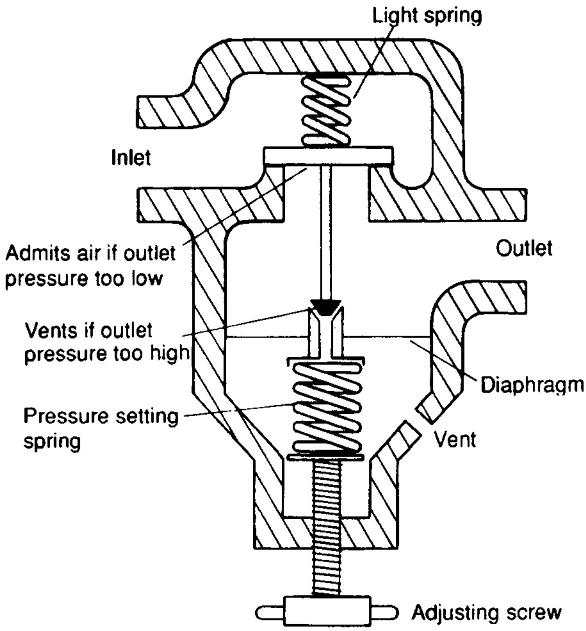


Figure 3.27 *Relieving pressure regulator*

setting spring. The diaphragm rises if the outlet pressure is too high, and falls if the pressure is too low.

If outlet pressure falls, the inlet poppet valve is pushed open admitting more air to raise pressure. If the outlet pressure rises, the diaphragm moves down closing the inlet valve and opening the central vent valve to allow excess air to escape from the load thereby reducing pressure.

In a steady state the valve will balance; *dithering* between admitting and venting small amounts of air to keep load pressure at the set value.

Both the regulators in Figure 3.26 and 3.27 are simple pressure regulators and have responses similar to that shown in Figure 3.28, with outlet pressure decreasing slightly with flow. This droop in pressure can be overcome by using a pilot-operated regulator, shown in Figure 3.29.

Outlet pressure is sensed by the pilot diaphragm, which compares outlet pressure with the value set by the pressure setting spring. If outlet pressure is low the diaphragm descends, while if outlet pressure is high the diaphragm rises.

Inlet air is bled through a restriction and applied to the top of the

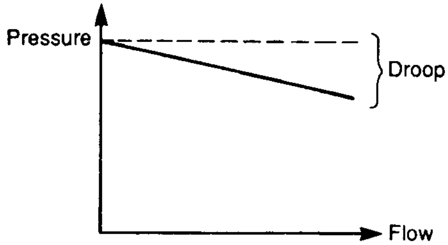


Figure 3.28 *Response of simple pressure regulators*

main diaphragm. This space can, however, be vented to the exit side of the valve by the small ball valve.

If outlet pressure is low, the pilot diaphragm closes the ball valve causing the main diaphragm to be pushed down and more air to be admitted to the load.

If outlet pressure is high, the pilot diaphragm opens the ball valve and the space above the main diaphragm de-pressurises. This

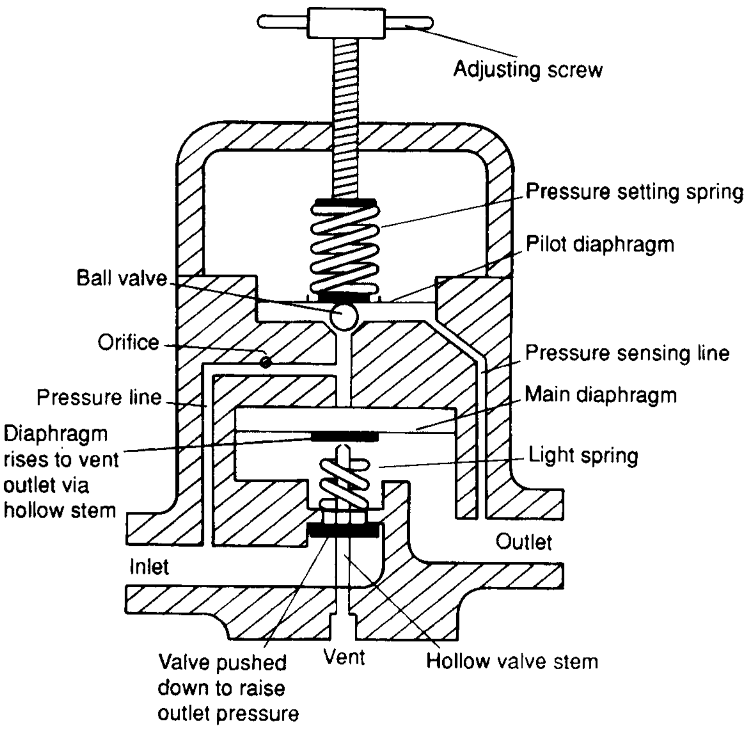


Figure 3.29 *Pilot-operated regulator*

causes the main diaphragm to rise, opening the central vent allowing air to escape from the load and pressure to be reduced.

Action of pilot diaphragm and inlet air bleed approximates to integral action, giving a form of P + I (proportional plus integral) control. In the steady state, the outlet pressure equals the set pressure and there is no pressure droop with increasing flow.

Service units

In pneumatic systems a moisture separator, a pressure regulator, a pressure indicator, a lubricator and a filter are all frequently required, local to a load or system. This need is so common that combined devices called *service units* are available. Individual components comprising a service unit are shown in Figure 3.30a, while the composite symbol of a service unit is shown in Figure 3.30b.

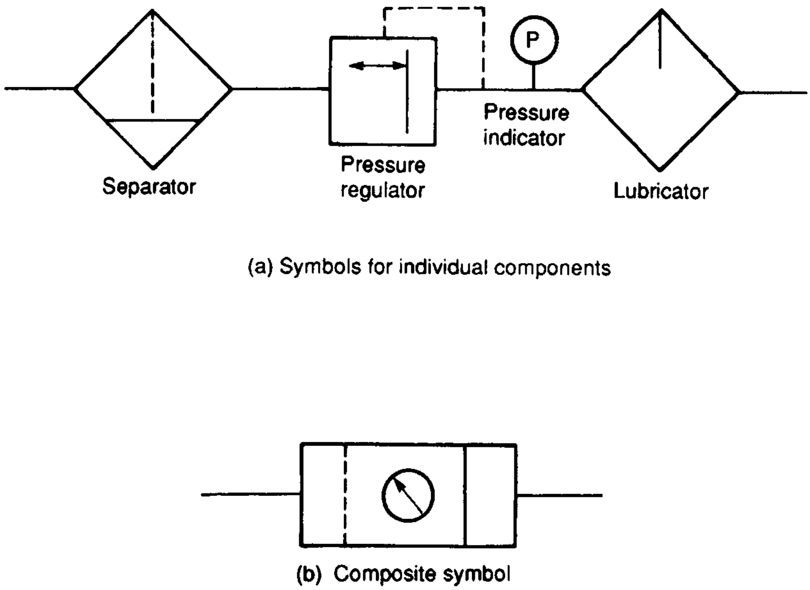


Figure 3.30 *The service unit*