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MARK THROWER MANAGING EDITOR

Saving the fourth utility

Eric Harding, managing director, Air Technology Ltd

Compressed air, often known as the fourth utility, is used throughout industry and other sectors as a very convenient and popular means of transmitting energy from the incoming source to usage points for many applications and processes at several pressure levels. If the system is designed and correctly operated compressed air is safe but it can be very dangerous if improperly applied.

Recent developments from the compressed air industry such as improved compressor and drive motor efficiency, variable speed drives, electronic compressor control systems and on line condition monitoring, improved efficiency of air treatment systems, smooth bore piping and energy-efficient using devices have helped to make air systems more efficient and these give opportunities for energy and other cost of ownership savings that can provide good paybacks on capital expenditure.

As industries turned from manual labour to use of machinery compressed air was used and still is in mining, shipbuilding, automotive manufacturing and general industry and its use has grown into many other fields such as waste water treatment, pharmaceuticals, chemical processes, microelectronics and a plethora of other applications. Many of the more recent applications demand very high levels of air purity all of which add to the cost of air generation.

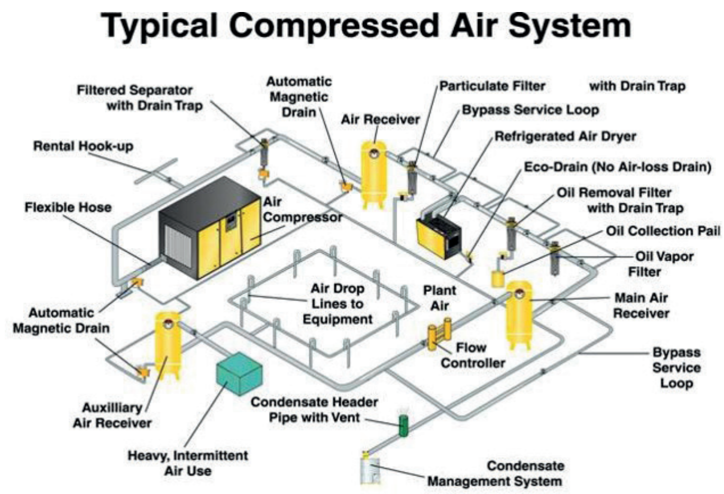

Fig 1 The components of a typical industrial compressed air system.

Other reasons are ease of connecting into distribution networks, safety in hazardous areas and flexibility (see Table 1).

What is not always understood is that compressing is an extremely costly method of transmitting energy (see Fig 1). As an example, the energy cost to drive a pneumatic tool at 7 barg such as a drill is increased by a factor of 10 when compared with using an electrically driven drill. This is due to the waste heat that is rejected by a compressor.

Compressors are only needed because the customer has a use for compressed air but as they are the beginning of the process it is logical to start with air generation.

There are several ways of expressing the efficiency of compressors such volumetric, isentropic and polytrophic but the only important measure of efficiency is the power input versus the air output at the specified pressure this is known as the specific power consumption (SPC).

The SPC depends on the size and configuration of the machines. At 7 barg it should be around 11 to 13kW/100m^3/h with the compressor on full load.

It is important to know the off load and part load power consumptions as well as the full load as very few compressors will be running at full load.

There are many configurations of compressors based on the flow and pressure requirements such as reciprocating, vane, diaphragm,

Table 1 gives typical applications of compressed air from ultra-high vacuum to the highest used pressures.

Description	Pressure barg	Applications
Ultra high vacuum	>-010^{9}	Surface spectrometers, particle accelerators and other scientific applications
Medium vacuum -10	-10	Glass blowing, dearation, dewatering and evacuation
Low pressure	Up to +4	Waste water treatment and product and powder conveying
Medium pressure	+7 to +10	General industry, handyman and dentistry
Medium to High pressure	+15	Aerosol filling
High pressure	+40	PET Bottle blowing
Ultra high pressure	+400	Specialist air bottle filling

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toothed rotor, scroll, roots blowers, rotary screw and centrifugal machines with lots of subsets around cooling, pressure and air quality requirements.

The most popular machines seen in the field are rotary screw and piston positive displacement machines and centrifugal flow dynamic machines.

The performance of positive displacement types can best be described with a pressure volume diagram as shown Fig 2. This type of machine inhales and compresses a fixed volume of air.

This would be for typical single stage piston or rotary screw machine.

Here it can be seen the air volume inhaled is compressed to the terminal pressure according to the equation PVn = C where n is the gas constant (for air this is around 1.39). As the air is compressed its volume decreases with the amount being delivered into the system being in relationship with the absolute compression ratio which in the case shown will be 1/8th.

Once the piston or open screw or vane flute completes its air delivery the compressed air left trapped within the machine has to re-expand until atmospheric pressure is reached at which time the machine can inhale more air.

The compressor can only deliver the amount of air that it inhales this is known as the free air delivered (FAD). The volumetric efficiency is the FAD divided by the swept volume.

The most efficient theoretical compression cycle is isothermal during which the temperature is constant.

Compressor designers attempt to approach isothermal by such methods as intercooling and oil or water injection.

When optimising air generation systems engineers should ensure that compressor intake air and cooling stream temperatures are as low as possible, suction filter pressure drop is minimised and the delivery pressure is set as low as possible to keep the compression ratio down and reduce the work being done.

Compressors are normally sized with some spare capacity to allow for peak demands so pressure drops are avoided and some growth for the future. This means that efficient control is important both of individual and groups of machines.

The most popular method of individual control of fixed speed machines can be by inlet valve opening when air is required or shut when there is no air demand known as two-step or all on-line off line control. Inlet valves can also be modulated over the higher ranges of demand from around 60 to 100 per cent. Inlet valve operation is controlled by the system air pressure that when rising to its top limit the machine will unload and when the pressure falls to its pre-set low limit the machine will load.

Two step control of fixed speed machines is the most frequently seen. Long periods of no-load running should be avoided as the power consumption will be around 20 to 25 per cent of the full load power.

Variable speed drive is available for positive displacement machines this can be more efficient than two step or modulation control as long

Fig. 2 Pressure volume of positive displacement compresssors

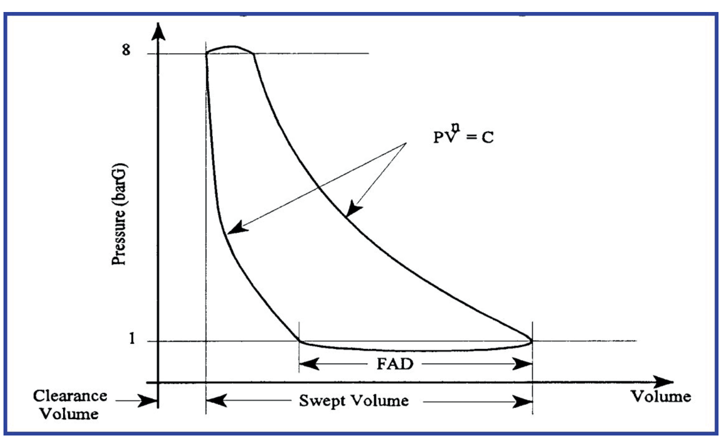
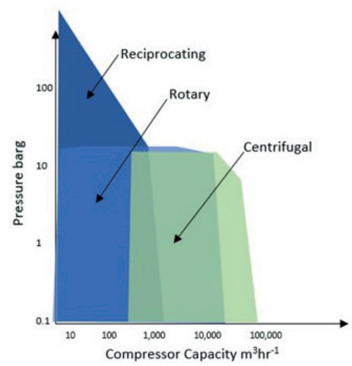


Fig. 3 The ranges of flow and pressure covered by the different configurations available



as the machine is correctly sized and does not run for long periods above 80 per cent of capacity where invertor and other losses make the machine less efficient.

The most common form of dynamic machine found in industry is the centrifugal flow machine. This type of machine inhales a volume of air at the atmospheric conditions prevailing then accelerates it in high speed impellors thus imparting kinetic energy that is transformed into pressure energy by reducing the air speed in the diffusers.

These machines can be controlled efficiently by inlet valve, inlet guide and diffuser guide vanes over the stable operating range before natural surge pressure becomes close to the design pressure.

Group control systems should always be aimed at ensuring that the most efficient machines in the installation are on line at all times at the minimum sensible generation pressure.

Electronic panels are available that the right mix of machines is on line at any one time. Correct sizing will avoid control gaps that can occur when running a fixed and variable speed control machine together.

To arrive at the best machine for a given duty the configuration must be established.

Issues to consider are:

- the air demand pattern over a typical process period;
- the air pressure required;
- the air quality required in terms of pressure dewpoint, hydrocarbon and particulate content and any special requirements such as silica free;
- maintenance requirements; and
- standby capacity needed.

Given this information a detailed specification should be written from which qualified vendors can produce proposals and detailed bid analysis can be undertaken. This work will result in ensuring that the machinery chosen may not have the lowest cost but will have the best life cycle costs for the duty.

Fig. 3 shows the ranges of flow and pressure covered by the different configurations available.

Following generation, the air is treated to the standard required by the end-using process by a variety of methods. The quality of the air used ranges from quite low for tools to extremely high for microelectronics paint finishing, food and pharmaceuticals where the air can be in contact with the product.

When the air leaves the final stage of the compressor at terminal pressure it is hot and fully saturated with water that has been inhaled from the atmosphere. As the air is cooled water condenses and if there is no treatment it will arrive at the usage points.

This cannot be tolerated and treatment to remove the water following air compression is required.

The first stage of treatment is the aftercooler that can be air or water cooled. This will reduce the air temperature from over 100°C to within 10° of the cooling medium's temperature and will remove around 80 per cent of the water. This is good enough for some end users but for some further treatment will be required.

There is usually a wet air receiver sized correctly for the delivered volume of the installed compressor capacity. This removes some of the entrained moisture and helps smooth out any pulsations.

There are many types of air dryer. Selection of the correct dryer for the duty will depend on the required pressure dewpoint for the process.

Condensate removal from the aftercoolers, air receivers, filters, dryers and other drainage points should be by use of automatic drains the best type being of the zero-loss electronic configuration.

Other contaminations found in compressed air are oil and particles. The most popular general purpose compressors are usually lubricated screw or piston machines that have oil in the compression chambers.

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Some hydrocarbons are present in the atmosphere in industrial areas and these are inhaled and concentrated by the compressors.

For specialist end users, such as pharmaceutical plants, microelectronic manufacturers, food and beverage plants and motor vehicle paint shops oil free compressors are normally specified.

Oil can be removed from the compressed air by filters sometimes in several stages to arrive at the quality required. Odours from air that is used for breathing can be removed by carbon towers. Particles come from compressor wearing parts and from pipework. Filtration is employed to remove particulate.

For specialist duties the air system pipework is manufactured from welded polished bore stainless steel or copper to prevent particles.

The ISO8573.1 compressed air quality standard should be used when specifying air quality for the above contaminants. This will ensure that the correct levels of treatment are applied for the duties the air is to be used on saving both capital and energy costs.

Another contamination that occurs in compressed air systems is microbial this must be avoided in pharmaceutical manufacturing and some beverages and food products for domestic use where shelf life can be reduced by microbes that live in the compressed air systems.

Treatment is by the use of steam sterilised filters and use of desiccant dryers as microbes cannot breed in air at pressure dewpoints below -30°C.

Distribution networks

Following treatment there is often a dry air receiver then air is fed to the usage points by distribution networks. These should be sized with a maximum flowing velocity of 6m per second with the full output of the compressor station on line to avoid pressure losses. Ring mains are preferred to spur mains and local air receivers can be beneficial close to points of high demand.

Because compressed air is expensive its use should be carefully considered. It may be possible to use an electric tool rather than an air tool, or a centralised vacuum system rather than local vacuum ejectors on a production machine.

Once it is established compressed air is to be used then the correct pressure for the duty should be applied. To avoid overpressure local regulators can be employed. When there is no production on a line, in a department or a factory the air should be turned off to avoid waste. Any essential users can be supplied by small compressors.

Leakage is one of the main sources of waste in air systems and can often be easily rectified. The optimum leakage rate should be less than 5 per cent of the mean production air demand. This figure can usually be arrived at by taking timings of the loaded and off loaded times or by speeds of variable drive units or by flow metering during and in and out of production times.

There are several methods of leak detection such as by ear and soap and water solutions but the most effective method is by use of a good quality ultrasonic leak detector.

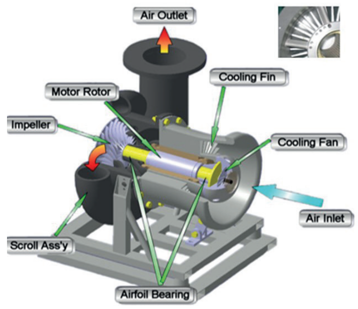
Leaks that occur in the hard piping before any system regulators will vary in air loss according the absolute system pressure ratio as the pressure rises and falls with compressors loading and unloading. This is known as artificial or unregulated demand. The leakage loss downstream of regulation is a constant amount.

The heat rejected by air and water cooled compressors in their cooling streams can be recovered and used if a suitable application can be found.

The compressed air and using equipment supply industries are becoming much more aware of the energy costs associated with the service. With compressors the drive efficiencies have been improved by use of permanent magnet motors mounted directly on the compressor drive shaft. These have very high electrical efficiencies eliminating the coupling or belts reduces the drive losses. This type of motor can be controlled by an invertor to provide variable speed drive. It is possible to purchase twin element oil free screw compressors with LP & HP air ends individually driven by its own permanent magnet motor thus eliminating the need for a gear box and oil that enables the machine to have very good efficiency over a wide range of flows.

Latest designs of centrifugal flow dynamic machines include permanent magnet motors with the high-speed pinions directly driven. The pinions can be supported on magnetic or air foil bearings again meaning that no gear box and lubricating oil is required saving energy and maintenance. Fig. 4 shows one of the latest compressor designs that is used in waste water treatment plants.

Fig. 4 One of the latest compressor designs



Desiccant dryers

Energy-saving developments in air treatment systems include desiccant dryers using waste heat of compression to regenerate the towers, dewpoint sensing control and low pressure loss dryer and filtration systems.

At the point of use there are several air-saving devices such as multi-stage vacuum generators and nozzles that can be employed.

Making sure that all the components of a compressed air system are properly maintained is most important from the energy efficiency and reliability standpoint.

It is recommended that the original equipment manufacturer or their accredited agent are used to undertake all service work and that it is conducted within the recommended hours run. It is a false economy to run machinery for longer than the recommended intervals this can apparently save money but the additional energy costs far outweigh and advantages.

Optimising compressed air systems can enable excellent energy savings of around 30 per cent over the original generation cost to be achieved some at little or no cost.

Achievable savings can be generalised with the first low cost 10 per cent coming from reducing leakage, wastage and generation pressure and condensate trap losses, the next medium cost 10 per cent that should provide a return on investment within one year from improving distribution networks, compressor control and air treatment and improved maintenance with the final higher cost 10 per cent coming from new compressors, variable speed drives, new efficient air treatment systems and point of use improvements where ROI can be much longer unless savings in maintenance costs are also taken into account.

Energy savings areas are air generation, air treatment, distribution networks, use and misuse, leakage and waste heat recovery. Each of these is discussed in detail below:

With air generation the minimum pressure that is required at the usage points should be established then the potential saving by reducing the air generation pressure can be calculated based on a cost reduction of 6 per cent per bar of pressure reduction. To enable pressure reduction restrictions in the air system should be identified and eliminated.

With the air system on full load the pressure loss across the air treatment system should not exceed 0.5 bar and from the exit of the treatment system to the far end of the distribution system the loss should not be greater than 0.2bar.

Control systems that ensure only the minimum number of machines to meet the duty are on line. Variable speed driven machines can be very beneficial but should not be run for extended periods at over 80 per cent capacity due to invertor losses. Control systems should always be programmed to ensure that variable speed machines are always used as the control unit when there is a mix of variable and fixed speed units. Fixed speed machines should always be used as base load units.

Treatment should be to the minimum standard required as an example air at a pressure dewpoint of +3°C is perfectly suitable for most factories but there may be a small use of high quality air at -40°C for instrumentation that should be treated by a local dryer to save energy costs.

All desiccant dryers should be fitted with dewpoint sensing controls that will avoid over regeneration of the towers.

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SERIES **17** | MODULE **07** | JANUARY **2020**

ENTRY FORM

COMPRESSED AIR

Please mark your answers below by placing a cross in the box. Don't forget that some questions might have more than one correct answer. You may find it helpful to mark the answers in pencil first before filling in the final answers in ink. Once you have completed the answer sheet, return it to the address below. Photocopies are acceptable.

QUESTIONS

1. Approximately what percentage of industry's electricity bill is spent on generating compressed air?

☐ 10% ☐ 15% ☐ 20% ☐ 25%

2. Why does compressed air at 7 barg used for an air tool cost 10 times more than the electricity used for an equivalent electric tool?

☐ Because the air is supplied through a hose of too small a diameter

☐ Because the air tool bearings are too stiff

☐ Because the compressor rejects over 90% of the input energy

☐ Because the air is on all the time

3. What is the best method of determining compressor full load and part load efficiency?

☐ Its power consumption

☐ The temperature of the cooling medium

☐ Its specific power consumption

☐ The unloaded power consumption

4. What is the typical off load power for a screw compressor running load/no load?

☐ 25% ☐ 65% ☐ 10% ☐ 80%

5. What is the difference between positive displacement and dynamic machines?

☐ The dynamic machine runs at a higher speed than the positive displacement machine.

☐ The positive displacement machine inhales a fixed volume then pressurises it to terminal pressure whereas the dynamic machine imparts kinetic energy on the inlet air stream.

☐ The dynamic machine is only available for oil free duties

☐ All of the above

6. What contaminants can occur in compressed air?

☐ Oil ☐ Water

☐ Particulate ☐ All of the above

7. To avoid pressure losses what should the flowing velocity in air mains be?

☐ 6 m/s ☐ 10 m/s

☐ 2 m/s ☐ 30 m/s

8. How would you use waste heat from a compressor?

☐ For space heating of a factory

☐ To heat domestic hot water

☐ To preheat boiler feed water

☐ All of the above

9. How much can the energy cost for generating 7 barg air be reduced if the pressure is lowered by 0.5 bar?

☐ 3% ☐ 6% ☐ 2% ☐ 11%

10 What is the best method of making a desiccant dryer efficient?

☐ Change the desiccant

☐ Bypass the dryer

☐ Fit dewpoint sensing control

☐ Buy a new dryer

Please complete your details below in block capitals

Name .... (Mr. Mrs, Ms) ....

Business ....

Business Address ....

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Completed answers should be mailed to:

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This is the seventh module in the seventeenth series and focuses on **Compressed Air**. It is accompanied by a set of multiple-choice questions.

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