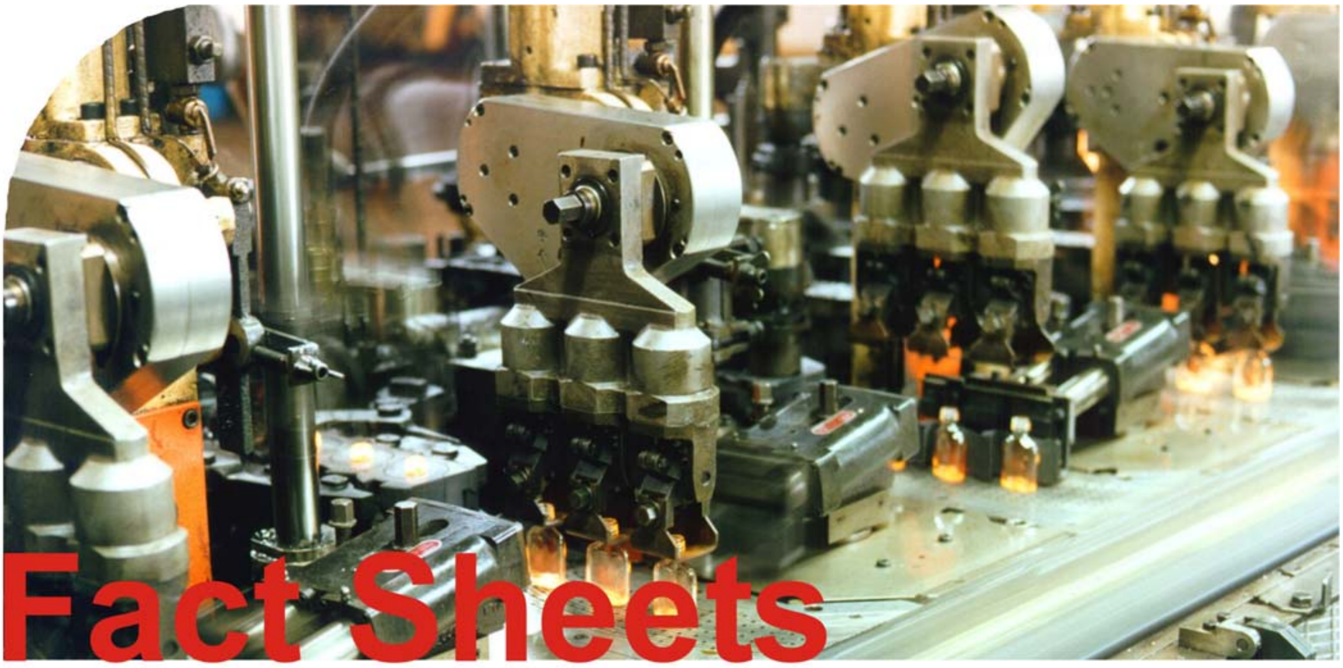

Fact Sheets
Compressed Air

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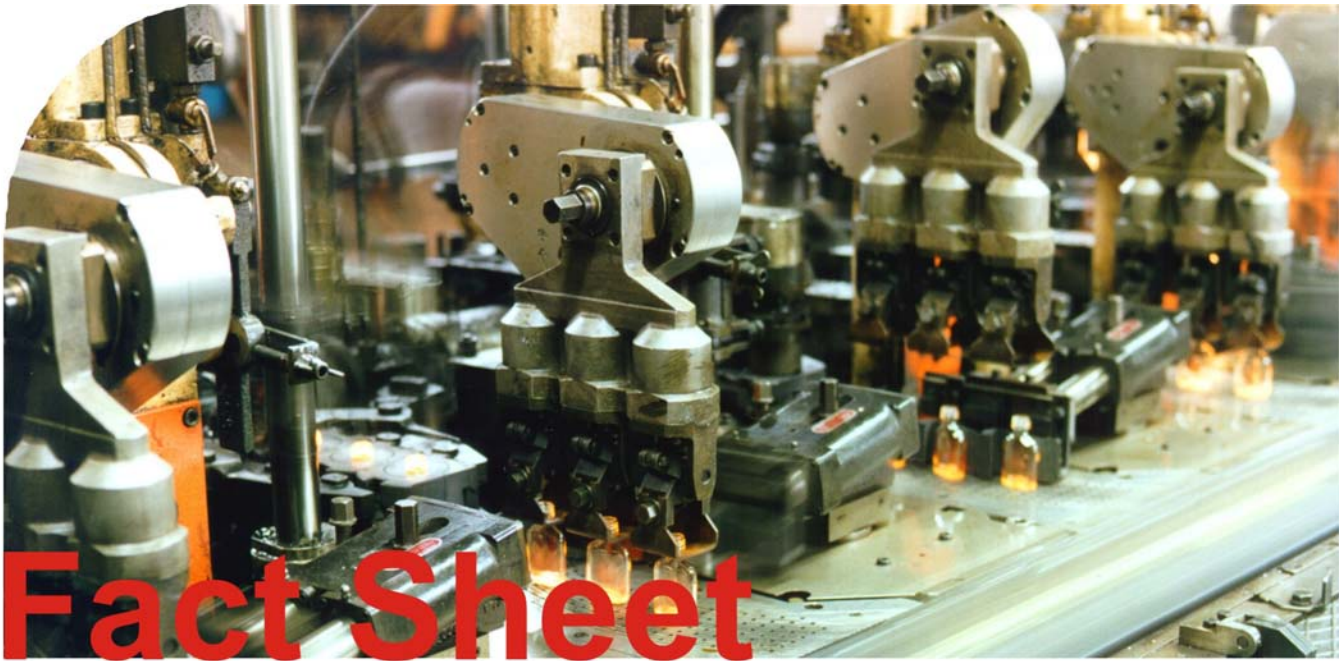

Applications

Characteristics of compressed air

Compressed air is an energy form offering an unrivalled range of applications and combining speed, power, precision and safe handling. These characteristics make compressed air irreplaceable in many cases. However, there are applications in which compressed air is in competition with other forms of energy such as electricity or hydraulics which are of interest. Here, the principle of economic efficiency demands a precise cost-benefit analysis. The relatively high costs of producing compressed air always have to be weighed against factors such as working speed, reliability, maintenance costs etc. The best available technology should be taken as a base. Compressed air applications have made tremendous progress in recent years with regard to energy efficiency.

The versatility of compressed air becomes very clear if one looks at application examples:

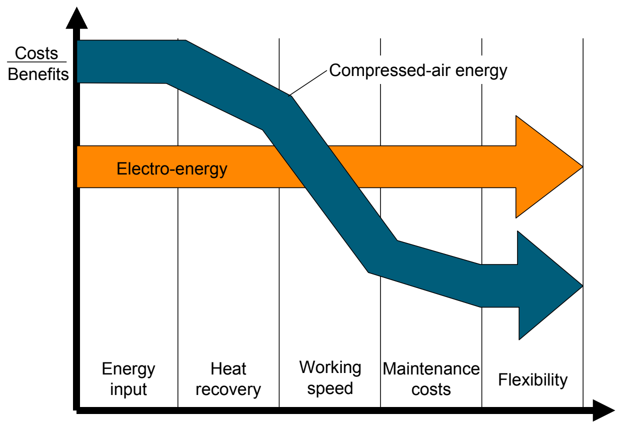

Fig. 1: Qualitative cost-benefit comparison taking into account relevant parameters

Working and energy air

As an important field of application for compressed-air, pneumatics has shown a two-digit growth rate for years. More and more new patents are being filed on compressed-air cylinders, air engines and compressed-air valves.

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Fig. 2: Automation using compressed air

The speed, precision, flexibility and miniaturisation of these components play an important role.

Without compressed air the degree of automation essential for the competitiveness of companies would not be possible.

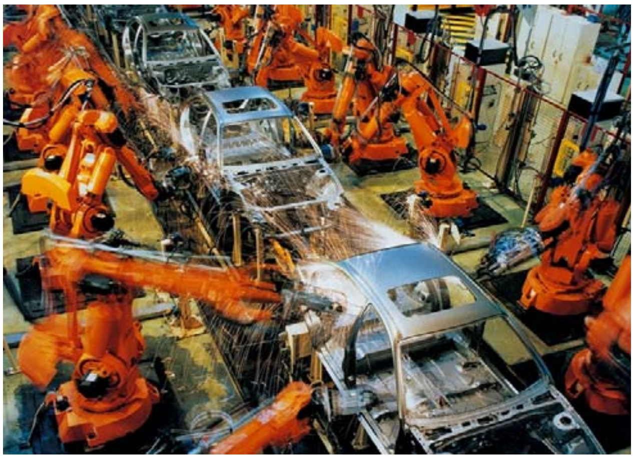

Fig. 3: Robots operated using compressed air

Life today cannot be imagined without a multitude of products which can only be produced using compressed air.

Fig. 4: Plastic bottles

Another special feature of compressed-air devices is their possible application in explosion-proof areas.

For example, compressed-air hoists ensure that there are no sparks caused in varnishing plants.

Fig. 5: Explosion-proof mechanical hoist

To equate compressed air only with old-fashioned applications does not correspond to the state-of-the-art. For example, cleaning work benches using compressed air is no longer up-to-date. In many cases, a hand brush would also do the job. However, if compressed air is still being used for such a task then it is recommended to use optimised jets which achieve a maximum cleaning effect with minimal air consumption.

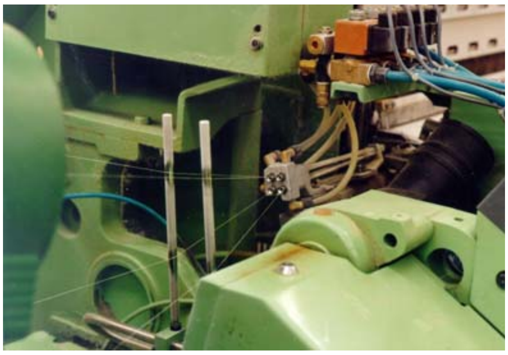

Fig. 6: Air-jet loom

Active air

You talk about 'active air' if compressed air is being used as a transport medium. Current application examples are transporting bulk goods, shooting the shuttle back and forth in looms, applications in air bearings or the recently rediscovered pneumatic post.

Several advantages of compressed air can be shown based on the example of air bearings. Laser guns for aiming GEO satellites have to be positioned exactly and automatically guided. In order to achieve the necessary precision of ±1/3600 degrees, the optical system is air cushioned. The air bearings allow completely smooth and infinitely variable telescope movements for high measurement accuracy and shield it from vibrations. Without compressed air, such modern methods of geodesy would hardly be practicable.

Process air

If compressed air is directly incorporated as a process medium in certain processes, then it is called process air. Common areas of application are drying processes, the aeration of clarifiers or air for fermentation processes.

Fig. 7: Fermenting and bottling

Industrial Vacuum

Industrial vacuum technology is closely related to compressed air. Several applications can be solved using either compressed air or a vacuum. Using an industrial vacuum it is possible to pack, dry, stretch, perform suction, hoist, position and many others. More and more sectors are recognising the merits of vacuum applications.

The electronic industry can be cited as an example, where production depends on absolute precision with the largest possible output. In accordance with "clean production", extremely precise, very small vacuum pumps ensure the exact handling of electronic circuit boards under clean-room conditions and their fitting with microchips. The stable, controlled vacuum "grasps" the chip and positions it at exactly the right place on the printed circuit board.

Fig. 8: Circuit board production

Pressure ranges

Different applications require different pressures. It is very rarely economically justifiable to compress to the highest pressure required and then subsequently reduce the pressure again. Therefore it is necessary to categorise the pressure ranges and apply correspondingly suitable generation systems.

- **Vacuum and blower applications**

  These range from rough vacuums up to the excess pressure range of approx. 1 bar. These pressure levels can be generated very economically using rotary valve vacuum pumps, rotary piston blowers and side channel fans.

  There is the possibility to generate industrial vacuums using compressed air but in almost every case this would represent a misuse of compressed air. Specialised vacuum pumps operate on only a fraction of the energy input necessary for compressed air.

- **Low pressure applications**

  Low pressure applications refer to those in the range from 2 up to 2.5 bar excess pressure. Rotating positive-displacement compressors are generally used here, but turbo compressors are also feasible for extremely large amounts.

  Specifically in low pressure applications which make do with much lower excess pressures than the classical 6 bar, it can frequently be observed that these appliances are connected to the 7-bar grid. At the point of use, the pressure is then simply reduced accordingly. In such cases it should be a matter of urgency to check whether the introduction of a separate low pressure supply could raise economic efficiency.

- **Standard pressure applications**

  There is a broad range of compressors available for standard pressure applications which are served from a 7-bar grid. The specifications regarding the amount and quality of air determine which combination of compressors operates most economically

- **High pressure applications**

  Oscillating positive-displacement compressors such as piston compressors or membrane compressors have their field of application in the two and three figure bar range. Radial turbo compressors may also be an economic choice when large amounts of air are involved.

  It is quite common that a few high pressure consumers can be supplied very economically via the standard compressed air network with decentralised booster compressors close to the high pressure consumers.

Correct pressure

Every consumer of compressed air requires a certain working pressure in order to be able to deliver an optimal performance. For example, for tools which are powered with only 5 instead of the necessary 6 bar, the on-load speed falls by 25 % even though the idling speed only drops by 5 %. Regular checks are therefore indispensable to see whether the required working pressure is available, especially under full load conditions. Pressure losses due to an insufficient piping cross-section or bottlenecks can only be detected if the compressed air is actually flowing. Excess operating pressures do not bring any gains in performance. They only increase the consumption of compressed air and the wear and tear of the equipment

Quality of compressed-air

There is a similar picture for insufficiently processed compressed-air. Particles, damp and oil afflict compressed-air equipment and increase their fault liability. Increased wear and tear and output losses are still relatively small problems compared with total failure which may lead to loss of production. But even if the compressed-air equipment is operating trouble-free, impurities can enter processes via insufficiently conditioned compressed-air which may result in the loss of whole production batches.

Conclusion

Whoever selects his compressed-air applications with care, adjusts the compressed-air system accordingly and consistently monitors the parameters relevant for economic efficiency and operating safety, has certainly made a decision in favour of a modern and efficient energy supply.

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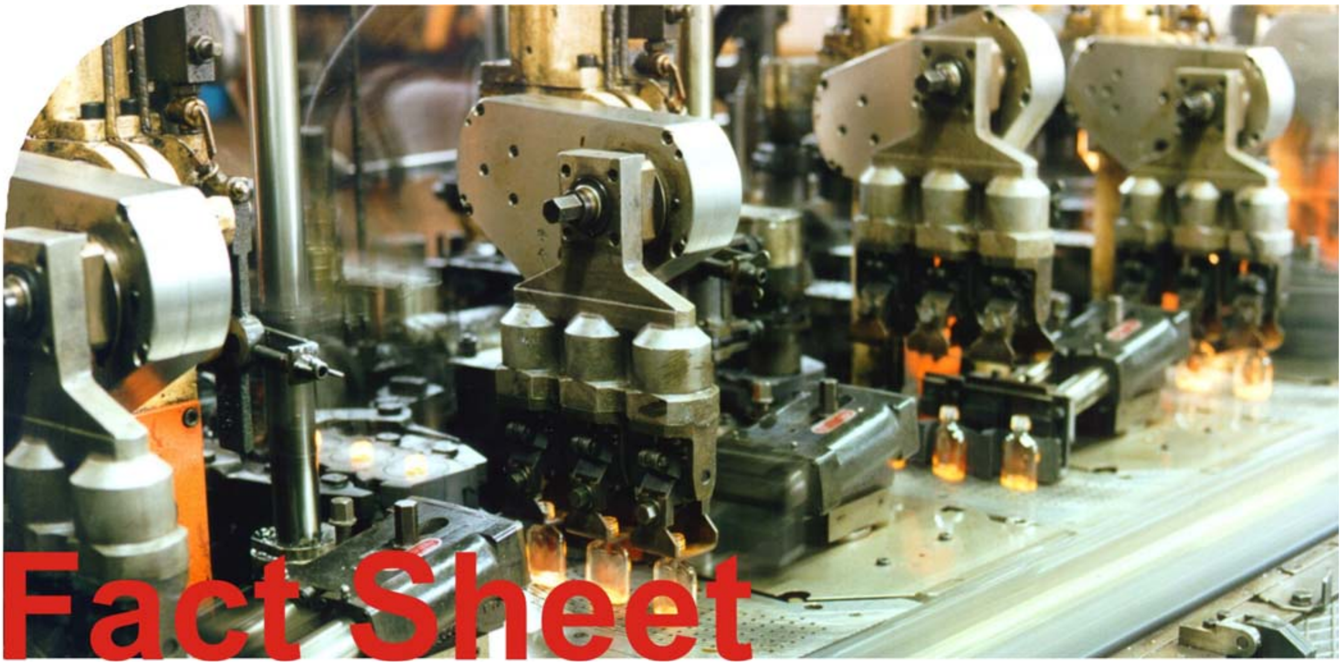

Fact Sheet
Thermodynamics

Compressed air is used in industry as an energy source like electricity from the wall outlet. The effort and expense necessary for producing, treating and distributing the compressed air is frequently overlooked. In order to provide a better understanding, the basic physical correlation are explained here and typical misunderstandings are pointed out.

Composition

Compressed atmospheric air is usually implied by the term 'compressed air'. The major components of unpolluted air are **nitrogen (78 vol-%) and oxygen (21 vol-%)** as well as small amounts of other gases (1 vol-%) (Fig. 1).

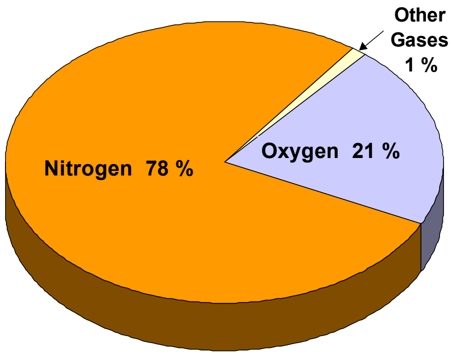

Fig. 1: Composition of dry atmospheric air

Water is also contained in atmospheric air in the form of water vapour, the amount of which varies strongly depending on temperature, volume and geographical conditions. For this reason, the share of water is usually given separately from the other components.

Pressure

This is the main parameter of compressed air which is usually expressed in the units bar or PSI (PSI = pound/(Inch)^2; 1 bar = 10^5 Pa = 10^5 N/m^2 = 14.504 PSI).

Absolute pressure (PSIA) is the pressure measured from a base of absolute zero. It is required for all theoretical observations as well as in vacuum and fan technology.

Gauge pressure (PSIG) is the practical reference value and is determined based on atmospheric pressure. Absolute pressure and gauge pressure are given in the same units. Therefore, when looking at pressure values, care must be taken to determine whether absolute or gauge pressures are involved. In practice, gauge pressures are usually meant since pressure sensors mostly display gauge pressures, i.e. the difference between absolute and atmospheric pressure (see Fig. 2). To avoid confusion, it may be sensible to show the reference in pressure figures using an index.

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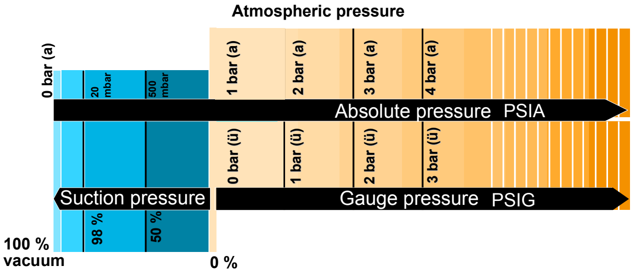

Fig. 2: Gauge, absolute and suction pressure

Water content

The maximum water vapour absorption capacity of air is described by the saturation pressure p_s. How much water can be absorbed is solely a function of the temperature. The absorption capacity increases with increasing temperature (Fig. 3).

If the air is cooled, therefore, there is always the danger that the water vapour contained will be condensed out and that condensate will be formed.

Condensate may also occur if the saturation pressure is exceeded during compression. If humid, atmospheric air is compressed at constant temperature, the partial pressure of the water vapour also increases corresponding to the increase in overall pressure. If the saturation partial pressure at this temperature is exceeded due to compression, condensate is precipitated. Since the air leaves the compressor with a much higher temperature, the condensate is only precipitated if the compressed air is cooled down beneath the pressure dew point. Below this temperature, condensate is precipitated continuously, i. e. in the aftercooler as well. Approx. 60-80 % of the total amount of condensate are formed here. A further intentional separation and drying of the compressed air takes place subsequently in the drier or unintentionally in the pipes.

If air with a relative humidity of 60 % and a temperature of 15 °C is compressed to a pressure of 7 bar and subsequently cooled again down to 25 °C, 30 g of condensate are obtained per cubic metre compressed air.

Further information on this topic can be found in the fact sheet "Treatment".

Power demand for compression

When describing changes in the state of air (compression, expansion, cooling) thermodynamically, air can be regarded as a perfect gas in the temperature and pressure range relevant for compressed air. The perfect gas equation describes the relation between the pressure (p), volume (V) and temperature (T) of a gas.

The following applies:

$$p \cdot V = m \cdot R_i \cdot T$$

or with reference to the amount of substance n

$$p \cdot V = n \cdot R \cdot T$$

with R as the universal gas constant with the value R = 8.3144 J/(mol K). It is then valid that the product from the pressure and volume of the air is proportional to the temperature. The perfect gas equation can be used to describe the changes in state occurring.

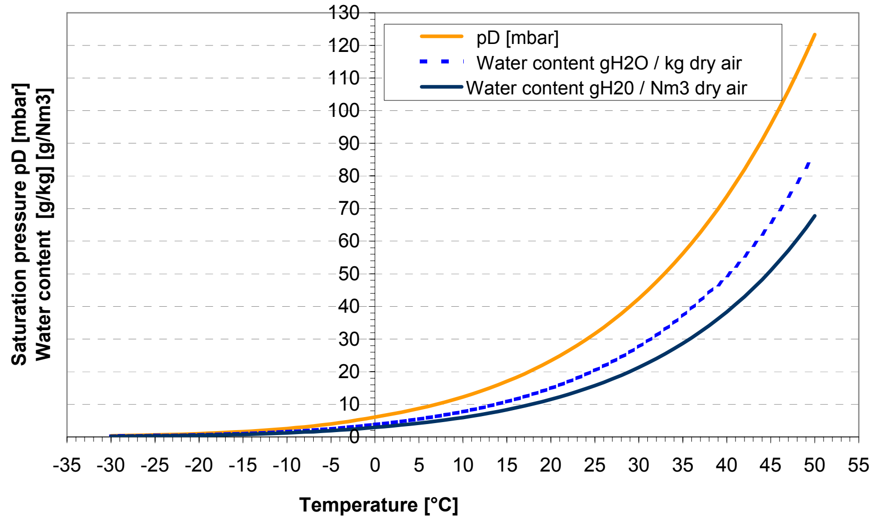

Fig. 3: Saturation pressure and water content of air

The two most important kinds of state changes are the isothermal (pressure change at constant temperature) and the adiabatic (isentropic) (pressure change without heat exchange with the surroundings).

For isothermal changes, the following applies:

$$p_1 V_1 = p_2 V_2$$

with *R* and *T* = const.

The specific work for compression results from the work for changing the volume

$$w_{12} = -\int_1^2 p \cdot d\upsilon = -p_1 \cdot \upsilon_1 \cdot \ln \frac{\upsilon_2}{\upsilon_1}$$

The following applies to **adiabatic** changes:

$$\frac{p_1 \cdot V_1}{T_1} = \frac{p_2 \cdot V_2}{T_2}$$

with R = const.

For temperature:

$$\frac{T_1}{T_2} = \left[\frac{\upsilon_2}{\upsilon_1}\right]^{(\kappa-1)} = \left[\frac{p_1}{p_2}\right]^{\frac{\kappa-1}{\kappa}}$$

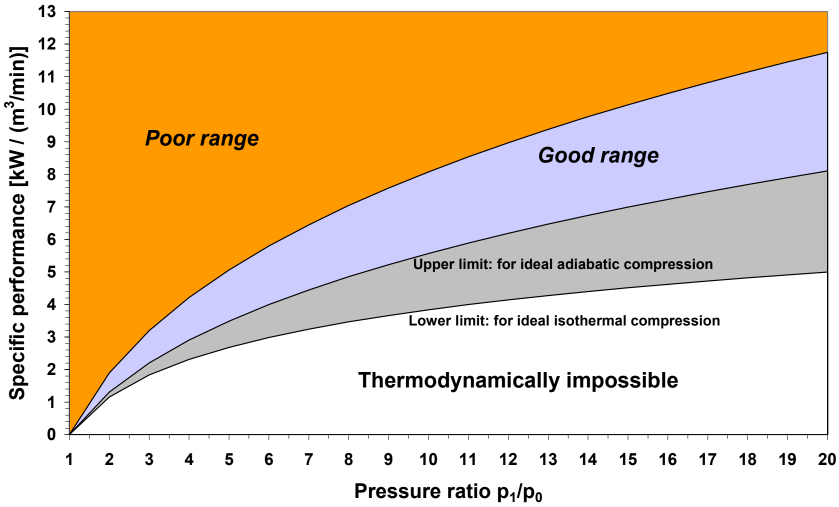

Fig. 4: Specific power demand for compressed air production

and for the specific work

$$w_{t,12} = \int_1^2 \upsilon \cdot dp = \int_1^2 c_p \cdot dT = c_p \cdot (T_2 - T_1)$$

For air in the relevant range for compressed air, the adiabatic exponent κ has a value of κ = 1.4 kJ/(kg K).

The theoretical energy demand for compressing air is thus dependent on the compression ratio and the type of change of state. Whereas the isothermal compression results in the lowest specific work, the actual state characteristics during compression (polytropic compression) are closer to reversible adiabatic compression.

These optimimum values are not achievable in practice, since the compression process is afflicted with losses. Good compressed air systems are characterised by specific capacities which are approx. 45 % above the theoretically possible ones of adiabatic compression (Fig. 4). It should be noted that the specific energy required decreases with increasing system size. The specific performance data given incorporate all electrical and mechanical losses during compressed air production. They are not directly comparable with the rated power listed on the nameplate of the drive motor of the compressor. The specific power consumption of a compressed air system should lie within the good range. The lower limit of the good range is described by the adiabatic compression which represents an ideal case and therefore cannot be achieved by real compressors.

Further information on compressed air production can be found in the fact sheet "Production".

Pressure losses

After production and treatment, the compressed air has to be distributed in a network to the user points. As well as the pressure losses occurring during treatment, other losses occur during distribution due to the pipe resistance which represent a loss of energy. The loss due to friction is much greater in turbulent flows than in laminar flows (Fig. 5).

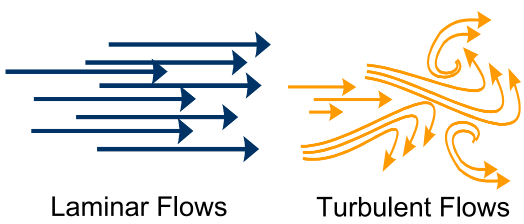

Fig. 5: Laminar and turbulent flows

Whether a laminar flow occurs in a pipe depends mainly on the velocity of flow. The influence of pipe roughness is negligible and can be ignored, more decisive are the changes in pipe diameters at joints. Turbulent flows in the whole of the distribution system are predominant in compressed air systems. The degree of turbulence increases with increasing flow velocity. The greater the velocity of flow, the greater the flow losses.

The flow velocity results from the relation of volume flow and cross-sectional area for incompressible flows.

$$\upsilon = \frac{\dot{V}}{A}$$

Pipe diameters which are too small result in high flow rates and high pressure losses in the piping. To restrict these losses, the flow rate in compressed air distribution should be preferably smaller than 6 m/s.

Further information on distribution can be found in fact sheet "Distribution".

Measuring compressed air

Although compressed air is a high quality and expensive energy source, usually neither the compressed air consumption nor the energy demand for its generation and treatment is recorded. Measuring and recording the consumption is, however, a key element for optimising the costs and energy use in the field of compressed air. Further details can be found in the fact sheet "Measurement technology".

More information can be found in the fact sheets on other topics. This fact sheet aims to supply initial information but cannot replace the problem-specific advice given by specialists.

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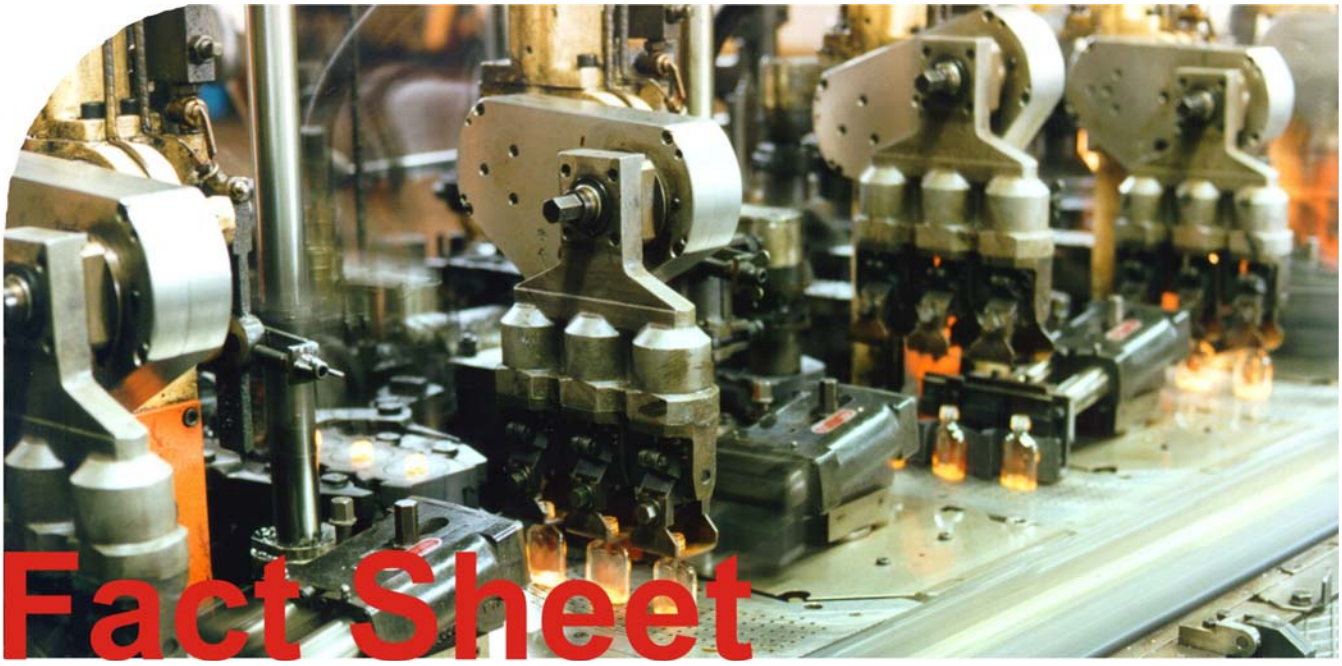

Measurement Technology

In the field of compressed air, measuring pressure provides the data basis for rating the correct pressure head of pressure differences in the distribution system as well as for controlling and regulating the compressors. Before a compressed air system is dimensioned or optimised, the volume flow should be measured. If especially high compressed air quality is required, the relevant measurements provide the basis to ensure compressed air quality as well as to optimise compressed air processing.

Pressure measurement or differential-pressure measurement

Measuring pressure under flow conditions is mainly done to control and regulate compressors or compressor systems as well as to assess compressed air systems.

Differential-pressure measurement is used in addition to monitor the functional performance and economic efficiency of the air processing systems such as filters.

Membrane pressure switch

In many of the compressors and compressor systems used today, membrane pressure switches record the pressure and pass on the data measured in the form of an electrical switch signal.

Please note:

- the ageing of the mechanical components impairs the repeatability.
- Membrane pressure switches require a high differential gap before they react and need a lot of room.

Contact manometer

Up until the 1990s, it was considered state-of-the-art to use mechanical contact manometers for differential-pressure measurements, e. g. to monitor filters or to control compressor systems.

Please note:

- in order to achieve sufficient resolution, the optimal measuring range should be close to the operating range.
- Electrical connections result in mediocre repeatability and complicated adjustments of max. four usable contacts.

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Electronic pressure sensor

The compressors of modern compressor systems should be controlled based on the pressure measurements of electronic pressure sensors which convert the pressure values into analogue signals.

Please note:

- pressure sensors with an output signal of 4 to 20 mA help to avoid cable breaks.
- If the maximum of the measuring range is close to the range of parameters to be controlled, a higher resolution should be aimed at.
- These very robust and reliable systems are characterised by their high repeatability as much as their compact construction.

Measuring the volume flow rate

Measuring the volume flow rate is used to detect the capacity of compressors both with regard to the total air consumption of a plant as well as with a view to individual air consumption of local production facilities.

It must be taken into account that the volume flow data of compressors and air consumers refer to the operational environment, but that the measurement is made in the system conducting the pressure. It is therefore necessary to convert the measured data to the operational environment.

In order to obtain an absolutely exact result, not only the volume flow rate, the temperature and the pressure of the compressed air, but also the atmospheric pressure, the atmospheric temperature and the humidity of the inlet air have to be determined (see Fig. 1). This is indispensable for performance testing compressors.

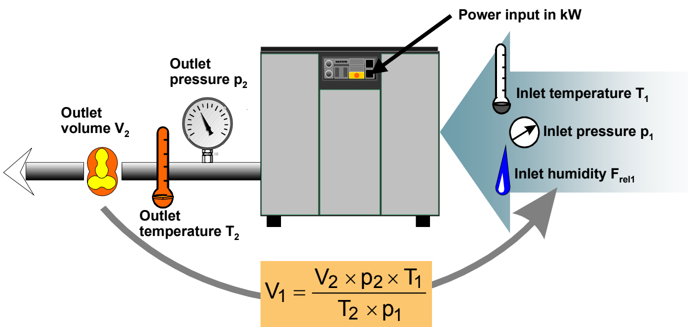


Fig. 1: Measuring the inlet volume flow rate

Volume flow rate measurements for in-plant accounting or planning a compressor system do not justify the cost of parallel measurements of the ambient temperature, humidity and atmospheric pressure.

However, a backward projection should be made based on average pressure and temperature conditions at the installation site.

Temperature and pressure compensation

Pressure and temperature are rarely constant in a compressed air system. Therefore when measuring air consumption, the pressure and temperature should be determined as well as the volume flow rate, so that a correct backward projection of the measured operating state can be made based on the ambient conditions (see gas equation, Fig. 1). This is essential for an accurate measurement.

Without temperature and pressure compensation

If a volume flow rate measurement is made without parallel pressure and temperature measurement and without backward projection of these factors to the relaxed state, it is only possible to determine the volume flow at actual temperature and pressure conditions. Otherwise pressure and temperature fluctuations occurring during the measurement result in errors when projecting backwards to the ambient state.

Direct measurement of the volume or mass flow rate

Measuring the dynamic pressure makes it possible to determine the volume flow rate with a high degree of accuracy. A venturi nozzle can be used or alternatively a dynamic pressure sensor (see Fig. 2).

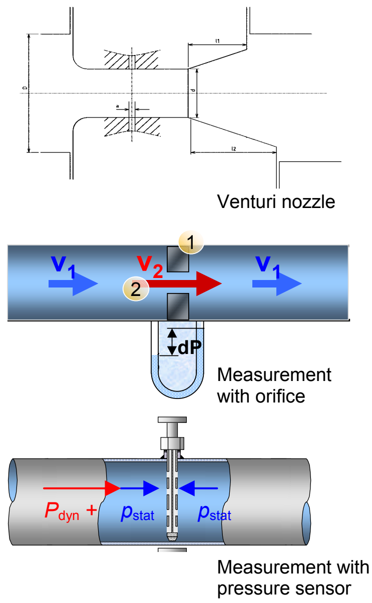


Fig. 2: Measuring dynamic pressure

Please note:

- In order to reach sufficient resolution, the optimum measurement range should be close to the operating range.
- Electrical connections result in mediocre repetitive accuracy and complicated adjustments of the max. four usable contacts.
- The correct lengths of the inlet and outflow zones are important as is the insertion of the measuring device into the distribution system and the exact geometrical data of the pipe.
- Attention!: contamination hazard.
- If the flow rate falls below 10 per cent of the maximum measured value, this results in lower measurement accuracy.

Volumetric measurement

Volumetric measurements are highly accurate measurements which are used, e. g. to determine the capacity of compressors. The most important measuring devices are rotary displacement gas meters and turbine gas meters. Whereas the rotary displacement gas meter should be applied in a measurement range from 10 to 90 % of its max. volumetric flow rate, the turbine gas meter is very accurate in the lower measurement range as well.

Please note:

- these measurement devices are complex mechanical components requiring intensive monitoring.
- Not overload-proof (danger in depressurised compressed air system).

Calorimetric measurement

So-called hot-wire anemometers can measure the volume flow rate as a function of the mass flow rate in a compressed air pipe by relating the heat removed to the volumetric flow rate (see Fig. 3).

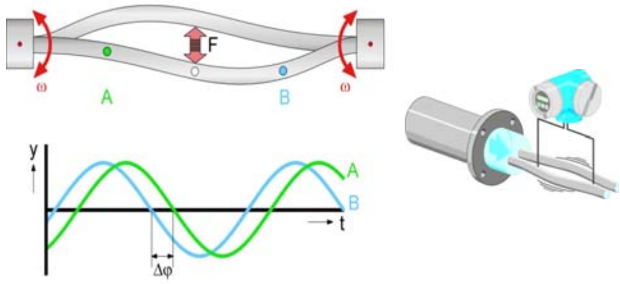
Fig. 3: Calorimetric volume flow rate measurement

Please note:

- Without temperature and pressure compensation, deviations from the design point in temperature, humidity and pressure fluctuations have a strong influence on the result.

Coriolis mass flow rate measurement

Is based on exploiting the controlled generation of the coriolis force. These forces occur where translatory (straight) and rotary (rotating) movements overlap. The magnitude of the forces depends on the masses moved and their velocity and thus on the mass flow rate (see Fig. 4).



ω	= Angular velocityt	A, B	= Sensors
F	= Coriolis force	y	= Amplitude
Δφ	= Phase shift	t	= Time

Fig. 4: Coriolis mass flow measurement

Others

In addition to the classical methods of measuring volume flow rate, there are several new measurement systems available today.

Karman Vortex Street

The volume flow rate measurement is based on the Karman vortex street (see Fig. 5).

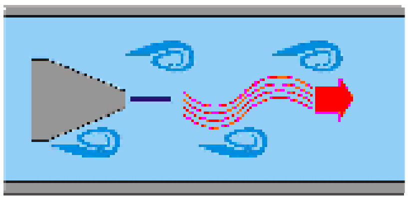


Fig. 5: Karman vortex street

An exactly defined body fixed in a compressed air system generates a vortex and thus vibrations which can be recorded. They vary analogue to the changes in the volume stream shed from the diverting body.

This test set-up has similar features to dynamic pressure measurement systems

Please note:

- Vibrations caused by the pipeline construction can influence the measurement result.

Ultrasonic measurement

Ultrasonic measurement devices such as those common in gas and water engineering, have not yet been widely used in compressed air systems (see Fig. 6).

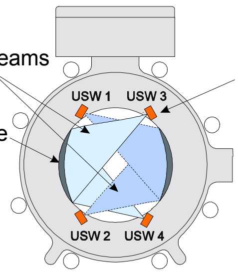


Fig. 6: Ultrasonic flow measurement

Indirect measurements

Whereas the direct measurements already described can be applied centrally and locally to measure the air consumption in companies and to determine the performance data of compressors, indirect measurements with the aid of the compressors serve to determine air consumption values and characteristics of complete compressed air systems.

Digitally recording the load time of compressors

Discontinuously regulated compressors are connected to a data logger which records the full load, no-load and downtime of the compressors (see Fig. 7).

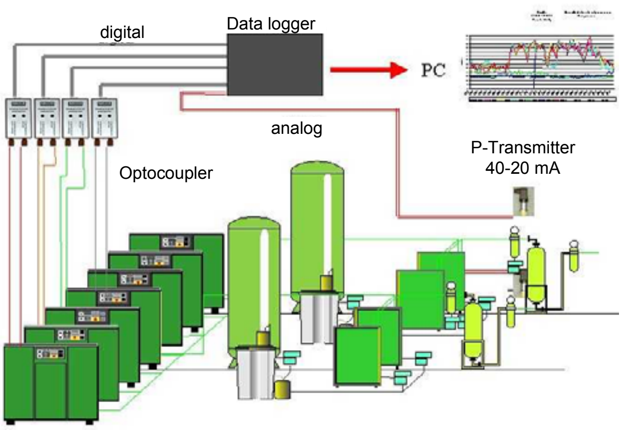


Fig. 7: Digital load time recording

After these data have been entered into a computer, the capacities of the individual compressors and the total air consumption value of the plant can be simulated.

Please note:

- One advantage of this indirect measurement method compared to direct measurements is that it not only provides information on air consumption values but also data on the efficiency and running performance of the compressors.
- Easy to set up.
- Min. measurement phase 1 sec to include consumption peaks.

Other methods

Simple air consumption measurement or load measurements of compressors can also be determined by reading the counter for load operating hours and measuring the time needed to drain the boiler.

Please note:

- Very personnel-intensive and rather vague.

Measuring leaks using pressure measurements

Using a pressure sensor which can be easily integrated into the compressed air system the pressure can be measured and recorded over a longer period of time at short intervals. In order to do so, the system does not have to be separated, a coupler or a one inch connection are sufficient.

The pressure curves are subsequently processed using a mathematical method so that the contractor knows exactly how high the share of leaks and how large the load capacity share (in per cent) is for each individual measurement point. This is done by calculating the pressure losses and their gradients, which result in a perfect curve using a mathematical algorithm. The perfect curve is then compared with the actually measured curves (see Fig. 8).

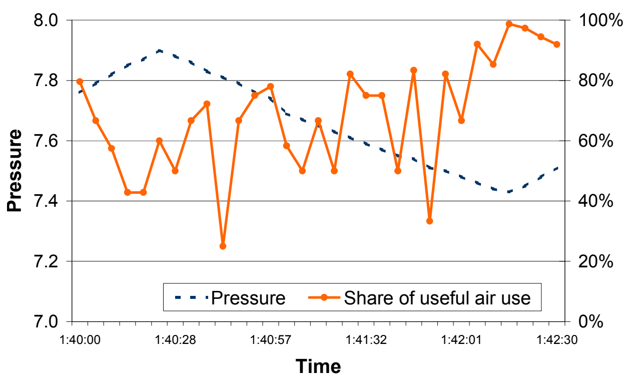


Fig. 8: Leckage measuring during plant operation

The results are the relative shares of the load capacity or the leaks at each point in time. If the flow rates or compressor. Operating times are recorded at the same time, the relative values can be converted into absolute losses.

Please note:

- The advantage of the method is that it is possible to calculate the leaks during operation. It is therefore particularly suitable for plants operating in continuous production.

Measuring leaks by draining compressed air receiver

A simplified leak measurement is also possible via the air receiver. The pressure here is increased to the maximum required in the system and the time it takes for a pressure drop of 1 to 2 bar due to leaks is measured (see Fig. 9).

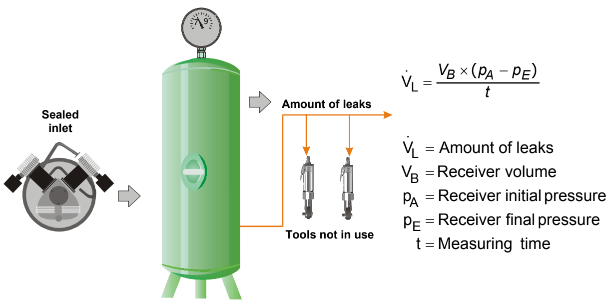
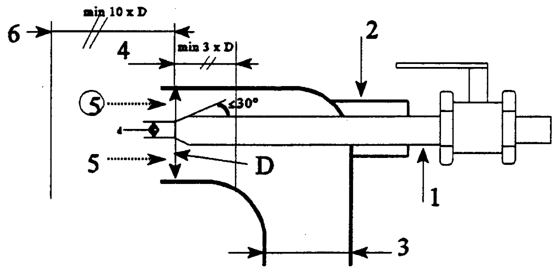


Fig. 9: Measuring leaks by draining compressed air receiver

Air quality measurements under ISO 8573

The manner of taking samples is particularly important for exact air quality measurements.

If there is a turbulent stream in a compressed air pipe and especially if boundary flows are present, the sample must be taken at a point at which it can be ensured that it contains a representative and utilisable mix of all the components of the compressed air. This can only be guaranteed with a so-called isokinetic sample (see Fig. 10).



1. Sampling probe in main pipe
2. Adjustable socket to fix probe
3. Compressed air pipe cross section "D"
4. Screw-in depth min. „3 x D"
5 Direction of flow
6. Min. length of inlet zone = 10 x D

Fig. 10: Isokinetic sampling

For the individual groups of contaminants, e. g.

- ISO 8573-2: Oil aerosol content
- ISO 8573-3: Water content
- ISO 8573-4: Particle content
- ISO 8575-5: Oil vapour and hydrocarbon content
- ISO 8573-6: Gaseous contaminants
- ISO 8573-7: Microbiological contaminants

the measuring systems described in each of the norms should be introduced downstream of the sampling point.

The air qualities are classified under ISO 8573-1.

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Further information can be found at www.druckluft.ch

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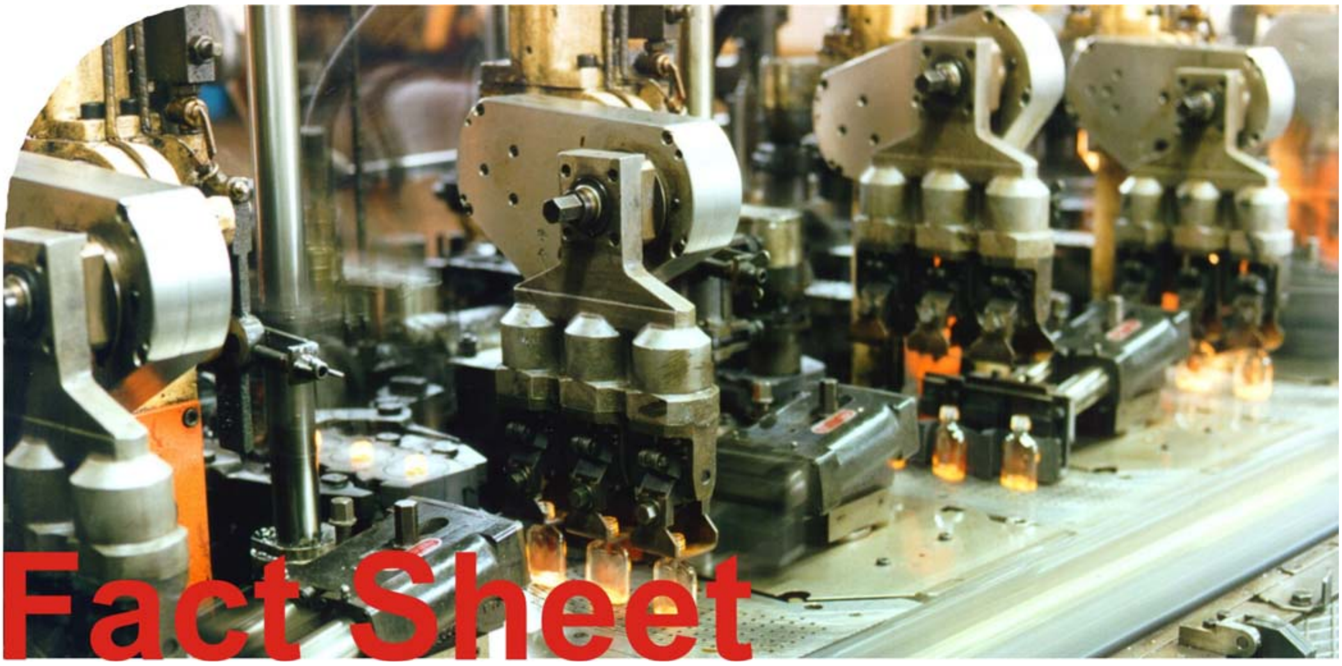

Production

What type of compressor?

In practice, piston, screw, and turbo compressors are the main types. In addition, there are membrane, sliding vane, helical, rotary tooth and rotary piston compressors.

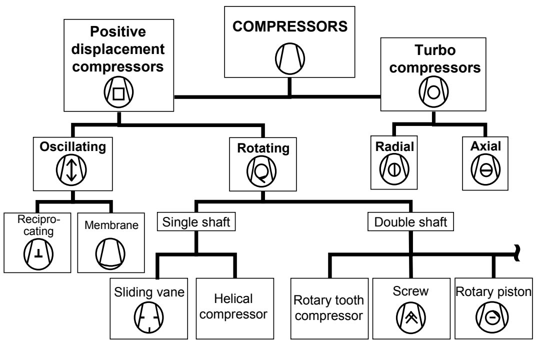

Fig. 1: Types of compressors

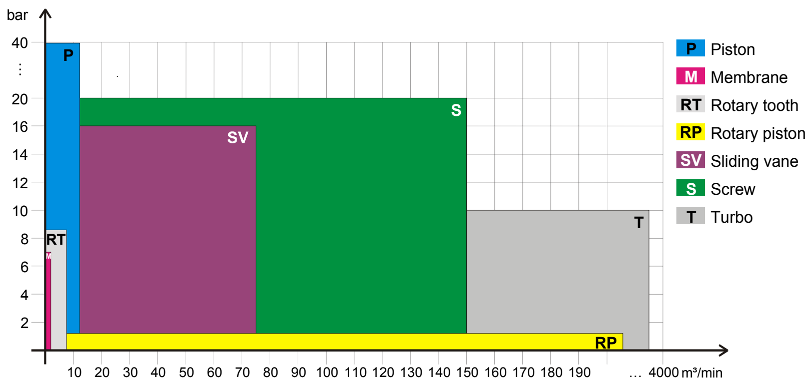

Fig. 2: Potential power of compressor types

Compression principle

Piston compressors

Reciprocating compressors function according to the positive displacement principle. When moving downwards, the piston sucks air in from the atmosphere via the suction valve. When the upstroke begins, the suction valve closes. The air is expelled via the discharge valve. Piston compressors are multiple-cylinder (higher capacity) or multiple stage (high pressures).

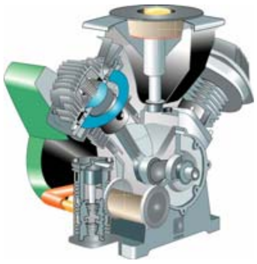

Fig. 3: Piston compressor

Screw compressors

Screw compressors function according to the positive displacement principle. Two parallel rotors with different profiles counter-rotate within a common housing. There are screw compressors with capacities up to 1000 kW. They are powered directly or with transmission or V-belts.

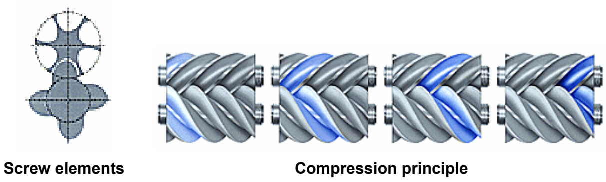

Fig. 4: Screw elements and compression principle

Injection-cooled screw compressors work in a single-stage up to 15 bar and in two stages up to 20 bar max. pressure. Oil-free screw compressors work up to 3 bar in a single-stage of compression and up to 10.5 bar in two-stages with intercooling. The main and auxiliary rotors are driven by a synchromesh gear in oil-free screw compressors to avoid contact.

Turbo compressors

Turbo compressors are dynamic, the rotating element (called impeller) has blades to accelerate the gas to be compressed.

Fixed control devices on the blades transform the kinetic energy into pressure energy. Turbo compressors usually have large capacities and compress oil-free. They compress up to 2 bar in a single stage and up to 7 bar in two stages. Twenty-stage compression is possible.

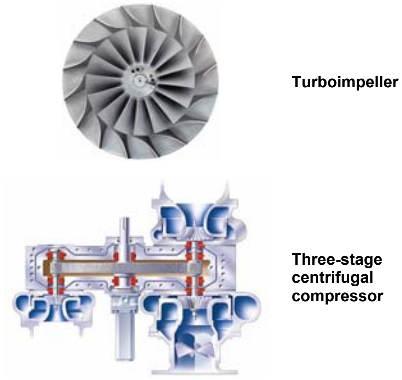

Fig. 5: Turboimpeller and centrifugal compressor

Pressure ranges of screw compressors

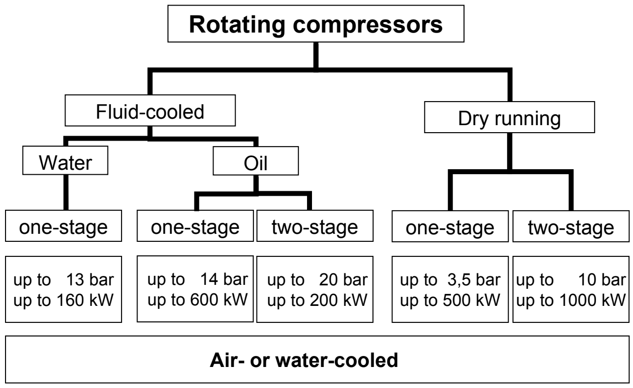

Fig. 6: Pressure ranges of screw compressors

Performance testing ISO 1217 Appendix C

Performance testing for screw compressors under ISO 1217 is described in Appendix A. Appendix B describes the performance testing of the compression stages, while Appendix C is to be used for complete screw compressor systems.

Volume flow rate

The volume flow rate (quantity delivered) of compressors is measured in accordance with the given measurement method at max. pressure at the compressed air outlet of the entire system and projected backwards to the inlet conditions.

Inlet conditions:

Inlet temperature +20 C
Inlet pressure 1 bar
Relative humidity 0%
Cooling water temp. +20 C

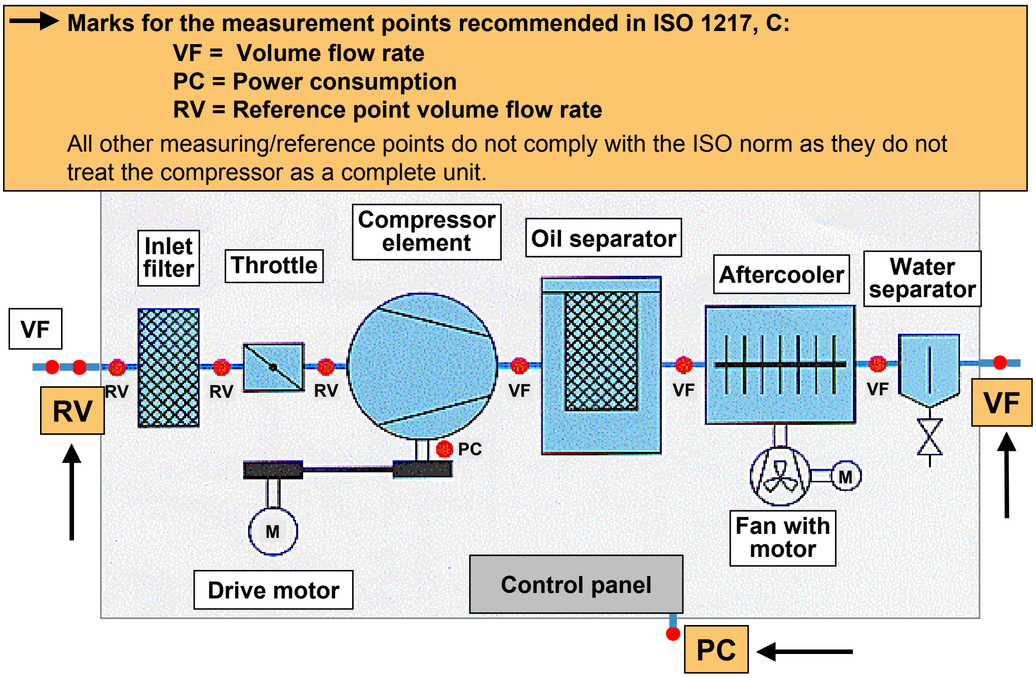

Fig. 7: Performance testing under ISO 1217

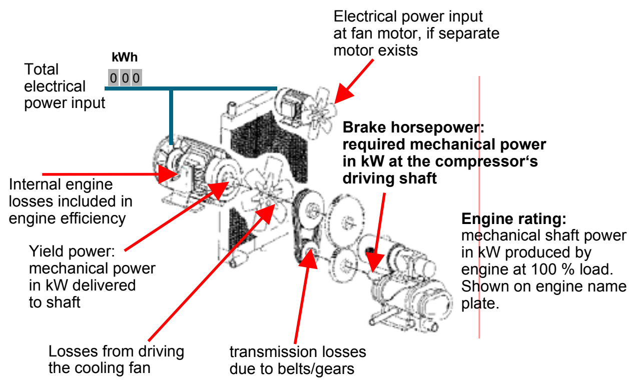

Fig. 8: Power flow in compressors

ISO 1217: 1996 (PN2 CPT)			
Volume flow rate at given conditions	**Volume flow rate**	**Specific power input**	**Power input no-load operation*)**
below 0.5 m^3/min	+/- 7 %	+/- 8 %	+/- 20 %
0.5 – 1.5 m^3/min	+/- 6 %	+/- 7 %	+/- 20 %
1.5 – 15 m^3/min	+/- 5 %	+/- 6 %	+/- 20 %
above 15 m^3/min	+/- 4 %	+/- 5 %	+/- 20 %

The tolerances shown contain the manufacturing tolerances of the compressor incl. the measurement tolerances for the values obtained during the inspection.
*) if povided by manufacturer

Table 1: Specific power requirements under ISO 1217

Power consumption

The electrical power consumption means the total power consumption of all motors (drive and fan) taken from the electrical mains.

Specific power requirements

The tolerances of the specific power requirement permitted (electrical power consumption divided by quantity delivered) are fixed in the performance testing standards.

Compressor rooms and compressor assembly (VDMA 4363)

The heat produced during compression – which is almost all the energy entering the compressor from the mains – has to be discharged. The permissible temperatures in the compressor room are fixed in the German Engineering Federation VDMA standard sheet 4363. They range between +5 °C and +40 °C. If the temperature is too low, there is the danger the compressor's safety devices will freeze. If it is too high, there can be problems with components overloading.

Depending on the on-site conditions, air-cooled compressors can be used up to approx. 250 kW capacity.

If there is no possibility to remove heat using air because the volume required is too large, the heat must be removed using water. The operating costs of water-cooled compressors are about 30 % higher than air-cooled ones.

Ventilation of compressor rooms

Supportet convection (with fan, without ducts)

- Low investment costs
- Minimal technical input
- Automatic space heating in winter

Note:

- Only applicable in small/medium compressors
- Room temperature increase by Δ t = 5-10 K, therefore increased volume of cooling air requested
- Risk if inlet air is warm.

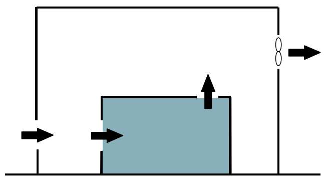

Fig. 9: Natural ventilation for small capacities

Ventilation via duct

- Average investment costs
- Average technical input
- Cooling air heated by Δ t = 25 K, therefore small volume of ventilation air necessary
- Compressor room only heated slightly
- Heating possible due to hinged vent
- Noise reduction.

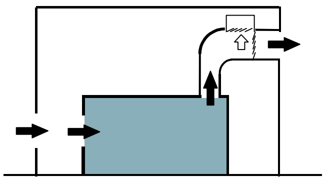

Fig. 10: Ducted discharge air in larger compressors

Air cooling

The simplest kind of heat removal is via cooling air. The cool air has to enter the compressor and the heated air then exit it. The volume required has to be supplied by the user. The cooling air can be fed in and discharged through free openings. If this natural ventilation, which is usually found in small compressors, is not sufficient, then either the injection or the discharge has to be supported using a fan. If this is also no longer sufficient, then the air supplied/discharged has to be fed via a duct. An additional fan is necessary in long ducts to bridge pressure losses in the duct. Special controls permit a mixed air operation in winter. Warm air from the compressor room is mixed with cold air drawn from outside through a louver. Drawing cool air in from outside through ducts is also recommended if the air in the compressor room is not clean.

Water cooling

It can be difficult to supply the necessary amount of cooling air if large amounts of heat have to be discharged, i.e. in large compressors, or if several compressors are positioned in one room. The machines then have to be cooled using water. Of course, the operator has to have a supply of cooling water at hand. Fresh water cannot be used on account of the high costs involved. Compressors can easily be connected to open or closed circuit cooling water systems. Before the decision is made for water cooling, it has to be ensured that the compressor's cooler is correctly designed for the water quality. Aggressive cooling water requires coolers made of resistant material.

Another point is often overlooked: in spite of water cooling, the heat emitted by the individual components in the compressor still has to be removed. Cooling air is still required for this, although a relatively small amount.

Heat recovery

Space heating

The most economic type of heat recovery is to exploit compression heat for space heating. Prerequisite is an air-cooled compressor over which the cooling air can be channelled. This kind of heat recovery is economic because all the heat, including that emitted in the compressor, can be used. The heated air has to be transported via a system of ducts. Care should be taken to keep the distances as short as possible. Firstly, long distances mean pressure losses in the duct, which in turn can only be compensated using an additional fan, and secondly, heat losses occur if the air is in the duct for a long time. Insulated ducts are an alternative but would also involve higher investment costs.

It must be borne in mind that only winter months can be used for the amortisation time of heat recovery through space heating. In summer, the waste heat is discharged outside through a hinged vent.

Heating water

For screw compressors with oil injection, the oil removes approx. 72 % of the electrical energy supplied. This energy can be recovered. It is irrelevant whether the screw compressor is air- or water-cooled. To recover the thermal energy, the oil passes through a heat exchanger which can heat water by 50 K up to 70 °C. The heat exchanger is usually a plate-type heat exchanger which is capable of very high heat utilisation, can be housed compactly and makes these high water temperatures possible.

It must be noted that water is only heated if the compressor is operating to capacity. Since this is not always the case, and thus hot water will not always be produced, heating water using heat recovery can only supplement the heating circuit. The amortisation of heat recovery in this case is only possible in the winter months.

Hot water production

If the plates are defective, there may be a breakthrough in the plate heat exchangers used to heat water so that water and oil mix. To avoid oil-polluted wastewater, a safety heat exchanger is used when heating sanitary or process water. The pressure of a carrier fluid between the oil and the water side changes if oil breaks through.

A signal is sent through a pressure switch to turn off the system. In this system, water can be heated by about 35 K to approx. 55 °C. In contrast to the production of heating water, an amortisation is possible over the whole year.

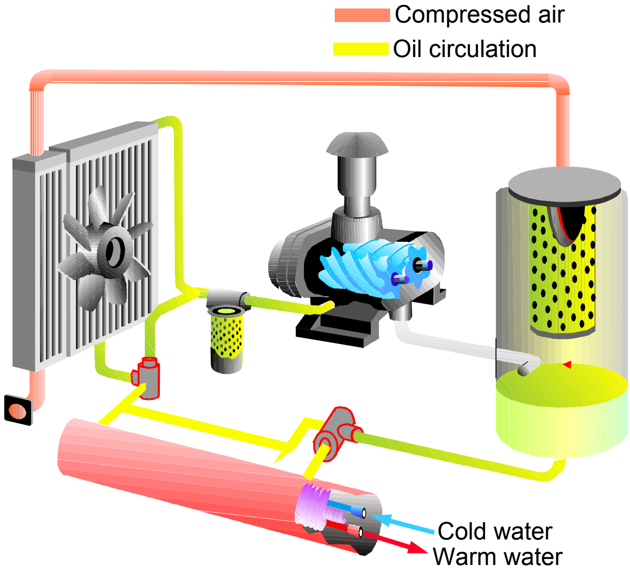

Fig. 11: Heating sanitary or process water by an oil-injected screw compressor

The "Druckluft Schweiz" campaign (efficient compressed air in Switzerland) motivates and supports the operators of compressed air systems in Switzerland in implementing measures to increase the energy efficiency of compressed air supply. The campaign is led by the Fraunhofer Institute for Systems and Innovation Research and sponsored by the Swiss Federal Office of Energy and the "Electricity Saving Fund" of ewz, the electricity company of the city of Zurich. It is part of the "EnergieSchweiz" Programme. Co-sponsors are the following companies from the compressed air sector: Airtag, Atlas Copco, Donaldson, Dopag, Kaeser, Oetiker, Prematic, Servatechnik, Vektor.

Further information can be found at www.druckluft.ch

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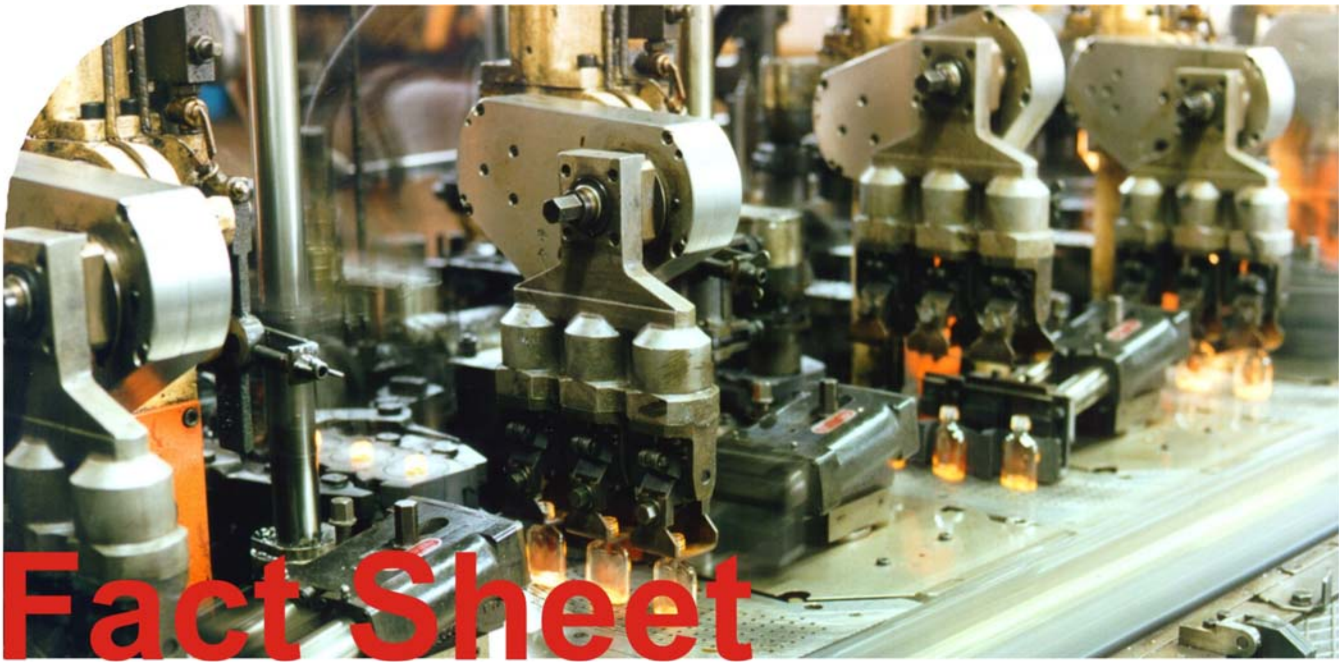

Fact Sheet
Control

Controls in compressor systems are used for both compressed air production and compressed air treatment. This fact sheet deals with the controls which match compressed air production to consumption (see Fig. 1).

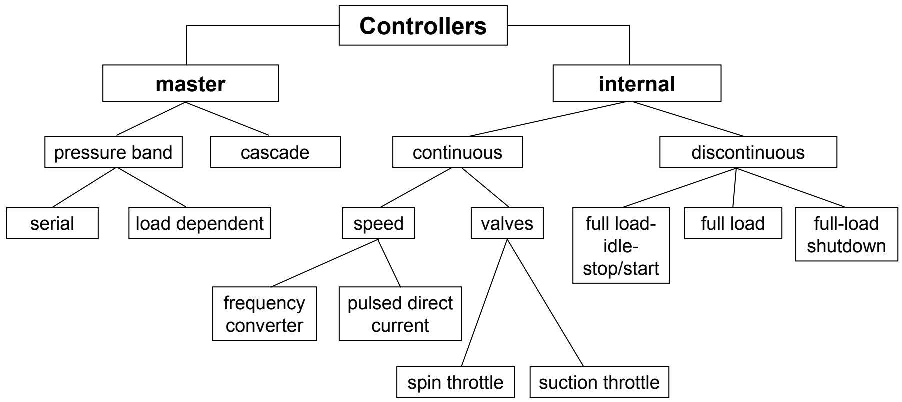

Fig. 1: Control of compressed air systems

Internal and master controllers

Within compressor systems, a distinction is made between internal and master control of the compressors. Internal controls are responsible for adjusting the respective compressor component to the air consumption required and to prevent overloading by an optimal coordination of the internal control processes. Since modern compressor systems are usually made up of several individual compressors, the task of the master controller is to operate the individual systems to capacity and to coordinate and monitor their use according to the actual air consumption.

Types of internal control

For internal types of control, a distinction is made between discontinuous and continuous controls.

Discontinuous control

The full load-idle-stop/start control is currently one of the most common controls in drives without variable speed control. If the operating pressure reaches the set lower pressure limit p_{min}, then the compressor is switched on and delivers compressed air. When p_{max}

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is reached, the compressor is not switched off but into idling mode by venting. If p_{min} is reached during the no-load period, the compressor then returns to full load operation. For low air consumption, the compressor is shutdown after a certain idling period (Fig. 2).

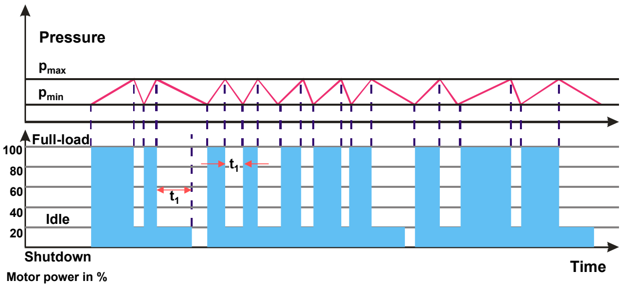

Fig. 2: Range of application peak load compressor

Note:

- Fast reaction
- High switching frequency without overloading the motor
- If poor load, high energy consumption during idling.

In no-load control with optimised idling time, the follow-up time is varied depending on the pressure fluctuations over time and the motor size and thus helps to make considerable cost savings in idling mode, especially in base load machines (Fig. 3).

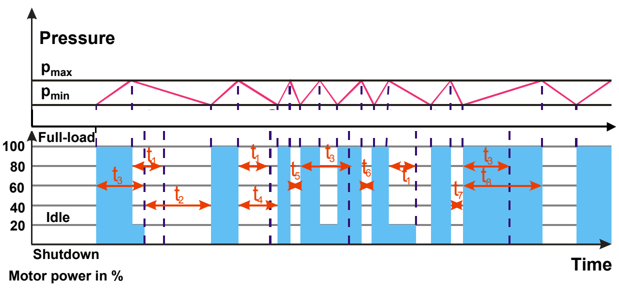

Fig. 3: Range of application base load compressor

Note:

- Lowest possible no-load share
- Good energy efficiency
- Longer reaction time.

Systems with discontinuous control have in common that they are controlled via pressure limits p_{max} and p_{min}.

Measuring transducer

The pressure limits required in mechanical pressure switches are sometimes up to one bar apart, but pressure differences can be reduced to 0.2 bar today using modern pressure sensors.

Note:

- Energy saving through small Δp
- High repeatability
- Low pressure fluctuations
- No universal interchangeability.

Continuous Control

Motor speed control

The most common ways to regulate speed in modern compressors are either to use a frequency inverter or direct current modulation. In both cases the systems are started at a pressure limit p_{min}. The motors then progress along a characteristic curve to a speed which is specified by the ratio of actual pressure to control pressure.

If the air consumption exceeds the control range of the machine, the system is either shutdown or switched to idling mode depending on the sequencer (Fig. 4).

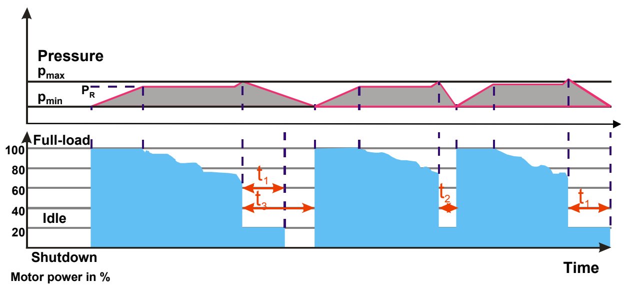

Fig. 4: Range of application peak load compressor

Note:

- Good controllability
- Fast reaction
- Constant pressure +/- 0.1 bar
- Good energy efficiency in the control range between 40 and 80 %
- Low energy efficiency at load > 80 %, < 40 %
- High investment costs
- Back coupling to electric grid

The characteristic curve of the controller, the motor and the air end in the partial load range is decisive for the efficiency of the control mode (Fig. 5).

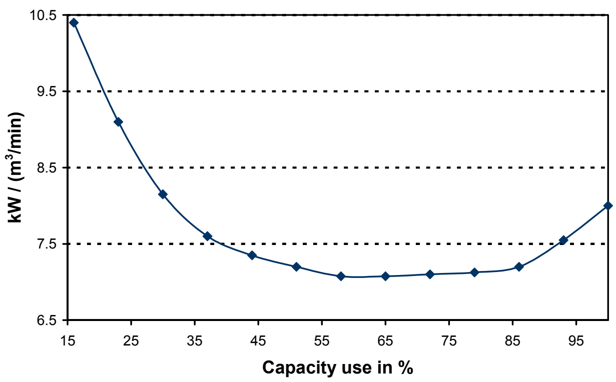

Fig. 5: Specific performance of a speed-controlled compressor

Suction throttle control

Machines with suction throttle control are normally compressors with a full load-idle-stop/start control and an additional control device. This is set to a certain control pressure. If this pressure is reached, the inlet valve of the compressor is either closed or opened depending on the plus-minus deviation from the control pressure. In positive displacement compressors, this actually only involves a reduction of the volume flow rate which only has a negligible influence on the performance of the compressor (Fig. 6).

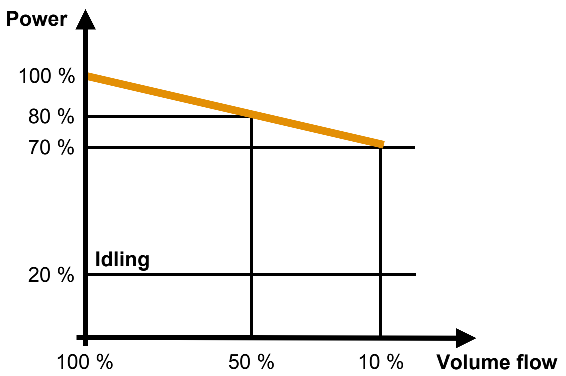

Fig. 6: Control of the volume flow rate using a suction throttle

Note:

- Low costs
- Large control range 100 % to 10 %
- Extremely poor energy efficiency.

Turbine bypass control system

Controls are characterised as turbine bypass controls in which the compressor discharges compressed air into the atmosphere and thus adapts the output to the actual air consumption.

This type of control is used in low pressure systems (e.g. fans) or also in dynamic compressors.

This control is also used in dynamic compressors to influence the performance but this is only possible in a relatively small control range (Fig. 7).

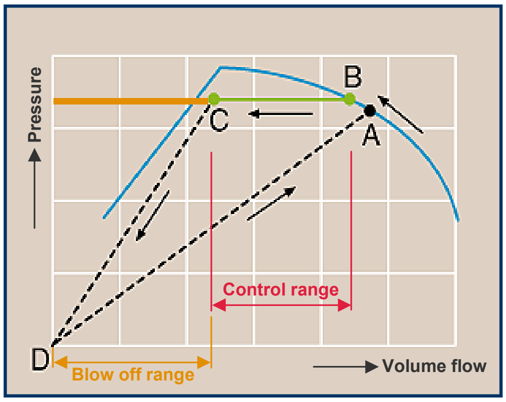

Fig. 7: Turbine bypass control system

Note:

- Linear performance in the control range
- Control range normally approx. 20-30 % without turbine bypass (higher energy loss).

Master controller

Among master controllers, a distinction is made between cascade and pressure band regulation.

Cascade control

The best known type of coordination is the so-called pressure cascade; in such setups, every compressor is assigned a particular Schaltbereich by the master controller (Fig. 8).

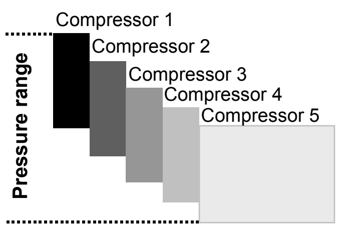

Fig. 8: Cascade control

Note:

- Pressure band, avoidable energy consumption as a result (per bar approx. 6-10 % excess energy consumption)
- No consideration of current air consumption
- Recommended only up to a maximum of 4 compressors.

For compressors of equal size, the compressors are transposed into base, medium and peak load depending on the running time of the compressors or via an interval timer. Sometimes when switching 4 compressors in a pressure cascade using membrane pressure switches or contact manometers, pressure spreads of up to 2 bar are required in order to switch the systems properly. The use of modern pressure sensors makes it possible to reduce the pressure spread to 0.7 bar for 4 compressors.

Pressure band regulation

Modern master controllers use the possibility to control an unlimited number of systems using a pressure band, the smallest control difference is 0.2 bar (Fig. 9). The advantage of this kind of control is a reduction of the maximum pressure in the compressed air system and thus a reduction of the primary energy costs and the losses in the compressed air system.

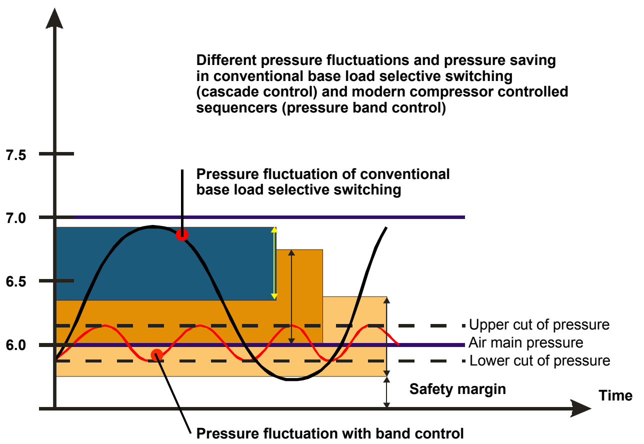

Fig. 9: Pressure band regulation

Extension possibilities with master controllers

Extended pressure band regulation can also select different compressor sizes depending on the load and coordinate these with each other should the demand arise. The correct selection of the compressor size prevents the production of so-called control gaps (Fig. 10). Control gaps can arise at incorrect grading of the compressors and a discrepancy between amount of air required and compressed air produced.

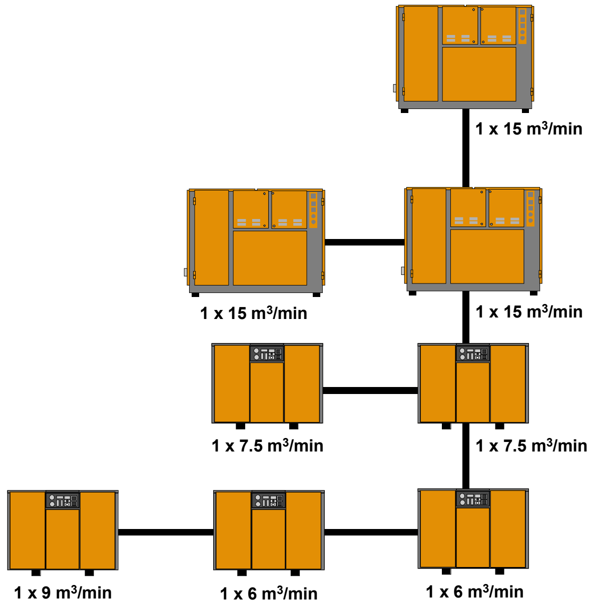

Fig. 10: Ways to split-up compressed air production

In order to improve monitoring and to depict the processes within a compressed air system, these master controllers can record not only the compressor data but also the data of each air treatment and distribution system in a compressed air system and then transmit these data via a suitable control and instrumentation installation software to a centralised control centre (Fig. 11).

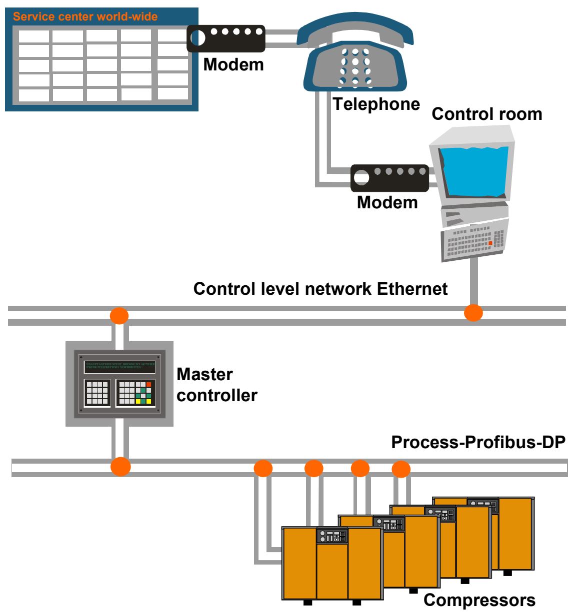

Fig. 11: Use of control technology for compressor control

Saving potential

According to an EU paper, master controllers can achieve an energy saving potential of 12 % on average by lowering the pressure and better coordination. Optimised internal controls can achieve an energy saving potential of 15 % on average by reducing internal losses.

Storing compressed air

The energy of compressed air is stored in the pipes and receivers. Compressed air users often work very discontinuously. Producing compressed air using compressors has to be reconciled with the discontinuous air consumption. Receivers constitute the backbone/mainstay of the efficiency of a compressed air system. They should be chosen to be larger rather than too small. The influence of the receiver on the efficiency of a system is dependent on the size of the pressure loss between the measurement point of the control and the storage location. Usually this should not be larger than 0.1 bar. Today, a distinction is made between decentralised and centralised buffers in a compressed air system.

Centralised buffers

The main buffer receiver in a compressed air system is primarily there to minimise the switching frequency of compressors. In addition it prevents overlarge pressure fluctuations in the system. It should be selected in accordance with the equation shown, although the efficiency of the compressed air system benefits if a larger receiver is selected than the minimum value calculated in the equation (Fig. 12).

$$V_B = \frac{\dot{V}_1 \cdot (x - x^2)}{z \cdot \Delta p}$$

Compressor power	Usual z-values/h for motor switching:
7.5 kW	30
30 kW	15
110 kW	8
250 kW	4

V_B = Volume of air receiver [m³]
$\dot{V}_1$ = Quantity delivered by switching compressor [m³/h]
$\dot{V}_2$ = Peak consumption minus average consumption [m³/h]
x = $\dot{V}_2 : \dot{V}_1$ = Load factor [m³/h]
z = Permissible switching cycle [1/h]
Δp = Pressure difference ON/OFF [bar]

$z \approx 45$ for screw compressors (full load; idle)
Rule of thumb: $(x - x^2) \approx 0.25$

Fig. 12: Dimensioning of centralised compressed air storage

Decentralised buffer

The decentralised buffer often serves to supply compressed air to users with sudden large and temporary demand and to prevent a pressure drop in the rest of the air mains. It has to be selected corresponding to the running time, the air consumption and the permitted pressure fluctuations of the decentralised user (Fig. 13).

$$V_B = \frac{\dot{V} \cdot t}{\Delta p}$$

Use as:

- Buffer for short but acute withdrawal of compressed air
- as emergency “power generator”

V_B = Volume of air receiver [m³]
$\dot{V}$ = Air consumption [m³/min]
t = Duration of air consumption [min]
Δp = Permissible pressure drop [bar]

Note: Does not replace the compressor over a longer period

Fig. 13: Dimensioning decentralised storage

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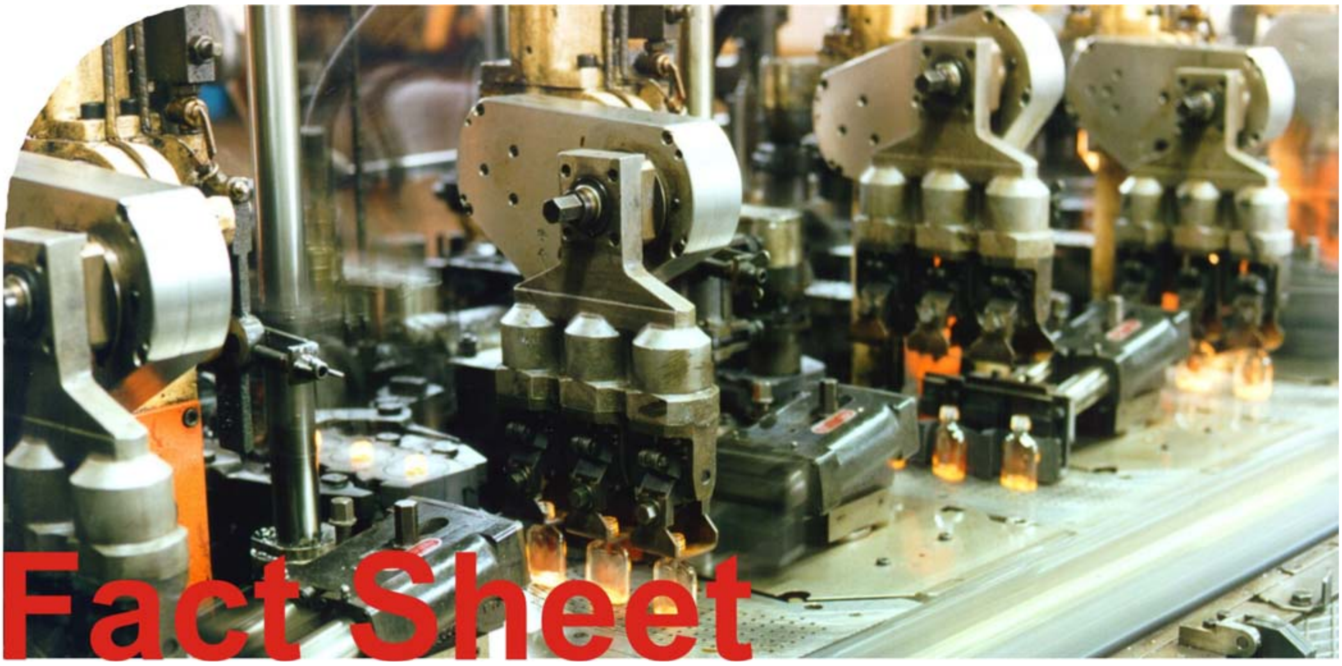


Treatment

The quality of untreated compressed air is no longer sufficient for most applications today and would result in quality reductions in compressed air products. This may mean disturbances of production systems right up to lost output or unusable products, i. e. a clear and critical reduction of product quality. The compressed air application determines the air quality required.

Class	Maximum number of particles/m³ Particle size d (µm) 0.1< d ≤ 0.5	0.5 < d ≤ 1	1 < d ≤ 5	Pressure dew point (°C)	Remaining oil content (mg/m³)
0	specified according to application and better than Class 1				
1	100	1	0	≤ -70	0.01
2	100000	1000	10	≤ -40	0.1
3	–	10000	500	≤ -20	1
4	–	–	1000	≤ +3	5
5	–	–	20000	≤ +7	–

Table 1: Purity classes under DIN-Norm ISO 8573-1:2001

The maximum loads with particles, water and oil are divided into purity classes in the DIN norm ISO 8573-1 (issue 2001). This allows manufacturers of compressed air products to define the required quality.

Drying compressed air

The different methods of drying compressed air can be classified as shown in Fig. 1 using the achievable pressure dew point and the energy necessary for this: depending on the system, the energy demand is recorded as compressed air or as electrical energy.

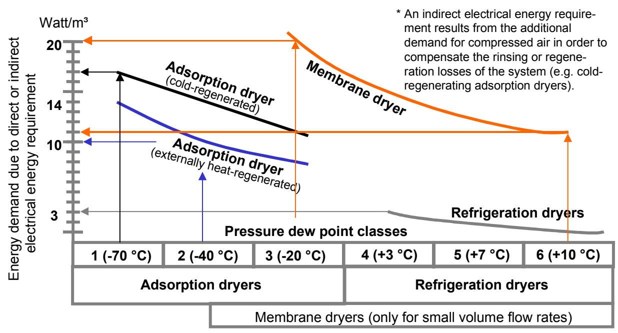


Fig. 1: Methods of drying compressed air

Refrigeration dryers

Refrigeration dryers are state-of-the-art today in compressed air systems and just as important as the compressed air producer itself. Furthermore they represent the most economic process for the majority of applications.

Physical basis:

The ability of compressed air to conduct water decreases with falling temperature. When the temperature drops, the water vapour condenses to water. The refrigeration dryer extracts the water vapour contained in the compressed air. To achieve this, the compressed air is cooled in a heat exchanger system. Water and oil vapour are extracted by condensation, oil by coagulation and coalescence. The condensate is drained off.

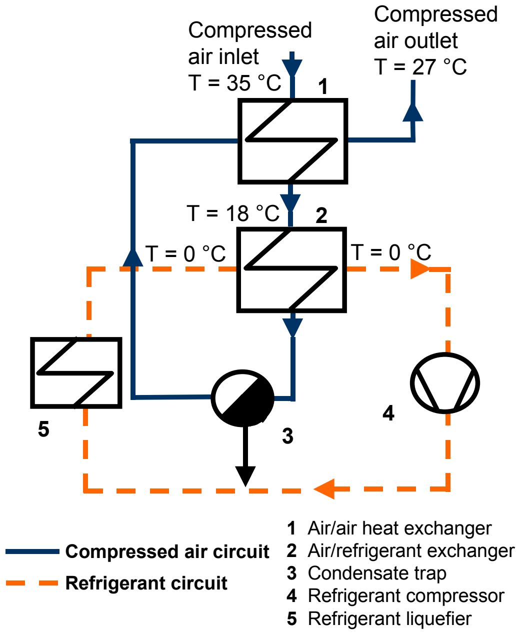


Fig. 2: How the refrigeration dryer functions

Economic refrigeration drying is divided into two phases. In the first phase, the warm incoming compressed air is cooled by the already chilled exiting compressed air in the air to air exchanger. Approx. 70 % of the accumulated water vapour are precipitated here. In the second phase, the compressed air flows through a coolant/air heat exchanger. This is where cooling to the required pressure dew point occurs. The condensate trap is downstream from the heat exchanger. The condensate is separated here from the compressed air.

Integrated heat exchanger systems which integrate air to air exchangers, coolant-air exchangers and condensate traps in one system component are more energy-efficient due to lower differential pressures compared to separate casings.

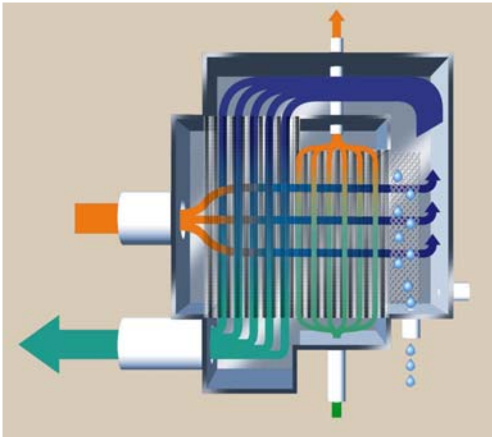


Fig. 3: Heat exchanger with integrated condensate trap (demister)

Adsorption dryers

Adsorption dryers extract the humidity carried in the compressed air using a desiccant. While adsorption takes place in the first container, the desiccant is regenerated at the same time in the second container. Pressure dew points between -20 and -70 °C can be achieved with standard products. There are various processes available for the regeneration. A distinction can be made between cold and warm regenerated adsorption dryers depending on the type of regeneration involved.

Cold regeneration

For the regeneration, some of the already dried compressed air is depressurised to atmospheric pressure.

+ simple technique
+ low investment costs
– consumption of compressed air
– high operating costs.

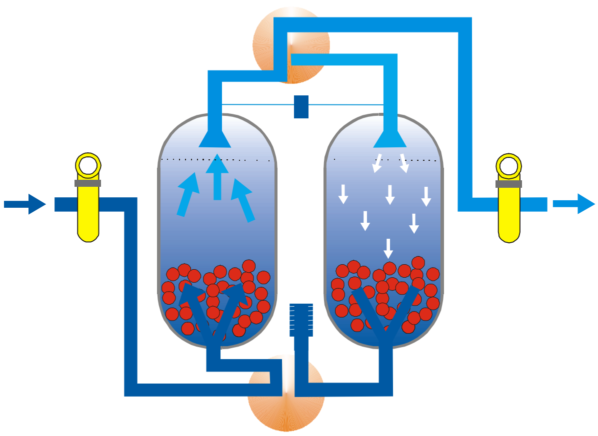


Fig. 4: Cold regeneration

Heated regeneration

Regeneration takes place with heated ambient air or heated air from the system.

Blower regeneration

In the heating phase, a blower forces ambient air through the heating. The heated air transports the humidity from the desiccant bed. Ambient air and compressed air are used for cooling.

+ lower operating costs by heating with steam or electrical energy
– compressed air consumption in the cooling phase.

Heated regeneration without using compressed air

By modifying the set-up and procedure, the desiccant bed can be cooled using ambient air. These adsorption dryers are divided into blowing, suction cooling or vacuum regeneration systems.

+ Lower operating costs by heating with electrical energy or steam
+ no consumption of compressed air in the cooling phase
– higher investment costs
– restricted use if ambient air is very humid.

Compressor heat regeneration

When using oil-free compressors in combination with adsorption dryers, the heat generated during compression is used specifically for the regeneration of the adsorption dryer. Pressure dew points of -30 °C and better are guaranteed by suitable compressors.

+ Uses the compression heat for regeneration
+ no consumption of compressed air
– only with oil-free compressors.

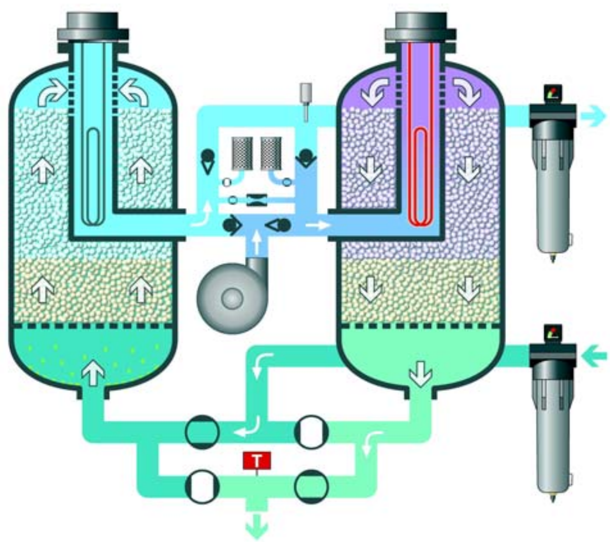


Fig. 5: Heated regeneration

Control

All heatless or heated-regenerated adsorption dryers are equipped with a time-dependent control. This comes as a manufacturer-specific variant or PLC depending on the extent of control required. A load-dependent control is an optional supplement. At the dryer outlet, a sensor registers changes of the pressure dew point. It automatically adjusts the cycle of the dryer to the load situation. The load-dependent control compensates possible part-load situations and reduces operating costs.

+ Minimum operating costs even at part-load operation
+ continuous pressure dew point measurement for quality control.

Membrane dryer

The membrane dryer is a supplement and alternative to the traditional refrigeration and adsorption dryers. It is particularly effective as a point-of-use dryer for smallest compressed air quantities, non-continuous operation or applications without electrical energy.

The heart of these membrane dryers are polymer hollow tube membranes which allow the water vapour to diffuse.

Filtration

This is used to remove contaminants from the compressed air to a large extent.

The main contaminants include oil vapour from oil-lubricated or oil-injected compressors as well as solid particles and hydrocarbons from the ambient air which are then contained in concentrated form in the compressed air. To guarantee the compressed air quality required today, purification is mandatory.

Due to an increased environmental awareness as well as stricter measures of health protection at work, requirements are also made of the emission values of the compressed air expanded after use, specifically with regard to oil vapour, which is emitted to the ambient air, e.g. directly from a compressed air cylinder or a nozzle.

However, filters also consume energy. Although there is no energy input to a filter, energy is consumed by the filter due to the pressure drop (differential pressure) caused which has to be provided by the compressor located upstream of the filter. The following rule applies:

The higher the degree of filtration, i. e. the greater the purity of the filtered air, the higher the differential pressure, i. e. the greater the amount of energy which has to be supplied by the upstream compressor.

Filters are therefore necessary, but cost energy and thus money. It is important to select the right quality of purification depending on the application involved. ISO 8573-1 or the manufacturer concerned can help with the selection.

It makes sense to think carefully about the degree of compressed air purity actually required, in order to individually select the filter(s) with the lowest possible differential pressure for the applications involved. Fig. 6 shows the saving potentials concerned. It shows the energy costs caused by compressors in compensating the pressure drop caused by the filter. These costs can amount to several thousand euro per year and may far exceed the purchase or replacement costs of the element. Enormous savings can be achieved by selecting the correct filter with the lowest possible differential pressures.

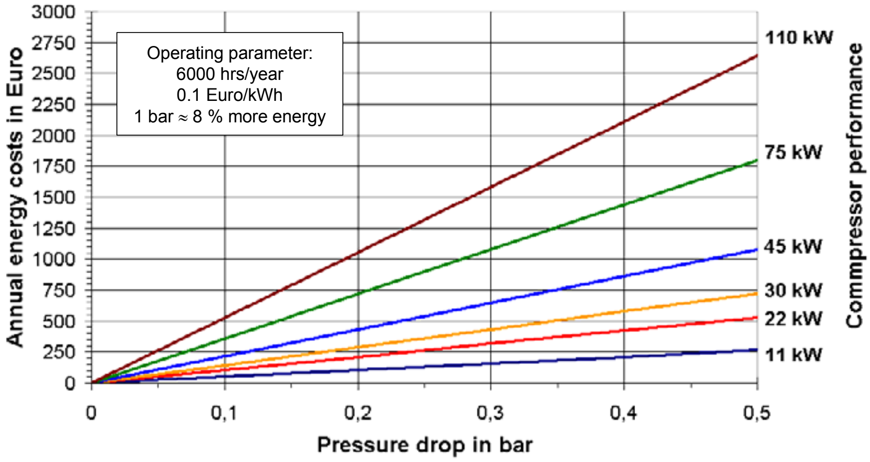


Fig. 6: Energy costs due to pressure drops

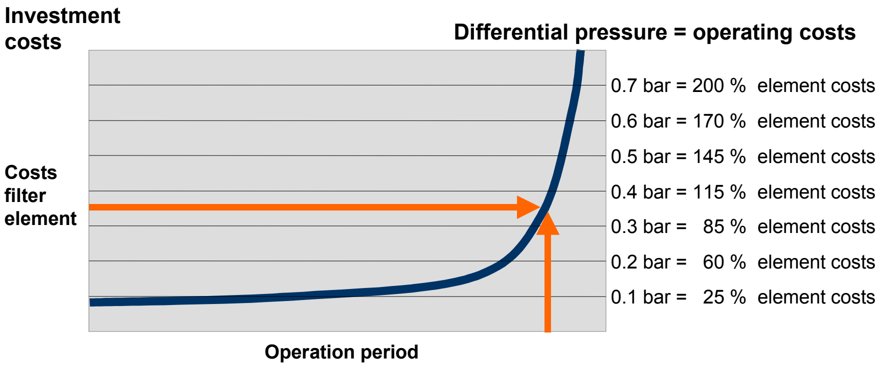


Fig. 7: Typical differential pressure; ratio of energy costs to filter element costs

Timing the replacement of dirty filters correctly, which have increased differential pressure, is equally important. As shown in Fig. 7, the differential pressure of a new filter element increases very slowly at first. The longer the element is in operation, the quicker the differential pressure increases. If this element is not replaced, the costs of covering the additional differential pressure are sometimes many times higher than the price of a replacement. As a rule:

Replace elements once a year, at the latest at a differential pressure of 350 mbar

Activated charcoal filters are the exception to this rule. Here, the following rule applies:

Service life of the elements: max. 1,500 operating hours or 3 months, depending on the inlet temperature and the oil content sometimes much shorter.

Finally there is the question of the operating safety of a filter. This criterion depends primarily on the quality of the tools used, the quality of production and the design features of the filter. The filter construction has to be assessed individually. The criteria for a filter are summarised below:

Filtration efficiency
+Operating safety
+Differential pressure
=Total operating costs

The sum of these three criteria then determines the total operating costs of the filter, breakdown costs due to insufficient filtration or a failure of the filter are already included.

Preliminary separation

The first treatment stage in a compressed air system is the separation of free condensate from the compressed air. To do so, a cyclone separator or a receiver is used at the compressor outlet. The **receiver** is the simplest system. By reducing the flow velocity and cooling the compressed air on the large surface area of the receiver, the condensate is collected at the bottom of the receiver and can be drained. With its vortex, the **cyclone separator** utilises mass inertia for separation. Both systems improve the performance of the compressed air treatment since considerable amounts of condensate are removed. Neither component replaces compressed air drying since the compressed air is saturated with 100 % water vapour after these separators and free water condenses with each further cooling of the air.

Condensate technology

Condensate is an inevitable by-product of producing compressed air. This condensate is formed from the humidity contained in the input air. At compression and the associated increase in temperature, this humidity is first present as vapour. Because only a minor fraction of the original volume remains after compression, the air becomes oversaturated. When cooled, the air humidity is precipitated as condense water. Apart from water and oil, this condensate also contains all the other components of the ambient air sucked in by the compressor. These are concentrated and result in contamination of the condensate.

Consequences of the condensate for the compressed air system:

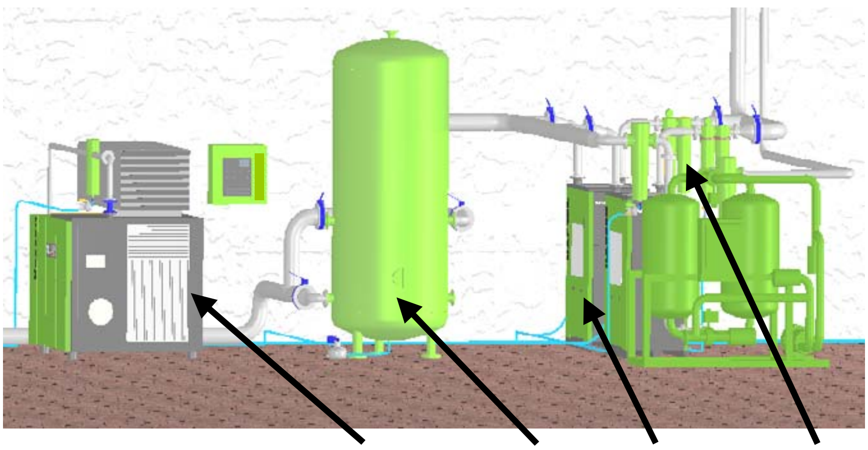
Condensate, irrespective of whether it contains oil or not, results in corrosion in the pipe system and downstream processes. Whereas oil-free condensate has a more acidic effect due to its pH value, oily condensates have the effect of clogging and sticking. The air quality required, even at lower classes, can no longer be achieved.

Where is the condensate formed?

Condensate is always formed if the temperature in the compressed air falls below the pressure dew point. This happens in after-coolers, receivers, cyclone separators, filters, dryers and in the pipe system. The largest amount of condensate is precipitated at the point of the greatest temperature drop after compression.

Trapping condensate

Due to the high costs of the resulting damage, removing the condensate from compressed air is assigned a very high priority. There are three common ways to trap condensate:



Condensate yield per 10 standard cubic metre in	Cyclone separator Aftercooler	Receiver	Refrigeration dryer	Filter
Winter	25 g/m³	3.5 g/m³	3.5 g/m³	- -
Spring/Autumn	28 g/m³	6 g/m³	9.5 g/m³	2 g/m³
Summer	53 g/m³	9.5 g/m³	21.5 g/m³	3 g/m³

Fig. 8: Condensate yield according to season

Float control:

The condensate is collected in a storage tank. A float opens a valve when a certain condensate volume is reached.

+ low investment
– very sensitive to dirt
– no monitoring possibilities.

Time-controlled valves:

A valve operated by a timer switch opens at a fixed interval.

+ large opening diameter
+ also available in a high pressure version
– compressed air loss
– high energy cost
– no monitoring and operational checks.

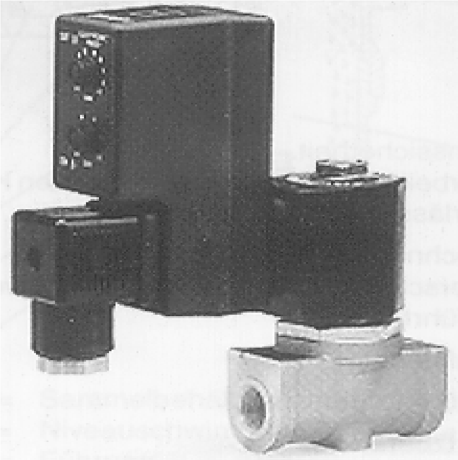


Fig. 9: Time-controlled valve

Electronic level-controlled separator

A sensor located in the condensate collector triggers the draining of the tank when a set value is reached.

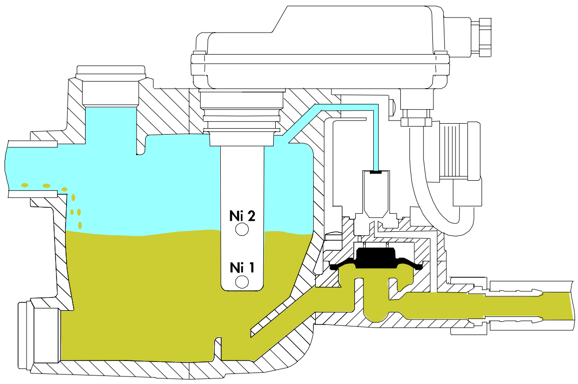


Fig. 10: Level-controlled separator

+ Energy saving
+ no compressed air losses
+ fault and alarm functions.

Condensate treatment

From the legal viewpoint, compressor condensate constitutes waste which requires particular monitoring. The law offers a choice of two possibilities for treating condensate. Either the specialist disposal by authorised companies or treatment on site with suitable and certified treatment technology. Condensates occur either as oil/water mixes or stable emulsions. In practice, these are the main methods.

Static oil/water separator

In this process, the condensate is held for a predefined retention time in a separating tank. The lighter oil components rise to the surface. The fine residue and other substances are filtered out in a downstream activated carbon stage. This method is always sufficient if the condensate is present in a disperse form.

+ simple system
+ fast amortisation.

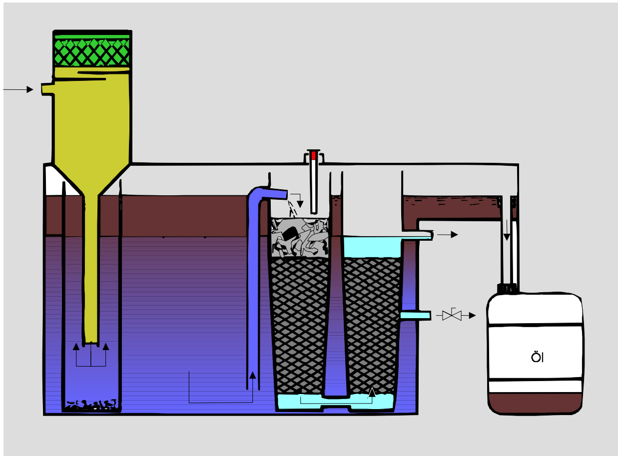


Fig. 11: Static oil/water separation system

Emulsion separation systems based on adsorption

With this method, a reaction separating agent is added to the pre-cleaned condensate. Electrolytes contained in the separating agent break down the oil-water compound and thus split the emulsion. The oil and other components of the condensate are adsorbed by the aluminium oxide and filtered out of the water. Only the residue formed has to be taken for disposal.

Ultrafiltration

With ultrafiltration, the condensate is circulated under pressure and filtered through a membrane with a controlled pore width. The oil components are retained and concentrated, while the water is purified and then discharged into the waste water system without any further filtering. The concentrated emulsion is then disposed of.

In each case, care must be taken when buying appliances and replacement parts that these are licensed, otherwise expensive individual technical approval of the appliances has to be conducted by the local authorities.

Summary

Compressed air treatment in air mains is state of the art today. The basic demand made of this treatment technology is the reliable and high-level removal of the contamination and humidity from the compressed air. This contamination leads to quality reductions and disturbances up to unusable products. How complex this treatment has to be and which operating costs are incurred can be clearly influenced by comparing the products found on the market and selecting the most suitable for a particular application.

In the compressed air treatment sector, the main concern is to achieve the optimum quality by fulfilling the specification of the application at optimum energy and operating costs. Increased energy or operating costs result from exceeding or failing to meet this specification. Figs. 12 and 13 give an overview of which order and choice of treatment products achieve which compressed air quality.

The available savings potential per subcomponent can amount to several thousand euro. Specifically, regular replacement of filter elements within the prescribed intervals can achieve obvious savings and thus minimise operating costs.

The serious analysis of the installed or planned compressed air system represents an investment which sometimes pays off very quickly.

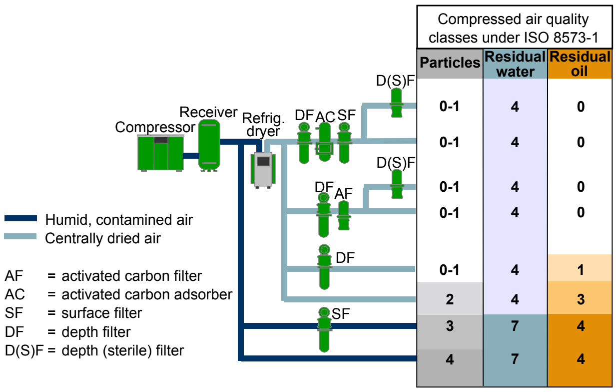


Fig. 12: Compressed air quality when using refrigeration dryers

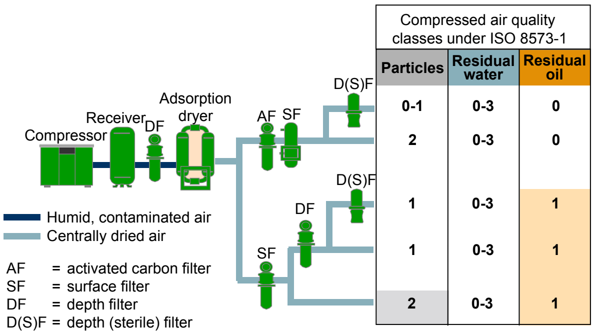


Fig. 13: Compressed air quality when using adsorption dryers

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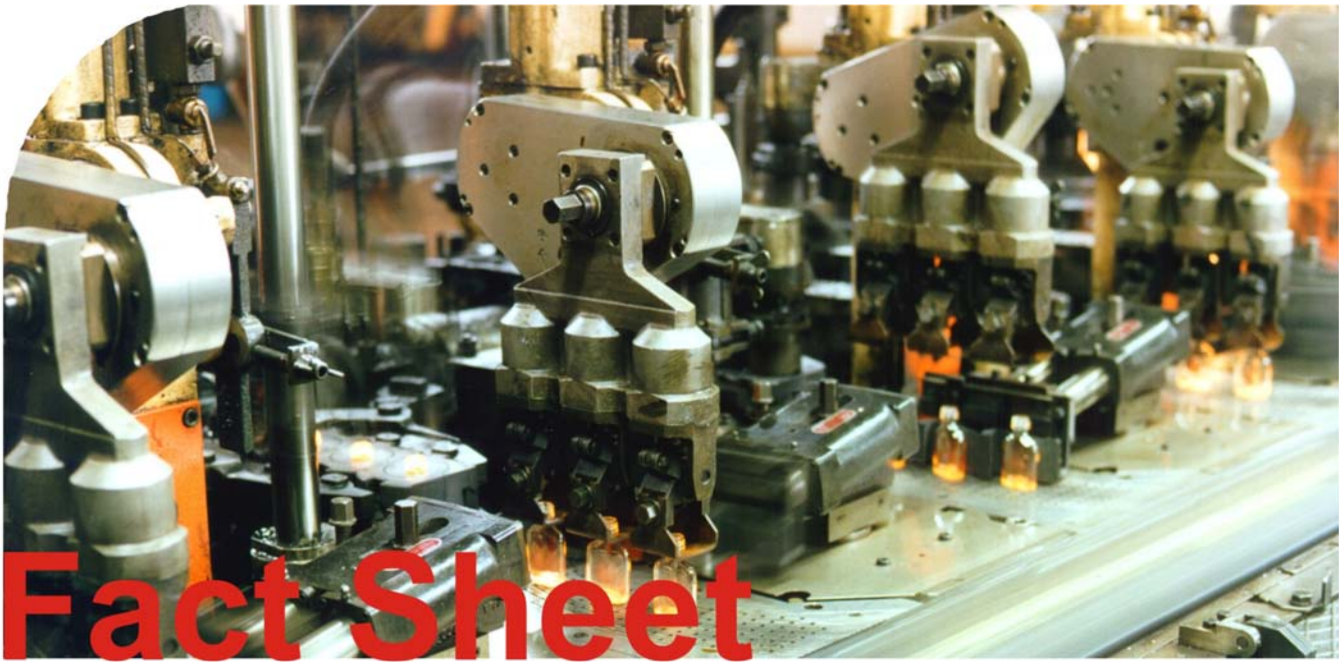

Air Distribution

Energy saving in air distribution

An optimum compressed air distribution is an energy pipeline like an electricity cable which transports compressed air energy with as few losses as possible, i. e. with the lowest reduction of the

- flow pressure (pressure drop due to narrow points in the pipeline)
- the air quantity (leaks) and
- the air quality (rust, welding scale, water etc.).

Pipeline system

In practice, compressed air tubes (main and distribution lines) are frequently selected without sufficient knowledge and without taking energetic issues into consideration with the result that in 80 of 100 firms (EU study), often 50 % and more of the compressed air energy are destroyed before they can reach the usage points.

The correct planning of a network has direct influence on the performance of the machines and the costs of producing compressed air. Select the correct diameter taking into account the flow rate required and the permissible pressure drop. The pressure drop from the air receiver in the compressor room to the final connection point should not exceed 0.1 bar. In an optimally designed compressed air network, the pressure loss is split into:

≤ 0.03 bar for the main line
≤ 0.03 bar for the distribution
≤ 0.04 bar for the connection
≤ 0.3 bar for connection equipment

Just as the economic efficiency of the compressor is documented, the operating efficiency of air distribution should also be documented – missing documentation always means wasted energy.

Main line (ML):
Connects the generator system (compressor room) with the distribution system. The main line should be sized so as to allow reserves for future extensions.

Distribution line (DL):
This distributes the air within a consumption sector. It can be designed as a branch or ring line, or as a ring line with integrated branch lines.

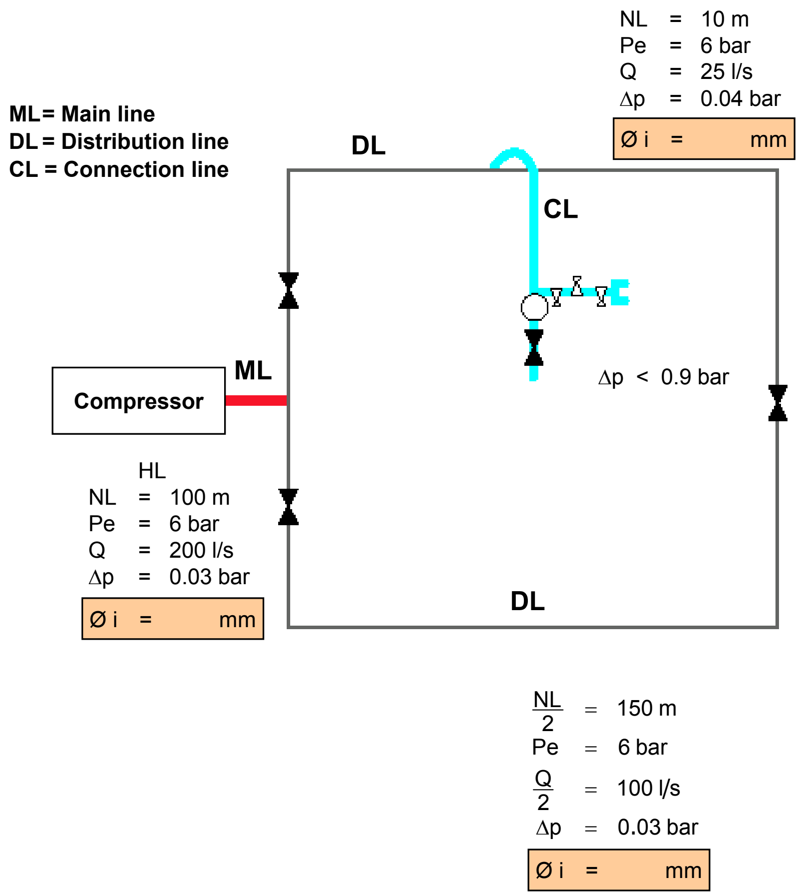

Fig. 1: Naming of piping segments

Explanation of terms deciding factors

Flow pressure

In spite of decades of awareness training by the manufacturers, the majority of compressed air tools are only driven with a flow pressure between 3 and 5 bar, that is 1 to 3 bar too low. The manometers on the controllers and maintenance units before the tools show the static pressure. But this does not drive the tools, the dynamic flow pressure does.

Other adverse effects on the flow pressure occur if the pipe diameter is too small or the pipe system has too many bends. Furthermore, when designing the system, the corresponding equivalent lengths have to be planned for all connectors.

Connection line (CL):
This is the link between distribution and machines or dispensers/points of use. The joint between the connection line and the distribution should be at the top in order to avoid condensate exiting with the air.

Connection equipment:
These system components are frequently the critical points of a system and also require careful attention. Couplings, hoses, coils or maintenance units often result in enormous energy wastes due to wrong design. In addition there are many connections here within a limited space which can leak.

Air quantity

In compressed air distribution systems which have grown over the years, are made of widely differing materials, with different, suboptimal diameters, more or less corrosion-free materials and very different types of connection, the rate of leakage can be between 25 and 35 %. Leaks cost a lot of money. They are the busiest consumers working 365 day per year.

Air quality

Corrosion- and oxidation-proof premium pipelines are preferable which have been specially developed for compressed air applications. A system should be selected so that the quality of air generated by production and treatment is not impaired by the pipeline even after a long period of time.

Flow pressure at tool (P_e bar)	Air consumption %	Measure	
8.0	125	throttle controller	**waste of energy**
7.0	111		
6.3 bar	**100 %**	**optimum performance**	
6.0	96	increase pressure	**disproportionate decrease in productivity**
5.0	77		
4.0	61		
3.0	44		

Table 1: Annual energy costs due to leaks

Hole diameter mm	Air loss		Energy loss		Costs	
	at 6 bar l/s	at 12 bar l/s	at 6 bar kWh	at 12 bar kWh	at 6 bar €	at 12 bar €
1	1,1	2,0	0,4	1,1	300	900
3	9,7	18,0	3,5	9,7	2 800	7 800
5	26,9	50	9,7	27,0	7 800	21 700
10	107,8	200,1	38,8	108,1	31 100	86 500

(*) kW x 0.1 €/kWh x 8000 Bh/a

Table 2: Annual energy costs due to leaks

Nominal Diameter	DN 50	DN 65	DN 80	DN 100
Pressure drop [bar]	0,60	0,16	0,07	0,02
Investment [Euro]	5 200	6 800	8 000	10 200
Energy cost to compensate pressure drop [Euro/year]	3 433	933	415	109
Total cost over 10 years [Euro]	39 530	16 131	12 147	11 294

Table 3: Costs resulting from selection of too small diameters

Storage

Another influencing factor for the air quality and quantity is the storage of the compressed air. Compressed air storage straight after production also called "central storage" influence the air quality to the extent that the direct condensate is removed. Furthermore, storage makes it possible to meet requests for much larger quantities of air within a short time than the compressor could provide immediately. There is also the possibility – depending on the use involved – of "decentralised storage" directly at the point of use. Further information on storing compressed air can be found in the fact sheets Control and Treatment.

Costs

When comparing the investment costs, the material and assembly costs of the different pipe systems should be compared as there is no generally valid formula for the correct pipeline material. For this reason, priority should be given to the individual demand case with its respective technical requirement.

With the exception of stainless steel, the costs of various pipeline materials do not vary widely, the differences are so small that they can be negated in the annual amortisation amounts/depreciation amounts.

However, selecting the correct nominal width is decisive. Considerable consequential costs can arise if the diameter is too small. Whoever tries to save on acquisition costs here, has to pay for this in consequential costs (see Table 3).

Refurbishment of air distribution systems

Generally, a pipeline inspection should not be delayed for economic and ecological reasons. But such an inspection should also be conducted step for step and not in haste.

Large saving potentials in compressed air distribution can be determined based on a quick rough diagnosis as follows:

- air quality
- leaks
- pressure drops.

Does the **air quality** meet the requirements?

Alongside the type of treatment, this is mainly a question of whether the pipe system is corrosion-free. Does the air at the points of use still correspond to the values (produced) at the production outlet? Carbon deposits/water, rust or zinc dust (even if only in subsections) often make additional expensive maintenance work necessary at each extraction point as well as a centralised treatment.

Are there **leaks** in the system?

By recording the load at the compressors and comparing this with the existing extractions, the quantity of leaks can be determined. It is vital to consider both "opened" and "closed" points of use, since leaks at the connecting equipment and in the machines may falsify these measurements.

The impact on the tools of supercharging can also be regarded as "leaks". A tool which needs 6 bar, but is charged with 7 or 8 bar wastes considerable additional amounts of air.

How high is the **pressure drop**?

This can arise due to too small diameters. In networks which have grown over time, more and more points of use have been added to longer and longer main lines without these having been redimensioned in accordance with the requirements. Perhaps, only the compressor capacity has been increased. After the diagnosis has been made taking into account all three criteria, an economically sensible refurbishment can be determined. Either, certain parts or sectors should be refurbished or, if all the negative phenomena coincide, a new network may be the most economic solution from the cost/benefit aspect. Such refurbishments often cost much less than years of wasting energy – the payback periods are very short.

An economic concept can be designed by any specialist compressed air company!

Often, a meticulous observation using measurements of the complete system from production and treatment through distribution right up to the mechanisms of the machines is a time-consuming necessity, which, however, pays off lucratively for a company – regardless of the type and size – quickly and long-term.

The maintenance of the most expensive energy source which is also vital to production should be done as diligently as it really deserves!!!

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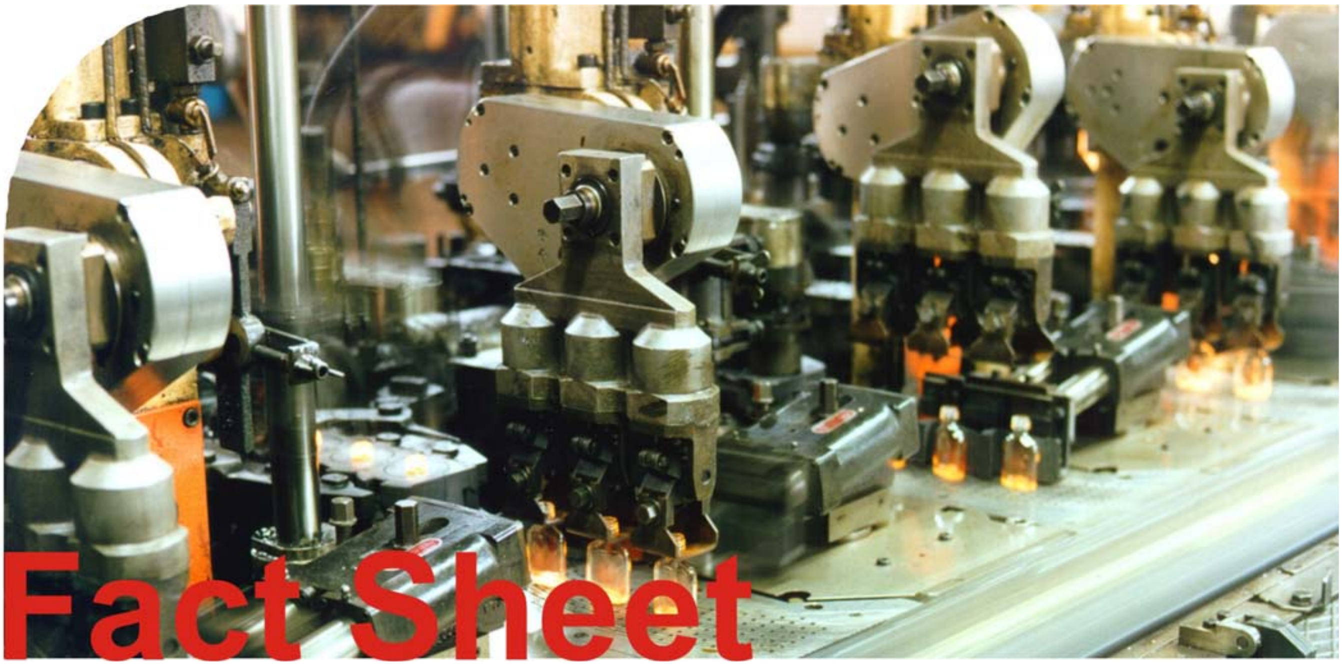

System Optimisation

Roadmap for optimisation

1. **Situation audit: assessment of actual state**
2. **Engineering – concept**
3. **Examination of complete system**
4. **Reducing interfaces**
5. **Efficiency of compressed air production**
6. **System follow-up – system optimisation**
7. **Outsourcing the compressed air supply**
8. **Organisational changes.**

In the age of rationalising industrial plants, the optimisation of complete systems is a very important tool to increase efficiency. This applies to compressed air technology as well.

Even if at the beginning of an inspection it seems that in the past decades not enough emphasis was placed on the planning and development of the relevant compressed air system and any possible extensions, at closer inspection the problem is usually revealed to be more complex. For example, in the past, the compressed air system was often considered the responsibility of departments which actually had nothing to do with the technology and was thus treated as a secondary concern. This "uncontrolled growth" was supported and even reinforced by the advantage of compressed air – that it is "accident-proof". That compressed air is one of the most expensive energies was often overlooked.

By inspecting the complete system with its diverse improvement options, quite considerable savings can be achieved at often very little expense. Several points have to be taken into consideration, although the emphasis here is on supplying ideas and practical assistance. Several ways to optimise a system within the frame of a complete system check are represented below.

Situation audit: assessing the actual state

The compressed air system consists of the following sectors:

- **Production**
- **Treatment**
- **Distribution**
- **Consumers.**

In order to assess the system's condition, an initial overview of the actual state should be obtained by viewing the plant, room and pipe system diagrams. With the help of the available measurement technology (Fig. 1), the relevant parameters such as volume flow rate, flow pressure, and compressed air quality (temperature, humidity, pressure) can be recorded. In addition, alternative values for the electricity consumption of the compressor (load/no-load measurements) with subsequent illustration of load profiles or the measurement of leaks can be carried out (see fact sheet Measurement Technology).

Fig. 1: Measurement technology

Particular attention has to be paid to the predominant system pressure. The most important user is often located at the end of the network (possibly supplied via a branch line) and is decisive for the pressure generated in the system. To some extent a "historically developed pressure level" is carried, which has originated primarily from network and plant extensions and which could be reduced at closer inspection, and through only minor changes in the network, e.g. through ring closures.

From the individual measurements cited above, valuable information about the system's condition (e.g. inlet and outlet air problems, overloading of processing units, cooling etc.) can be obtained. This opportunity should also be used to check the specifications for the compressed air quality required. All requirements which deviate from the usual standard (oil-lubricated air processed using refrigeration dryers, with simple filters of 1 µm particle size and 1 mg/m³ residual oil content, pressure dew point +3 °C), require additional investments and operating costs due to the treatment measures then necessitated. see fact sheet Treatment).

As soon as the specifications regarding amount, compressed air quality, necessary availability and the associated redundancy have been fixed, the system's durability can be checked for what can continue to be used with regard to condition, age, energy efficiency etc.

To assess the compressed air system downstream, it is prudent to estimate the distribution losses occurring in a leak check. These should normally lie between 15 and 40 % (rule of thumb).

Ascertaining leaks can either be calculated by maintaining the pressure in the distribution network while the plant is not operating, or, if this is not possible, be calculated from the pressure curves measured during operation. There is a mathematical analytical method available to do this. To estimate the leak potential during operation, an ultrasonic detection tool is helpful.

Another aspect is the higher level control of several compressors in a system and thus in a network. Large market innovations have become available in recent years with integrated processor technology so that it is always sensible to regard controlling and control technology separately.

According to up-to-date studies, no-load periods, for example at unregulated screw compressors of up to 30 % and electrical power required at no-load operation of likewise 30 % of the drive power are cited as starting points for a possible optimisation in connection with the use of state-of-the-art controlling and regulation concepts (see fact sheet Control).

The audit should be completed by a detailed report on all the work conducted and processes with relevant diagrams and illustrations of measurement curves, Process and Instrumentation Diagram P&ID (any analyses of saving potentials conducted), as well as formulating suggestions for optimisation.

Engineering – concept

Particular attention must be paid to the overall concept when implementing the insights gained from the audit (effectively taking a wider view): it is obligatory to comply with frame parameters such as, e.g. legal regulations and possibly a given supply concept (e.g. for condensate).

The energy concept cannot be regarded as a separate unit, but has to be seen as linked to possible heat recovery and the synergy effects of other necessary energies, such as, e.g. nitrogen demand. Furthermore, it is important to correctly select the individual components including redundancies to be used in extensions, modernisations and new constructions in accordance with the overall concept.

With modern integrated control technology (keywords tele-service, remote monitoring and control) the service quality of the system can be boosted quite a lot. This usually involves guaranteeing the largest compressor unit or supplying the corresponding system redundancy. A corresponding reliability can be achieved by additional network connections.

Another important point is the overall concept of maintenance and service, which essentially co-determine any resulting expenses.

Examination of complete system

When examining the in-plant measurement technology, particular care must be taken to use the technology sensibly. It has to be determined which permanent measurements of, e.g. energy consumption, leak detection, pressure losses, specific overall performance should be made to monitor the system alongside the "normal" plant measurements such as volume flow rate, pressure and pressure dew point. Corresponding to the measures involved, it might be prudent to carry out a cost-benefit analysis.

With regard to controlling, it has to be checked whether automatic regulation or an infinitely variable one should be installed (see fact sheetm Control).

Note: According to the EU study "Compressed Air Systems in the European Union" an energy saving potential of approx. 20 % is realisable through employing efficient and higher level control systems.

Reducing interfaces

Examining the organisational coordination of the compressed air system is also important. It should be checked whether it is sensible to consign the compressed air system its own organisational unit. The resulting cost transparency is one big advantage of this and thus better cost control. Up to now, compressed air technology has been knowingly or unknowingly billed at several accounts, which made it very difficult to check the costs incurred.

This can be changed if someone is put in charge of a project and thus of the costs in order to improve the organisation.

When conducting service and maintenance measures it is advantageous if the work can be planned in the long term. In practice this means preparing the necessary checklists and maintenance plans in plenty of time in order to ensure maintenance of the plant components without interruption (keyword fault management).

Efficiency of compressed air production

To determine the efficiency, the m³ costs can be taken as a benchmark for energy/maintenance/capital. Determining the components via the specific output and service costs is also possible. A cross comparison with other consumers or projects with subsequent optimisation suggestions is to be recommended.

After these assessments, estimating the potential should be done including the calculation of additional internal costs, investment costs, replacement investments, operating costs and service and maintenance costs.

The next recommended step is to prepare a balance sheet of the compressed air system. This includes identifying the specific benchmarks, the degree of efficiency together with the affiliated network parameters.

The energy efficiency can be further increased by, e.g. examining heat recovery possibilities. When optimising the system, it is also very important to check for misuse of compressed air such as, e.g. cooling workers on hot days etc. This is to do with increasing workers' awareness of the issue.

Finally, the targeted improvements are put into practice.

Fig. 2: Compressed air system

System follow-up – system optimisation

Here it is necessary to carry out basic examinations such as checking the energy efficiency with alternatives and the examination of existing energy forms such as, e.g. combined heat and power. Linked with this is the general examination of the existing operating and installation conditions and the maintenance friendliness.

It is not sufficient to optimise the system only once. Indeed it is necessary to regularly adjust the system to changing specifications (consumption, system pressures etc.). The changes in the system are caused by modifications which are not centrally coordinated. It is therefore very important that internal system modifications should have to be registered or even better have to be officially authorised first.

In practice in the past different control mechanisms such as cost controlling and systems to maintain performance have paid off repeatedly. System prognostication is a good tool used to compare today's requirements with future requirements.

Outsourcing the compressed air supply

The pros and cons for this course of action have to be carefully balanced. The contractor's guarantee of an energy consumption per NM³ compressed air is one argument in favour of outsourcing compressed air. It is therefore in his interests that the system operates efficiently. Furthermore, it is ensured that the system will be in the hands of a specialist and that the firm's own staff are not burdened with unfamiliar tasks.

Arguments against outsourcing are that the key skills involved in optimising compressed air systems, planning new systems and maintaining systems are then lost to the customer. If the compressed air system is reintegrated at some point, these skills have to be built up again. (See contracting guidelines.)

Organisational changes

In practice, it has been shown that management in general does not have a high regard for the compressed air system. However, those in charge of the system are usually to blame for this situation since they do not pass on important concerns to the management and thus lead a "wallflower" existence.

The personnel situation has to be examined. If necessary, staff have to be trained for the relevant tasks. Another possibility is to appoint someone to be responsible for compressed air.

Conclusion

As well as the utilisation of individual energy efficient components for the production, treatment, distribution and use of compressed air, the optimum coordination of all the components with one another is also of particular significance. The sum of efficient components does not necessarily result in a reasonable overall result. The existing optimisation potential is also considerable.

Professional external help is probably often necessary here, but it is also important to ask the right questions before commencing the project, and when planning and implementing it.

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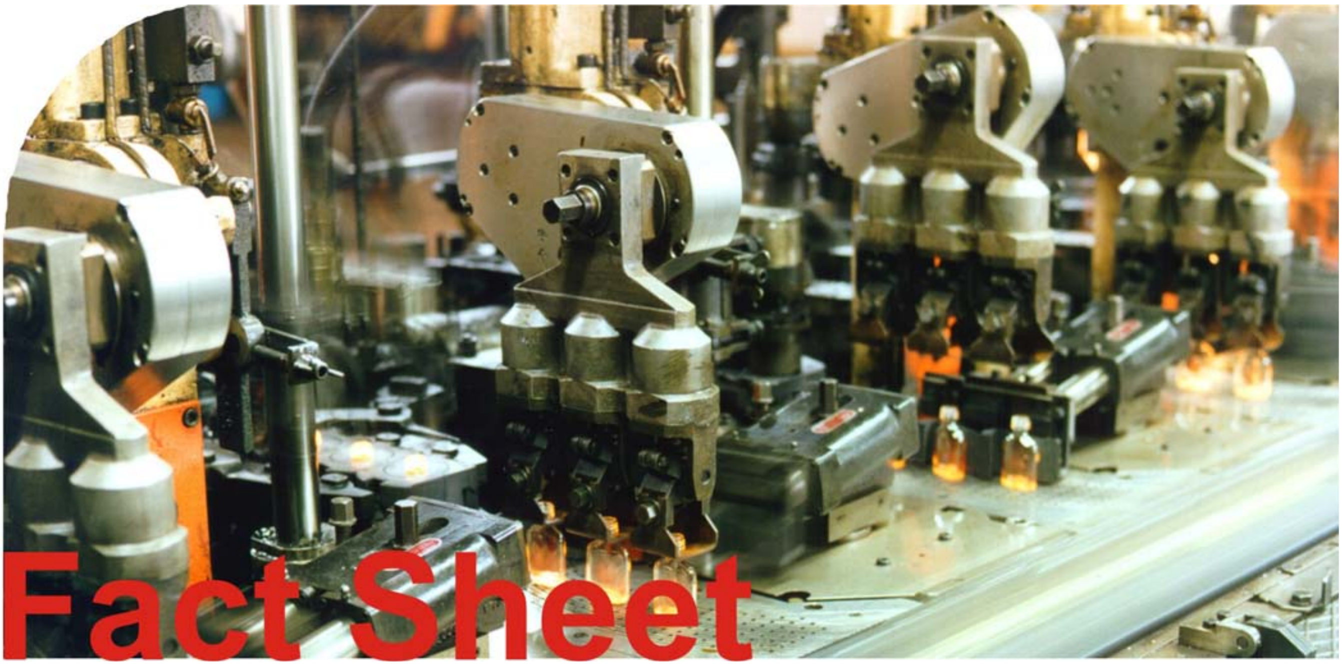


Tools

"Before" the tool

Compressed air as an energy source for tools has a strong influence on the efficiency of the work performed by the tool.

Measures at the workplace to optimise the air supply of the tool can often contribute to clearly increasing productivity and lowering energy costs.

Correct system design, from the compressor to the tool, is essential for the efficiency of the overall system. Many systems have "grown" over time, with older components which have not always been adapted to current conditions. Wrongly sized compressors or too long running times cause high costs in the same way as pipe losses and leaks (see "correct working pressure").

More detailed information on the design of individual components and their coordination can be found in the fact sheets "Production", "Control" and "Distribution".

Massive deterioration of productivity because of too low working pressure!

Compressed air tools are designed for a particular working pressure (usually 6.3 bar). It should be noted that this concerns the flow pressure and not the static pressure often shown at the service station.

The flow pressure can either be measured by a manometer positioned upstream of the tool or by a tool simulator. Anything below the optimum working pressure results in reduced performance of the tool. As an example, here the cutting performance of an angle grinder:

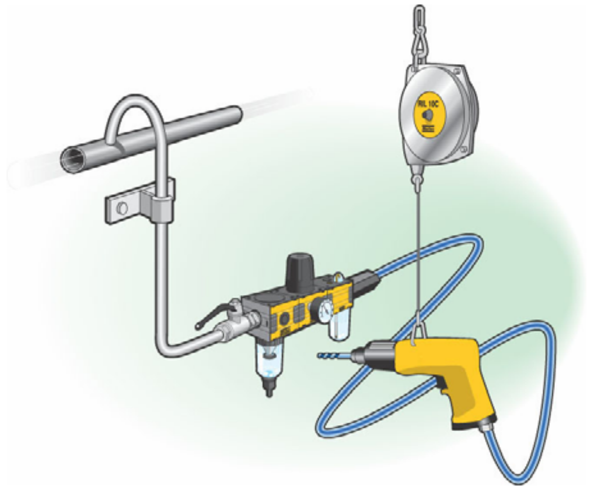
Working pressure in bar	Material removal in kg/h
6.3	5.5
5.8	4.5
5.3	4.0

The example shows that even a reduction of 0.5 bar in the working pressure results in a clear reduction in productivity. As a result, not only the necessary working time is increased, but also the energy costs.

The air consumption per time unit does fall but the longer working time still has an effect here.

Example

The total costs are listed based on the example of a drill as shown in Figure 1.



Working pressure in bar	Drilling time in s
6.3	2.0
5.8	3.2

Fig. 1: Power drill with air service unit and supply line

This means that the drilling time is increased by 60 % due to the lower pressure. And yet a working pressure which is 0.5 bar lower is by no means an exception, but often expensive reality.

In the drill example, the costs would increase as follows:

at	
Air consumption of drilling machine at 6.3 bar	15 l/s
efficient drilling time	1 h/day
working costs	20 €/h
energy costs	0.1 €/kWh
additional costs per month result for	
work	240.00 €
energy	5.97 €
TOTAL	245.97 €
	i. e. 2,700 € per year!

The way to efficient tool use

1. Optimisation of the environment

Long hoses = pressure loss!

Consequently, hoses should be kept as short as possible, spiral hoses should be avoided. Where spiral hoses are used, e.g. between mains and balancer, normal hoses could often be used. Attention must be paid to suitable hose diameters, this can help to avoid unnecessary pressure losses at couplings.

Install loss-free couplings!

The majority of self-venting quick release couplings - especially those made of brass - use up a lot of pressure (0.6-1.3 bar flow pressure). The reason is a ball positioned in the air stream. Modern quick release couplings drastically reduce the losses (to approx. 0.2 bar) and thus recover their initial cost within a short period of time.

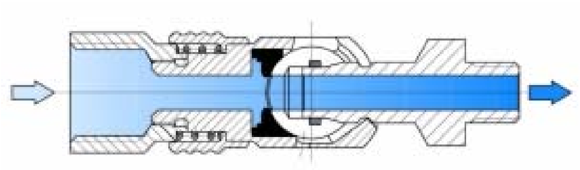


Fig. 2: Modern quick release coupling

Avoid too much tinkering!

Large diameter tolerances, more couplings than necessary, too many nozzles and incorrect hose diameters all add up to a large energy "gobbler". Tailor-made installations almost always pay off.

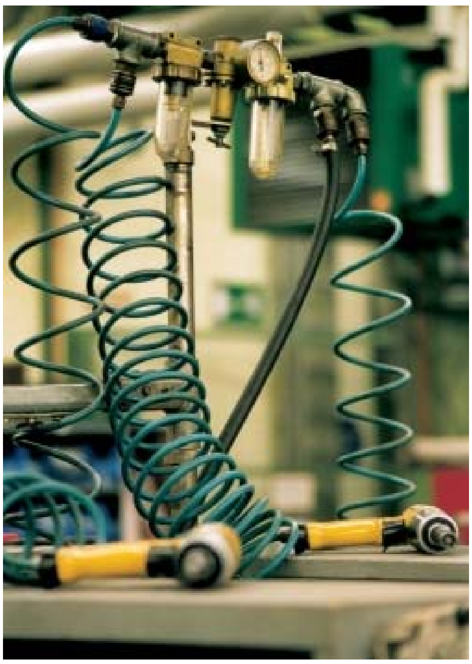


Fig. 3: Energy “gobblers“ in compressed air system

Oil lubrication in the air supply only where necessary!

Turbine-driven tools or those fitted with oil-free multi-disc motors do not need oil lubrication. Oilers cause pressure losses. If they are required, the oiler should be positioned 3-5 metres away from the tool.

2. Measuring and adjusting the flow pressure

After optimising the environment, the working pressure at the tool will probably be too high. This can now be reduced using the pressure controller of the air service unit. The tool then operates in the most efficient state, air consumption is minimised.

Flow pressure at the tool in bar	Air consumption in %
6.3	100
7.0	110
8.0	125

3. Adjusting the air mains pressure

The air mains pressure can also often be clearly reduced. This results in reduced compressor running times and thus massive reductions in energy costs!

Optimisations of the tool's surroundings often pay off within the shortest time!

Maintenance of the air pressure system

After optimisation has been completed, the efficiency gained has to be retained. Regular maintenance of the components is of fundamental importance here. Alongside the draining and cleaning of the filters, care should be taken to regularly check for leaks.

The supplier of the compressed air system will be able to assist you in making a maintenance plan.

It pays to remember that the condition of the tool itself has considerable effect on efficiency.

It is just as important to take into account that every change in the compressed air system has consequences for the pressure relations in the system.

Should this not always be possible because alterations occur very frequently, then the entire sytem should be checked at regular intervals.

Summary

Making a check of the environment pays off quickly where compressed air tools are being used. Incorrect sizing, adjustments and poor maintenance dramatically reduce productivity.

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