

Selection and projecting of compressed air generation in railbound vehicles

By Dieter Reinger and Hans Lütte, Rheinfelden*)

General – Interfaces for Compressed Air Generation – Definition of a Compressed Air Generation Plant – Volume Power Demand – Requirements to the Compressor – Drive Motor – Compressed Air Preparation – Vibration Decoupling – Compressor Management – Basic Frame – Provisions and Legal Notices – Installation Examples

1. General

Changes in the infrastructure in urban and rural areas lead to new requirements to railbound traffic. New constructions mirror the current trend in their specifications. Old vehicles are brought up to date by modernisation measures.

Cost pressure of the traffic operations and growing environmental consciousness of urban and rural areas require reduction of emission at increase of energy efficiency.

The following contribution on building a state of the art compressed air generation plant, comparison of different compressor builds and installation situations is to support the user in making decisions on modernisation of his compressed air plant.

The customer and supplier enter a long-term commitment at required product service lives of usually 30 years. It is therefore important that the differences between the products are known and that their advantages and disadvantages are weighed against each other.

2. Interfaces for compressed air generation

The scope of modernisation depends on specific requirements of the traffic operation. In particular when modernising a compressed air generation plant, the vehicle-side interfaces are provided and cannot be changed or only insignificantly because they would, e.g. require repeated acceptance.

Typical interfaces are:

- Attachment points at the vehicle frame,
- Rated width and position between the pipe connections and the board grid,
- Electrical connection forms and connection assignments (pin assignment) for control and main flow.

Under consideration of further limitations like traverses in the vehicle frame and other units, the installation space and accessibility for maintenance are pre-defined.

These inflexible interfaces partially lead to a pragmatic action of the operations: They only overhaul or replace individual components of the compressed air system even though planning and designing a completely new compressed air system would lead to higher efficiency increases. At this time, almost any imaginable measure can be implemented.

Example: Energy consumption of a compressed air system is not only determined by efficiency of the compressor used, but also by the interaction of all system components.

3. Definition of a compressed air generation plant

The essential components are (figure 1):

- Suction filter
- Compressor
- Drive motor
- Compressed air filter, cooling, drying
- Compressor management (demand-dependent compressor and dryer control)

*) Dieter Reinger and Hans Lütte, project scheduling, construction and sales compressors and compressed air systems for street railbound vehicles, CVS engineering GmbH, Grossmattstraße 14, D-79618 Rheinfelden, Phone: +49 (0)7623 71741-75, Internet: www.cvs-eng.de

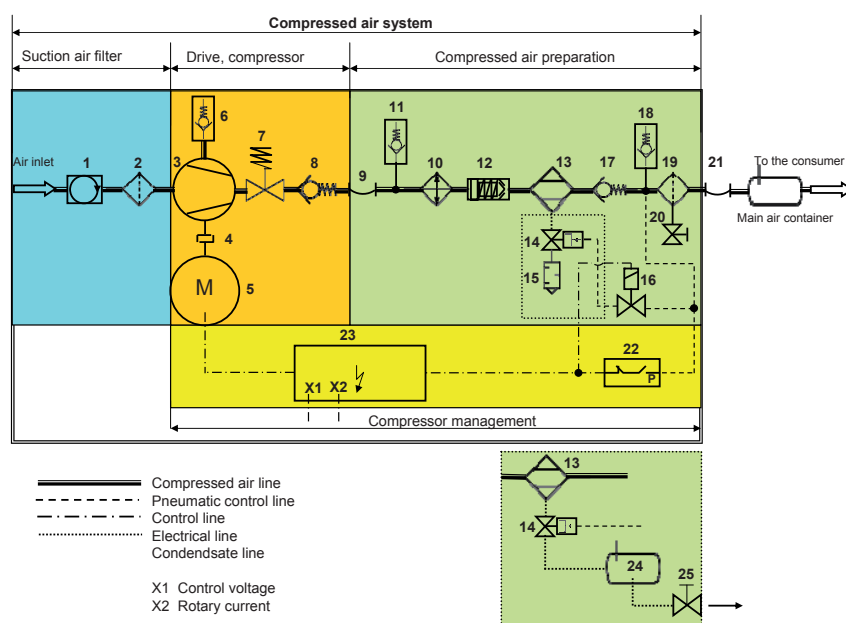


Figure 1: R & I flow chart of a compressed air generation plant
 1 = Prefilter/cyclone, 2 = Air filter, 3 = Compressor, 4 = Coupling, 5 = Drive motor, 6 = Safety valve compressor, 7 = Minimum pressure-relief valve, 8 = Non-return valve, 9 = Compensator / hose, 10 = Compressed air cooler, 11 = Safety valve, 12 = Pulsation damping valve, 13 = Compressed air dryer, 14 = Drainage valve, 15 = Muffler, 16 = Control valve for drainage, 17 = Non-return valve, 18 = Safety valve, 19 = Fine filter (optional), 20 = Manual emptying (optional), 21 = Compensator/hose, 22 = Pressure switch, 23 = Compressor management, 24 = Condensate container, 25 = Manual emptying

- Condensate collection system (the condensate contains oil in oil-lubricated compressors; see chapter 7.5)
- Unit frame to take up the components and fasten them to the vehicle

4. Volume flow demand

The required volume flow demand (figure 2) results from the sum of:

- Vehicle's volume flow demand
 - Meeting the maximum permissible filling time for vehicle equipment
 - Meeting the maximum permissible filling time in operation
 - Considering the individual consumers and total volume of the compressed air tanks
- Volume flow demand of the compressed air dryer (drainage, regeneration air)
- Volume flow reduction of the compressor by pressure and heating loss at suction
- Permissible switch-on frequency of the drive motor

- Permissible switch-on duration of the compressor

Where trains with tractor units used to supply personal traffic, state of the art trainsets are used almost exclusively today.

These vehicles now often use two or more individual compressed air generation plants installed in the trainsets under the floor, on the roof or in the vehicle.

The advantage of this redundant alignment is in best volume flow demand adjustment. During vehicle equipment, both compressors will be active; in normal operation, one compressor supplies the basic load, the second is used for peak load. A pre-determined switch of operating mode achieves even load of the compressors. Change of control is performed directly in the compressor unit or via the superordinated vehicle control.

The required overpressure is at 8 to 10 bar for all vehicle types, rarely at 12 bar.

Figure 3 shows an example for the interaction of the basic load and peak load compressors.

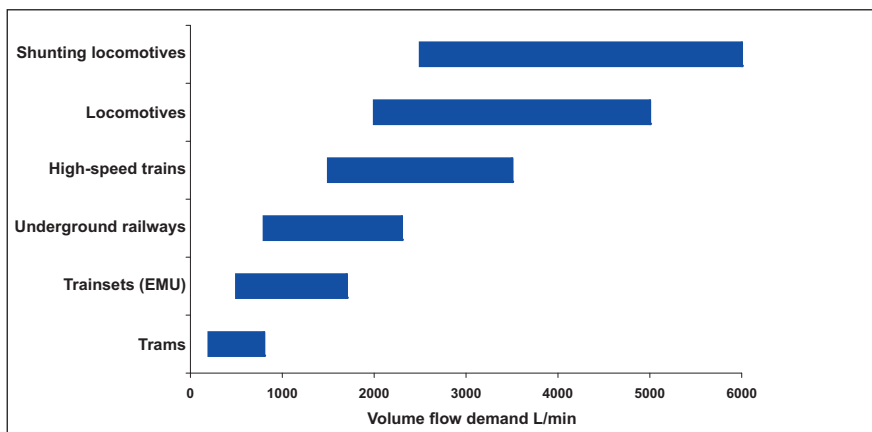


Figure 2: Volume flow demand of railbound vehicles

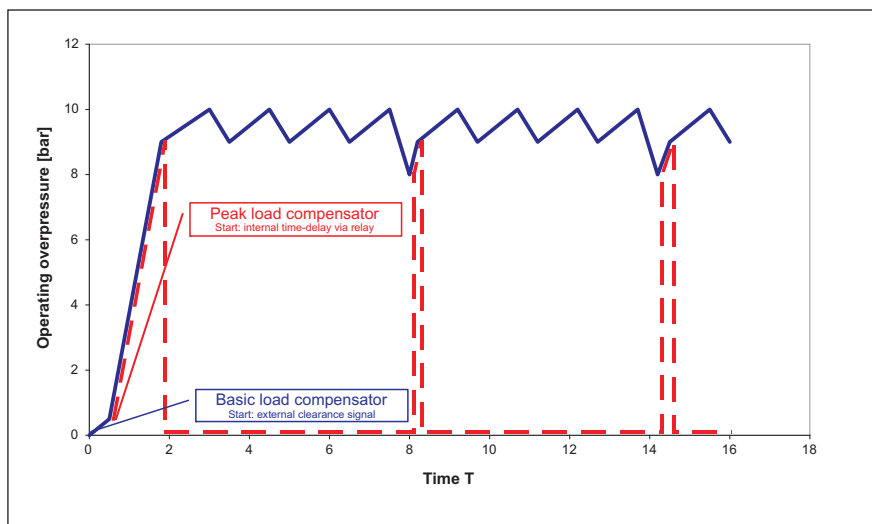


Figure 3: Example for the operation of two parallel compressed air generator systems

5. Requirements to the compressor

The core of the compressed air generation plant is the compressor. Only compressors working by the displacement principle with dry, oil loss lubricated or recirculating oil lubricated compression are used for the rail area. Many manufacturers offer modified industrial compressors; only a few use devices explicitly built for this special need.

The requirements to a train compressor are higher than those to an industrial one. Typical requirements include:

- Environmental influences
 - Ambience temperatures (quick temperature changes, tunnel drives with component cooling)
 - Altitude and routes with extreme slopes
 - Air pollution (sand, dust, pollen ...), proximity to the sea, spreading salt, water, flying snow
 - UV radiation, ozone
 - Resistance against aggressive cleaning agents
 - Load by acceleration and deceleration forces
 - Generous maintenance intervals
 - High protection against escaping operational fluids
- Verification of the track compressors or the complete compressed air generation plant is performed by:
- Climate chamber test (e.g. ambience temperature -45°C to $+60^{\circ}\text{C}$)
 - Vibration and shock test pursuant to EN 61373 category 1 class A
 - Endurance test
 - Start, stop and quick relief (simulation of power outage, e.g. due to frozen catenaries)

A decision on the correct product is characterised by:

- Procurement price
- Life cycle costs
- Design (accessibility for maintenance, resistant against contamination, dimensions and weight)
- Supplier know-how (application competence)

The comparison in figure 4 considers compressors mainly used in railbound traffic.

6. Drive motor

The compressors are always driven by electro motors (direct current or rotary current motors, figure 5) or hydraulics motors (figure 6). Railway applications almost always use rotary current motors with railway approval, protection type IP55. They work reliably, are light and low-wear.

Rotary current motors have a smaller volume as compared to direct current ones, no brush wear, lower weight and can be replaced easily. In connection with a frequency converter, the rotary current motor has other advantages, too: The compressor can be best adjusted to the required volume flow demand (vehicle retrofit, basic load, peak load) by variation of the drive speed. Therefore it can also be chosen in a smaller size.

Current frequency converters are electronic components and work free of wear. A converter for a 7.5 kW rotary current motor weighs approx. 30 kg. The package price of a rotary current motor with converter is less than that of a direct current motor.

7. Compressed air preparation

Compressed air preparation starts with filtering of the suction air and ends at the connection to the compressed air grid. Compressed air quality can be specified, e.g. via standard ISO 8573-1. 6 quality classes are available (figure 7); they differ by maximum number and size of particles, the required pressure dew point and the maximum permissible residual oil content.

7.1. Pre-filter/air suction cyclone

An upstream cyclone separator (figure 8) accordingly increases service life of the

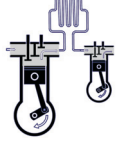

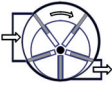
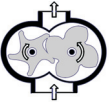
Valuation ▲ high ▶ middle (neutral) ▼ low	Compressor builds			
	Oscillating		Rotating	
	Double-stage piston	Single-stage piston	Single-shaft multi-cell compressor	Twin-shaft screw compressor
	Oil-free	Oil loss lubrication	Recirculation oil lubrication	Recirculation oil lubrication
				
Compressor build type features				
Purchasing price	▲	▼	▶	▶
Compressed air exit temperature ²⁾	▶	▲	▼	▼
Noise emission ¹⁾	▶	▲	▼	▶
Own vibration ¹⁾	▲	▲	▼	▼
Service life	▼	▶	▲	▶
Compressed air pulsation	▲	▲	▼	▼
Operating hours until the first general overhaul ³⁾	▼	▶	▲	▶
Overhaul cost	▲	▶	▼	▲
Accessibility for maintenance	▶	▶	▲	▲
Compressed air quality	▲	▼	▶	▶
Max. possible activation cycle	▶	▼	▲	▲
Maintenance interval ⁴⁾	▶	▶	▶	▶
Maintenance effort	▼	▲	▶	▲
Weight	▶	▼	▼	▲
Compressor speed	▼	▼	▼	▲

Figure 4: Comparison of compressor builds

- 1) The piston compressor principle requires a higher effort for reduction of the air and body noise or reduction of the compressed air exit temperature.
- 2) Rotating compressors are resistant against continuous operation at 100% due to their recirculation lubrication. The compressed air exit temperature is at approx. 75 to 90°C; the exit temperature of piston compressors is approx. twice as high. Project scheduling has to consider the following items:
 - the permissible activation duration of piston compressors is limited
 - the suction volume flow of piston compressors must be selected larger
 - output-dependent components like compressor drive motor, frequency converter, line cross-sections and electric power parts must be selected accordingly larger. The weight is increased accordingly.
- 3) For two-staged oil-free piston compressors, runtimes between overhauls are at approx. 5,000 to 8,000 operating hours. Recirculation-lubricated sliding vane compressors achieve 18,000 operating hours. The principle enables easy overhaul and does not require any special tools. It is usually performed by the traffic operations directly. The material costs are only at a fraction of that of oil-free piston compressors.
- 4) The maintenance interval should be no more than 1 x year.

air filter, in particular when installed under the floor. Dust, sand and, e.g. brake abrasion is collected in one place

by targeted flow guidance and then removed.

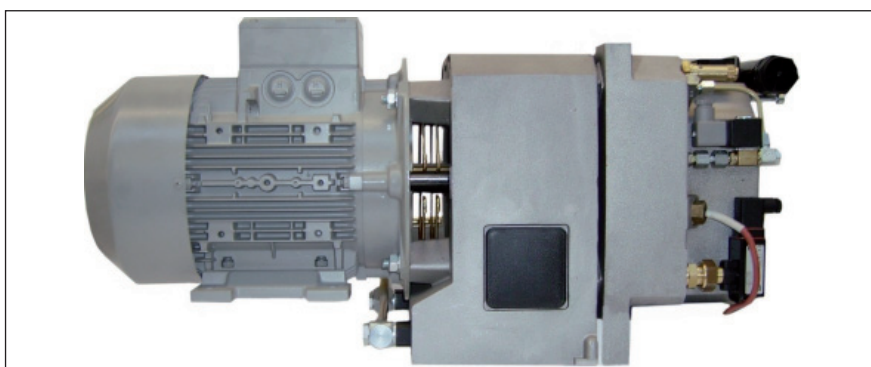


Figure 5: Drive with rotary current motor



Figure 6: Drive with hydraulic motor

Class	Maximum particle number / m ³ at particle size in m μm			Pressure dew point °C	Residual oil content mg/m ³
	0,1 < d ≤ 0,5	0,5 < d ≤ 1,0	1,0 < d ≤ 5,0		
0	Specified by the costumer or supplier and better than class 1				
1	100	1	0	≤ -70	≤ 0.01
2	100000	1000	10	≤ -40	≤ 0.1
3	not specified	10000	500	≤ -20	≤ 1.0
4	not specified	not specified	1000	≤ +3	≤ 5.0
5	not specified	not specified	20000	≤ +7	–

Figure 7: Excerpt from ISO 8573-1, tables 2, 3 and 5

If suction of moisture in the form of water or flying snow is expected, suction must be placed in a protected place with a vacuum-proof hose.

7.2 Suction air filter

The filter mesh of 3–5 μm of a standard filter element (figure 8) is usually sufficient. The filter area must be generously sized to achieve the annual change intervals at sufficiently small contamination resistance (max. 500 mmWS). With increasing filter resistance, e.g. the useful volume flow is reduced by 1% per 100 mmWS.

7.3 Compressed air after-cooler

To achieve a lower pressure dew point, the compressed air temperature at the dryer inlet must be lowered to less than 60°C.

For oil recirculation lubricated compressors, a simple pipe cooler with convection cooling suffices. Piston compressors require a force-vented compressed air cooler. Cooling off of the compressed air leads to condensation between the compressor and the dryer already. To prevent frost damage, the pressure line always has to be placed with a slope towards the dryer. If water pockets cannot be avoided when the compressor and dryer are placed in different positions of the vehicle frame, a water trap with automatic emptying must be installed. To prevent corrosion damage, the compressed air guide must be performed with corresponding material/materials pairs. Figure 9 shows an example for a simple compressed air after-cooler with inclination towards the dryer.

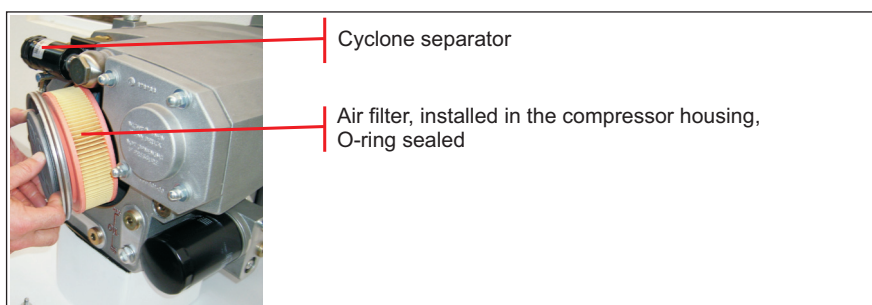


Figure 8: Cyclone separator / air filter

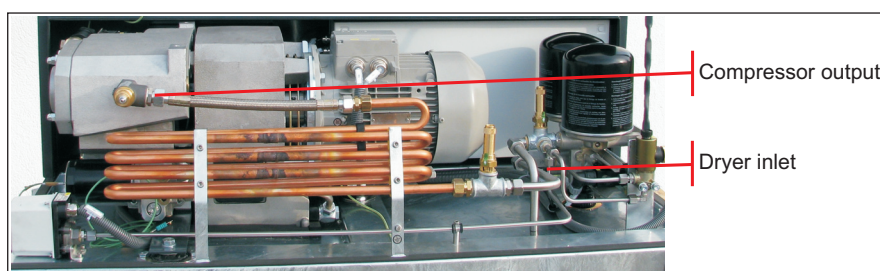


Figure 9: Compressed air after-cooler with convection cooling

7.4 Compressed air dryer

Compressed air dryers protect from corrosion, condensation and ice formation in the compressed air system. Two technologies are used in railbound traffic: Cold-regenerating adsorption dryers and membrane dryers.

Adsorption dryers are robust and resistant against contamination and can take up oil from the compressed air depending on size and equipment. They are standard equipment in trucks and buses.

Membrane dryers cannot handle contaminated compressed air due to their technology.

Both builds achieve pressure dew points of -40°C at 10 barg. The regeneration air demand is constant and depends on the desired pressure dew point. It is approx. 15% of the transported volume at a desired pressure dew point of -20°C and approx. 25% at -35°C.

For both technologies observe:

- Entry temperature of the compressed air at the dryer no more than 60°C
- Environmental temperature no more than 50°C
- Avoiding direct heat irradiation
- Consideration of permanent consumption of regeneration air

7.4.1 Two-chamber adsorption dryer

Two-chamber dryers consist of two replaceable cartridges filled with adsorption agent (silica gel). While the active cartridge takes up moisture from the compressed air, the passive cartridge regenerates because part of the flow of already-dried compressed air flows back outside through the drying agent. The cartridges are alternated in cycles. The collected condensate is time-controlled or removed when the compressor stops at a switch-on time below 60% (figure 10).

7.4.2 Single-chamber adsorption dryer

For volume flows up to 500 l/min and a compressor switch-on duration below 50%, single-chamber dryers can be used.

The second cartridge is dispensed with. With the compressor standing, the moist adsorption agent is dried by the regeneration air from a regeneration air container. It is filled again with dried air when the compressor starts.

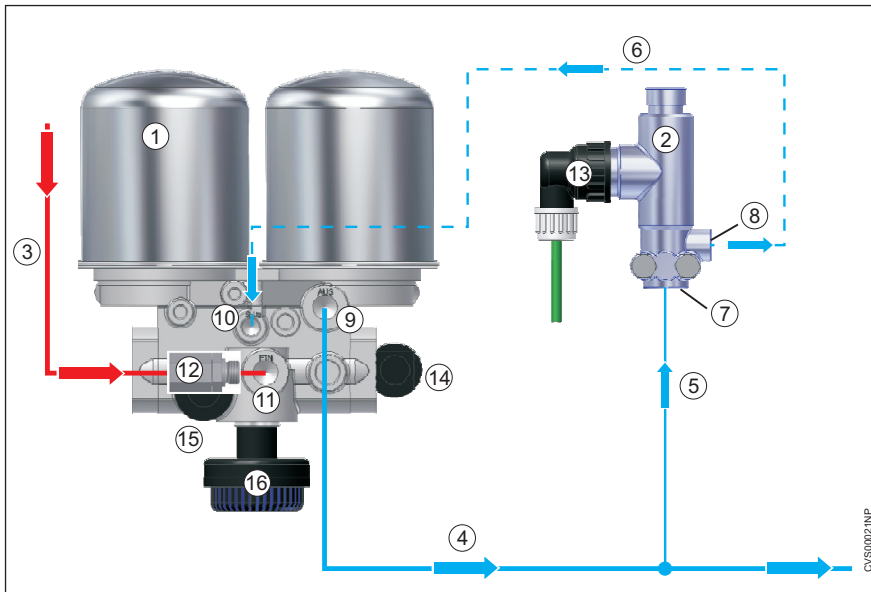


Figure 10: Chart of a two-chamber adsorption dryer

1 = Two-chamber adsorption dryer, 2 = 3/2-directional valve, 3 = Pressure line from the compressor, 4 = Pressure line to the consumer, 5 = Pressure line to the 3/2 directional valve, 6 = Control line for drainage, 7 = Pressure line input, 8 = Control line output, 9 = Dryer output, 10 = Control line input, 11 = Dryer input, 12 = Pulsation damping valve, 13 = Electric connection 3/2 directional valve, 14 = Electric connection cartridge switching, 15 = Electric connection heating, 16 = Condensate exit (drainage)

7.4.3 Membrane dryer

The moist compressed air flows through coated hollow fibres with walls permeable for water. A partial flow of already-dry compressed air flows without pressure around the outer surface of the hollow fibres. This regeneration air transports moisture outside.

7.4.4 Fine filter

To achieve a residual oil content of class 1 pursuant to ISO 8573, oil recirculation lubricated compressors can be equipped with a fine filter downstream of the dryer.

This filter also protects the downstream system from possible dust abrasion from the adsorption agent. This protection can

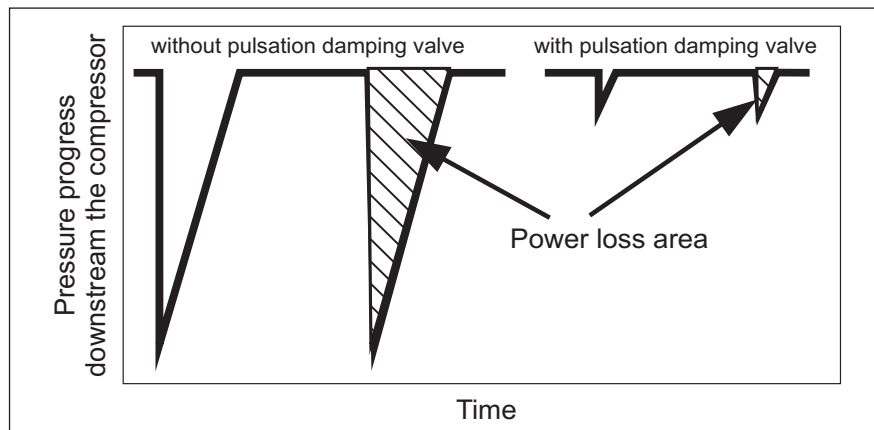


Figure 11: Pressure progress downstream of the compressor with and without pulsation damping valve

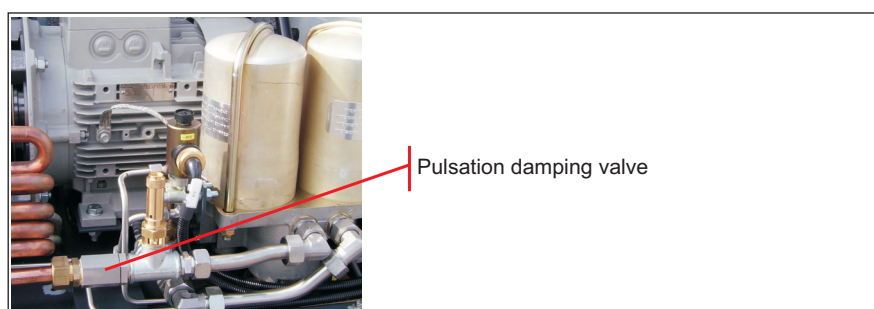


Figure 12: Installation position of a pulsation damping valve

be achieved by using dryer cartridges with integrated coalescence filter at the exit as well.

7.4.5 Safety valves

Safety valves pursuant to DIN EN 1012-1 are required.

7.4.6 Pulsation damping

In oil recirculation lubricated compressors, oil is injected into the compressor space for cooling and lubrication. The resulting oil aerosols (droplets) and oil vapours (mist) in the compressed air reach an oil fine separator that mechanically separates the oil aerosols from the compressed air (coagulation principle); the oil mist remains in the air flow.

The oil mist portion highly depends on the basic oil and vapour pressure of the oil used. Efficient oil aerosol separation requires a constant flow speed of the compressed air in the fine separator. In quasi stationary operation, the aerosol share in the compressed air is close to zero.

A subsequent adsorption dryer leads to a drastic pressure drop during cartridge change or drainage (figure 11). Depending on line volume size between the compressor and dryer, the final pressure drops almost to zero for a short period. This extreme pressure drop leads to strong increase of the discharge speed of the compressed air on the pure side of the oil fine separator. The oil is inadvertently taken along in flow direction from the outer surface of the filter element. The residual oil content in the compressed air is increased accordingly. This can be avoided with a purely mechanic pulsation damping valve that is controlled by the quick pressure drop. It is installed at the dryer input and effectively prevents strong pressure pulsation (figure 12) in the system parts upstream of the valve. Component stress of the pressurised components like filter and compressed air cooler is also strongly reduced.

7.5 Condensate collection

During compressed air generation, condensate is discharged at the dryer. With the amendment of the water management act (Wasserhaushaltsgesetz; WHG), the Abwassertechnische Vereinigung (AVTA) recommended threshold values of max. 20 mg/L for introduction of hydrocarbons.

Observing the items relevant for oil separation (compressor operating temperature, avoiding dryer pulsation, use of oils with low vaporisation loss), the threshold value of 20 mg/l is undercut.

Today, environmentally compatible, bio-degradable ester-based oils are available that are equal to conventional mineral oils and comply with the required technical performance.

8. Vibration decoupling

Compressor or compressed air system decoupling from the vehicle has the following advantages: On the one hand, this prevents that vibration of piston compressors (oscillating) is introduced into the vehicle frame; on the other hand, the vibrations transmitted to the compressor unit by the vehicle during a drive are damped, and standstill wear of the bearings is thus prevented when compressor and motor have stopped (figure 13).

The vibration dampers must take up forces in X, Y and Z directions.

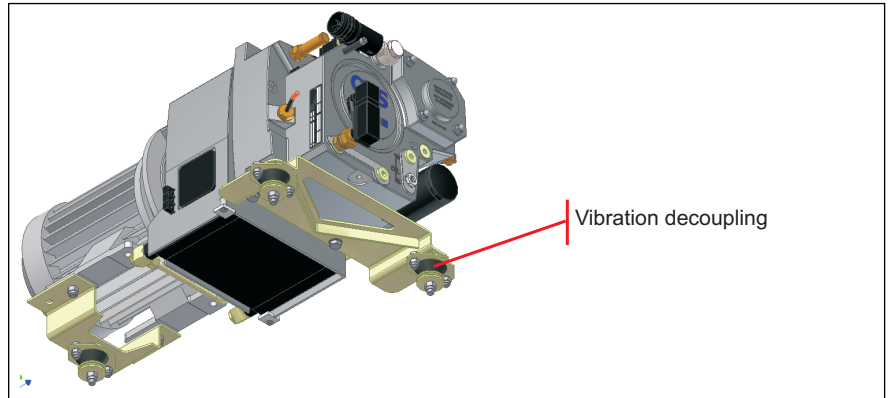


Figure 13: Vibration decoupling

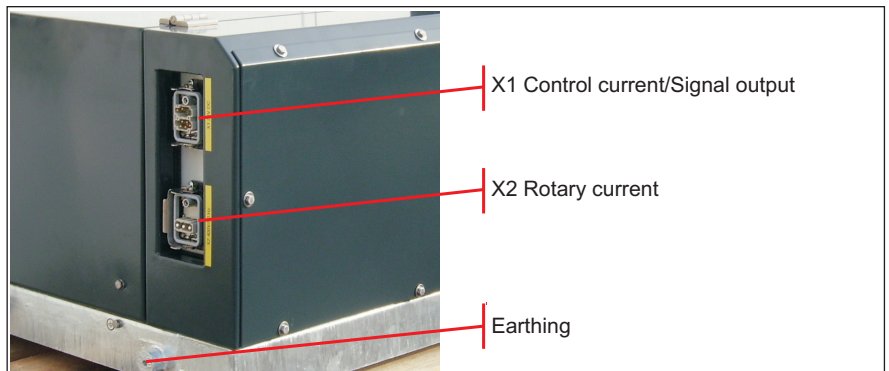


Figure 14: Electrical interfaces

9. Compressor management

The control and monitoring components are usually combined in a steel sheet housing (protection type IP65). The connection of control and main power line with plugs with encoded pin assignment enables quick and secure electrical connection to the vehicle (figure 14).

Typical compressor management tasks include:

- Demand-dependent start/stop control of the compressor
- Idle control of the compressor
- End temperature monitoring of the compressor
- Temperature monitoring of the electric motor
- Compressed air dryer control
- Processing of external signal (e. g. when setting up two compressors on the vehicle, basic and peak load)

10. Basic frame

The frame is customised to the present interfaces. The frame is used to take up all components required for compressed air generation.

The requirements to the material regarding resistance, weldability and documentation of the material quality

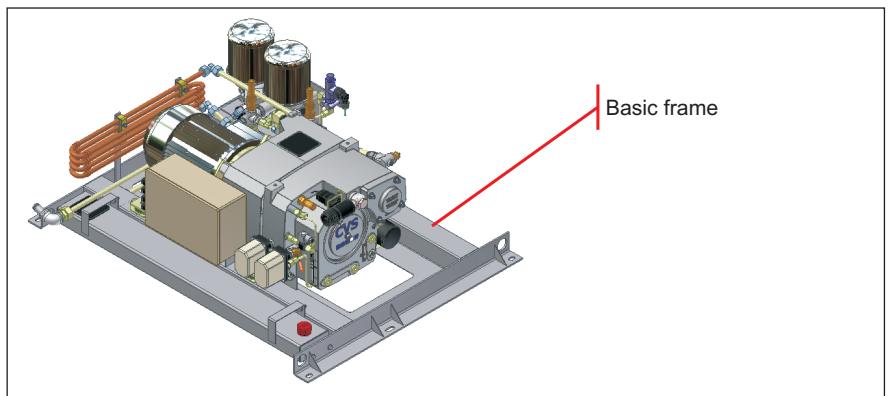


Figure 15: Compressed air generation system on the basic frame

by corresponding certificates and good availability makes sheet metal the best material. The welding-technical scope of documentation must correspond to DIN EN 15085. Solidity calculation is performed with customer-specific indications for acceleration and deceleration values in vertical and horizontal directions. A cover is used for noise reduction and to protect against contamination. Figure 15 shows an example component alignment on the basic frame. The maintenance side is placed towards the side with the best accessibility.

11. Requirements and legal notes

The compressed air generation plant is subject to the machinery directive 2006/47/EC.

Other relevant standards include:

- Pressure equipment directive 97/23/EC (in Germany pressure equipment ordinance 14. GPSGV)
- Directive on application of the simple pressure vessels 87/404/EEC (in Germany 6. GPSGV)
- Electromagnetic compatibility EN 50121-3-2
- Electrical equipment on rail-bound vehicles EN 60077

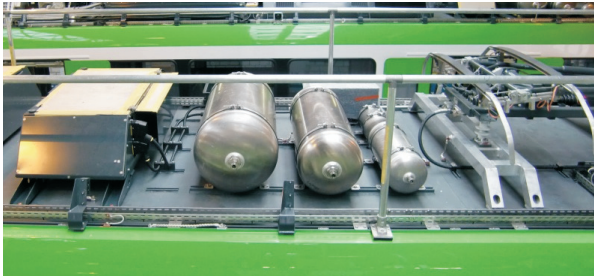


Figure 16: Examples for roof mounting with cover

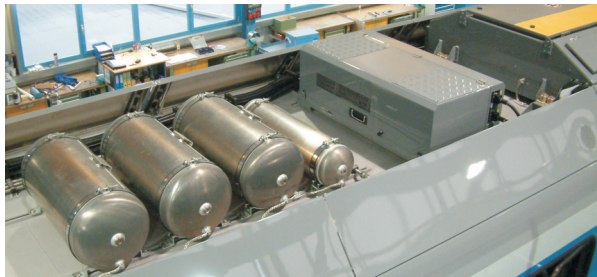


Figure 17: Example for roof mounting with walk-on cover



Figure 18: Example for roof mounting without cover

- Compressed air quality ISO 8573-1
- Preventive fire protection in railbound vehicles DIN 5510-2
- Welding of rail-bound vehicles and vehicle parts DIN EN 15085-1 to 5
- Vehicle- and railway-specific requirements
- Low-voltage directive 2006/95/EC (in Germany pressure equipment ordinance 1. GPSGV)
- Safety of machinery DIN EN ISO 12100-1/-2
- Compressor safety requirements part 1 EN 1012-1



Figure 19: Example for modernisation of under-floor installation

12. Installation examples

Figure 16 shows a compressed air generation plant (sliding vane compressor 800 l/min, drive motor 7.5 kW, total weight 205 kg), roof mounted on a new vehicle (EMU) of company Stadler Rail (CH). The design adjusted the lateral covers to the slanted vehicle roof sides.

Figure 17 shows another example of a compressed air generation plant (sliding vane compressor 400 l/min, drive motor 4 kW, total weight 172 kg), roof mounted on a new vehicle (EMU) of company Stadler Rail (CH). The cover is suitable for walking on it here.

Figure 18 shows an example for modernisation of the compressed air plant (sliding vane compressor, 310 l/min, drive motor 3 kW) in the Eurotram Straßburg. The requirement here was an installation height of 310 mm that could not be exceeded.

Figure 19 shows the modernisation of a compressed air generation plant under the floor of an EMU in Poland. The present system (screw compressor, 1000 l/m, drive motor 11 kW, total weight 340 kg) was here replaced by a state-of-the-art plant (sliding vane compressor, 800 l/min, drive motor 7.5 kW, total weight 190 kg).