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Adsorption dryer for use in railways

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Pneumatic brake, which use compressed air as a working medium, is the main brake of rail vehicles. The equipment used in the braking system requires sufficiently clean, without water vapour medium to work properly. Removing water vapour from the air prevents condensation and ice formation during winter, which guarantees correct brake operation. For this purpose, adsorption dryers are used in the railways to ensure the required pressure dew point value. This article includes an overview of available compressed air drying methods, the results of calculations and bench test of the dryer prototype developed at the Institute. Assumptions and requirements for the device intended for use in railways are based on European standards and UIC cards.

1. Introduction

Due to the railway industry development and increase speed of the railway vehicles, the safety requirements are more stringent for them. Bearing this in mind, it is quite obvious that the overall objectives must be searching new solutions and achieving better parameters.

Compressed air is working medium necessary for the proper working of railway vehicle. Unit of compressed air generation and treatment supplies systems such as: pneumatic brake, self-levelling air suspension, toilet, pantograph lifting, door opener, sandboxes, sirens. The role of the pneumatic brake is of utmost importance. The brake system is one of the critical components in ensuring the safety and reliability of the railway vehicle.

The right compressed air purity is key to safe, economic and reliable pneumatic system. It is also required to provide the right amount of compressed air, considering changing work environment.

Three primary contaminant types as prevalent in a compressed air system can be identified: particles, water (liquid and vapour), oil. Removal of water contamination is singularly important for proper operation of the vehicle. Insufficiently dried compressed air can shorten the useful life of a vehicle. In order to ensure appropriate purity class for compressed air, water should be removed from the working medium immediately after the compressor. Compressed air dryers, filters, separators and cyclone separators are used to separate water from the compressed air [6].

2. Literature review

Adsorption dryers are subject of the contemporary studies and are being still intensively improved.

In 1979, Litchfield et al. [10] developed an analytical model for freeze dryer that included both sublimation and adsorption. Moreover, numerical experiments were carried out by the authors and the results were compared with the experimental data. Compressed air systems with adsorption dryers used in rail vehicles were described by Schaumann and Stanley [18] in 2008. In this article the results from experimental researches were published. In 2008, Djaeni et al. [5] presented the results of numerical calculations of multistage adsorption dryer. The authors considered the profiles of water and vapour in the dryer and also its thermal efficiency. An automatic regenerative adsorption aerosol dryer was presented by Tuch et al. [21] in 2009. The authors conducted experiments to optimize the efficiency of particle transmission. This adsorption dryer has found its application in monitoring networks

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where the aerosol is dried below 50% r.H. Drying methods in railway were considered by Ripol-Saragosi [15] in 2010. The author presented the most reliable way of drying compressed air. In 2000, Mobley published a 12-chapter book [11] in which author considered the basics and problems of hydraulics and pneumatics. Chapter 15 of this book is devoted to air dryers. In 2011, Atuonwu et al. [2] developed a methodology for designing an energy-efficient adsorption dryer. The author compared a conventional dryer with an adsorption dryer designed in accordance with the developed methodology. It turned out that the energy consumption of the adsorption dryer decreased by 55%. In 2011, these authors [3] presented a procedure for optimizing a low-temperature adsorption dryer. Research on saving energy from the adsorption dryer was conducted by Kang et al. [7] in 2016. The authors considered an adsorption dryer, which was used in a process of air purification in a one company' room production. Based on experimental data, researchers searched for the optimal operating conditions for the adsorption dryer. In 2019, Ripo-Saragosi et al. [16] considered the main problem of compressed air systems- water freezing. The authors focused on the potential dangers of frozen water in railway air braking systems. In this article intelligent adsorption dryer was proposed in the aim to solve the problem of water freezing. In the same year Zhang et al. [23] presented the technology of automatic identification of a regenerative adsorption dryer. The technology proposed by authors analyzes the time curve of regeneration process, thanks to which the detection of the problem is very fast. Numerical studies of the drying and regeneration process of the air dryer adsorbent were made by Kozlov et al. [9] in 2020. The author conducted research on an exemplary scheme of an air dryer with separate processes of drying and adsorption. The results showed that such an air dryer provides a stable dew point. A double tower dryer for application in railway, pneumatic braking systems were considered by Xu et al. [4] in 2021. The authors presented the designed dryer and emphasized that its use in rail vehicles most effectively removes moisture from compressed air. In 2022, Sureshkannan et al. [19] developed a design procedure of adsorption dryer with a heatless regeneration mode. The proposed dryers can be used in applications requiring a dew point from –40 to –70°C and in which air pressure ranges from 5 bar, and inlet pressure temperature from 25 to 45°C.

3. Solutions overview

In this article the author focuses on machine designed to remove the humidity content of compressed air – compressed air dryer. There are many of compressed air dryers on the market, depending on the mechanism they use to eliminate water. Current compressed air dryer types include the following:

1. refrigeration with separation (refrigerant dryer),
2. overcompression,
3. air flows through membranes (membrane dryer),
4. adsorption (adsorption dryer),
5. absorption (absorption dryer).

Each of these dryer types will be discussed in some detail.

3.1. Refrigerant dryer

Refrigerant drying means that compressed air temperature is lowered below the dew point temperature. As a result of the cooling process, water vapour in compressed air is condensed and then separated. Water in the form of condensate is stored in reservoirs from which it is removed into the ambience. Refrigerant dryers consist of two heat exchangers: an air-to-air and an air-to-Freon.

Refrigerant dryer includes two heat exchangers. Compressed air flows through air-to-air heat exchanger, which is designed to cool the warm air coming from the compressor using of the cooled dried air. Cooling the warm air separates the condensate from vapour. Separated water is stored in reservoirs. And them compressed air flows through the air-to-Freon heat exchanger, where it is cooled again (precipitating water again). In the next stage compressed air temperature in air-to-air heat exchanger is increased using warm air from the compressor. Increasing temperature of compressed air to a room temperature prevents recondensation of the dried working medium in the pneumatic system [1].

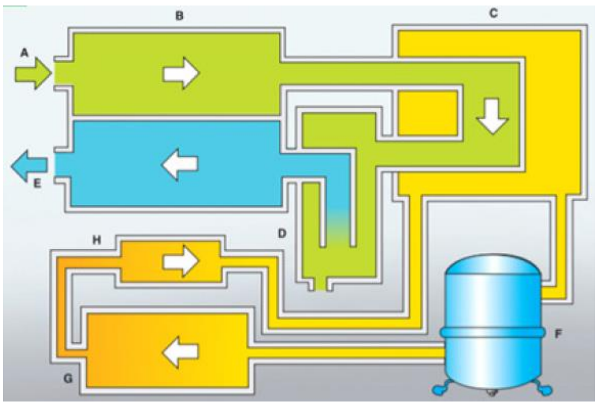

Fig. 1. Operational principle of a refrigerant dryer [1]: A – incoming compressed air, B – air/air heat exchanger, C – air/coolant heat exchanger, D – water separator E – dry compressed air, F – compressor, G – condenser, H – expansion valve

Advantages:

1. the cheapest method of removing water from compressed air,

– simple design,

– low pressure loss.
Disadvantages:
– limited dew point capability (up to 0°C),
– an increase in the ambient or compressed air temperature results in drop in performance of a device.

3.2. Overcompression

Compressed air drying using of overcompression consists in compressing working medium to a pressure higher than the operating pressure required in the pneumatic system. As a result of air compression, water vapour concentration increases. Then, after cooling the compressed air, it is saturated and condensed. In the next stage, the air expands to working pressure required for proper system operation. In this way achieving a lower pressure dew point temperature [22].

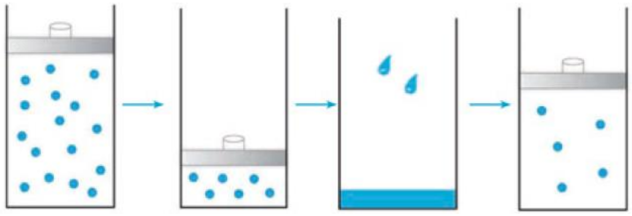

Fig. 2. Operational principle of an overcompression [22]

Advantages:
– the simplest method of drying compressed air.
Disadvantages:
– low efficiency,
– low flow rate,
– expensive method.

3.3. Membrane dryer

In the membrane dryer, the process of drying the compressed air is handled by a membrane cartridge. Cartridge consists of thousands of polymer tubes. Membranes ensure proper water vapour permeability, as a result of which water from the compressed air stays at the inside of the tubes.

In a membrane dryer wet air flows through the middle of the dryer case, in which there is membrane cartridge. Drying is caused by the counter flow of wet compressed air and regenerative air (10–15% of all dried compressed air). The regeneration air is expanded to the atmospheric pressure, which reduces its humidity. During the drying process, water vapour molecules pass through the walls and then are condensed on the outer surface with the fiber. Due to the humidity difference between dry compressed air and the regeneration air, the condensed water diffuses into the regeneration air. The dried air of the required quality feeds the pneumatic system and a small amount of it is directed to the membrane insert as regeneration air [1, 6].

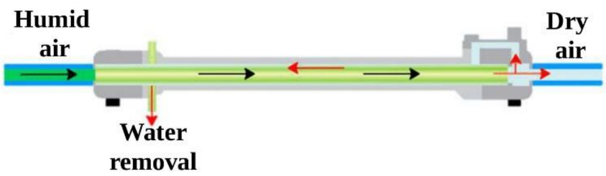

Fig. 3. Operational principle of a membrane dryer [1]

Advantages:
– dew point temperature up to –40°C,
– requires no external power source,
– simple design and high reliability,
– resistance to high and continuous pressure.
Disadvantages:
– low efficiency,
– loss of efficiency due to the consumption of 10–15% of the regeneration air,
– low resistance to sudden changes in pressure,
– highly sensitive to oils and aerosols.

3.4. Absorption dryer

Absorption drying is a chemical method of separating water from compressed air. Water is removed by passing air through a reservoir filled with absorbent and as a result the water vapour is bound with the desiccant. The most commonly used substances responsible for the process of binding water from compressed air are sodium chloride and sulfuric acid.

Compressed air is supplied to the reservoir filled with absorbent, in which the process of chemical binding of water molecules with the absorbent takes place. After flowing through absorbent, the dried air rises to the top of the reservoir and then flows through the outlet to further devices of the pneumatic system. The water-saturated absorbent is regenerated. In the second reservoir, absorbent is heated, so that the water contained in it is evaporated and flows into the atmosphere. The regenerated, unsaturated absorbent is directed back to the drying reservoir [1].
Advantages:
– constant efficiency regardless of the temperature,
– simple operation and design.
Disadvantages:
– low efficiency,
– high value of a pressure dew point of the dried air,
– require frequent replacement of the adsorbent material.

3.5. Adsorption dryer

Adsorption drying involves the removal of water from the compressed air on the surface of the desiccant material – the adsorbent. Adsorption can be divided into physical adsorption and chemical adsorption. Chemical adsorption is related to ionic or covalent bonds, while physical adsorption is related to the forces of intermolecular attraction. Physical adsorption (in which moisture migrating to the driest medium possible) is used in adsorption dryers. The adsorbent is highly porous material with a large specific surface area. A significant specific surface allows water vapour to accumulate on its surface.

The adsorption dryer has two columns filled with the adsorbent, which operate alternately: drying and regenerating. Depending on the work cycle to one of the columns is incoming compressed air. The second column regenerated adsorbent at the same time. In the drying column, the adsorbent collects the humidity contained in the flowing compressed air. Dried and purified compressed air leaves the dryer column. Part of the dried compressed air is directed to the regeneration column. In the regeneration column dried air is decompressed, so that the medium absorbs the water contained in the adsorbent. After flowing through the regeneration column, the wet air is directed to the atmosphere. A cyclic process change is implemented after adsorbent saturation in the drying column and adsorbent regeneration in the regeneration column [1, 6].

Depending on the adsorbent regeneration method, there are four different types of adsorption dryers:
– cold-regenerated adsorption dryers,
– heat regenerated adsorption dryers,
– blower regenerated dryers,
– heat of compression dryers.

Advantages:
– very low pressure dew point,
– slight pressure drops,
– no thermal influence on the environment,
– reliability.

Disadvantages:
– unstable dew point value,
– require regular adsorbent replacement,
– drop in efficiency due to the intake of regenerative air,
– sensitivity of the adsorbent to contamination from oil aerosols.

4. Requirements

Adsorption dryers are mainly used in traction vehicles because of very low pressure dew point achieved and the low pressure drops. Currently, membrane dryers are also increasingly used, mainly due to their small size and the lack of an external energy source. The dryer used in traction vehicles should meet the following requirements [8, 12–14, 20]:
– in accordance with ISO 8573-1 the dew point should be lower than –40°C,
– in accordance with UIC 612-2, the operating pressure should be between 8 and 10 bar,
– correct operation with variable humidity level (0–100%),
– correct operation with temperature ranging from –25°C to +45°C – for the T3 zone,
– high dust and dirt resistant in the working environment,
– significant vibrations resistance,
– proper maintenance susceptibility,
– protection against water freezing in the dryer.

5. Construction of adsorption dryer

The prototype of the adsorption dryer made by the Rail Vehicles Institute "TABOR" consists of three basic elements: inlet control valve covers (item 1), outlet covers (item 2) and columns (item 3). It is a cold-regenerated compressed air adsorption dryer.

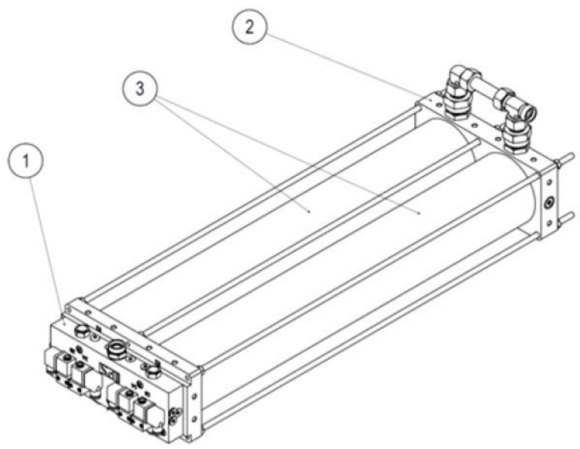

Fig. 4. Construction of the adsorption dryer

The purpose of the inlet control valve cover assembly (item 1) is to direct and control the flow of compressed air through the valves. Depending on the drying cycle of the dryer, the stream is distributed to the appropriate columns for the drying or regeneration task. The purpose of the outlet cover assembly (item 2) is to direct a portion of the dried compressed air (approx. 10–15%) into the regeneration column and exhaust the remaining dried compressed air to other devices of the pneumatic system. Columns (item 3) are filled with adsorbent. Depending on the cycle carried out, in the drying column, the air flowing through the drying material is dried, while in the regeneration column, water condensed on the surface of the adsorbent is removed. The dryer has heating elements which protect against water freezing in plate ducts.

The adsorbent selected for the dryer is a nanoporous molecular sieve which belongs to the group of aluminosilicate materials (zeolites). The high adsorption capacity of the desiccant material allows it to achieve a pressure dew point down to –80°C. The advantage of zeolites is a wide range of application temperatures, high abrasion resistance and low air flow resistance.

6. Working principle

The pre-dried air reaches the valve assembly of the inlet control plates, which, depending on the current cycle of operation, directs the medium to the appropriate column. The desiccant collects the water contained in the compressed air flowing through the column. Then the dried air leaves the drying column. The non-return valves built in the set of outlet covers ensure the flow of dry air to the outlet and prevent the flow of regeneration air to further elements of the pneumatic system. The dryer prototype designed by the Railway Vehicle Institute "TABOR" uses pre-dried compressed air (approx. 10–15%) in the regeneration process. The regeneration air expands in the regeneration column, increasing its ability to accumulate water vapour. Then, as it rapidly flows through the adsorption bed, it binds water and push it into the atmosphere. At the end of work cycle, each column switches tasks.

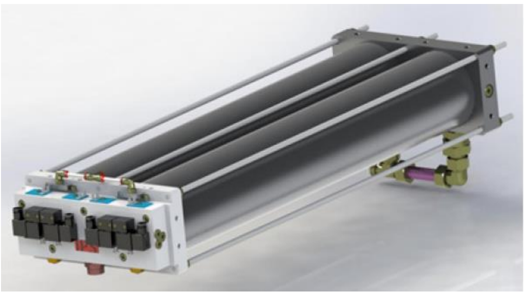

Fig. 5. Adsorption dryer IPS "TABOR"

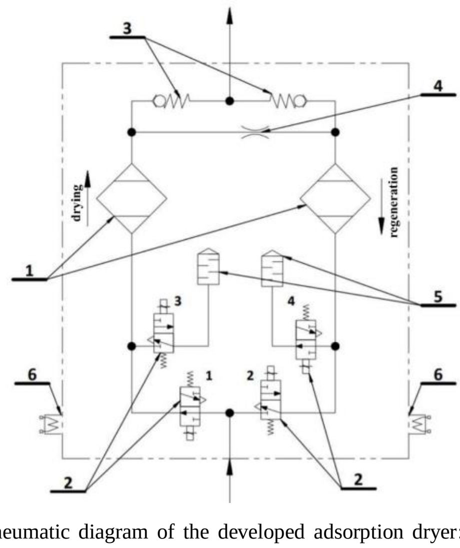

Fig. 6. Pneumatic diagram of the developed adsorption dryer: 1 – dryer column, 2 – electro-pneumatic valve, 3 – non-return valve, 4 – nozzle, 5 – noise damper, 6 – heating element

7. Methodology of calculations

To determine the required adsorption capacity of the dryer, it is necessary to calculate the mass flow rate of water vapor remaining in the compressed air after pre-drying in the cooler. For this purpose, a calculation methodology is proposed to check ensure this requirement.

In subsection 7.2 "Assessment of the required adsorption capacity" calculations were carried out according to methodology.

Properties of atmospheric air

Before proceeding with calculations, it is necessary to determine the conditions in which the adsorption capacity of the dryer will be tested. For this purpose, it is necessary to determine the values of the following parameters:

- atmospheric air pressure p_1 expressed in hPa,
- atmospheric air temperature T_1 expressed in °C,
- relative atmospheric air humidity φ_1 expressed in %,
- compressor capacity $\dot{V}_s$ expressed in $\frac{m^3}{h}$.

Based on the Enthalpy–entropy chart (Mollier diagram) and the values of the parameters of atmospheric air pressure p_1, atmospheric air temperature T_1, relative atmospheric air humidity φ_1 should be determined:

- humidity content in atmospheric air x_1 expressed in $\frac{g}{kg}$,
- atmospheric air density ρ_1 expressed in $\frac{kg}{m^3}$.

The next stage is to calculate the mass flow rate of atmospheric air intake by a compressor $\dot{m}_p$ expressed in $\frac{kg}{h}$, which is calculated as follows:

$$\dot{m}_p = \dot{V}_s \cdot \rho_1 \tag{1}$$

where $\dot{V}_s$ is compressor capacity and ρ_1 is atmospheric air density.

The next stage is to determine the amount of water vapor in the intake atmospheric air. For this purpose, it is necessary to calculate the mass flow rate of water vapor in the intake atmospheric air $\dot{m}_{H_2O(p)}$ expressed in $\frac{kg}{h}$:

$$\dot{m}_{H_2O(p)} = x_1 \cdot \dot{m}_p \tag{2}$$

where x_1 is humidity content in atmospheric air and $\dot{m}_p$ is mass flow rate of atmospheric air intake by a compressor.

Properties of the compressed air after the cooler

Next, it is necessary to determine the values of the properties of the humid compressed air after the cooler (directly behind the dryer). For this purpose, it is necessary to determine:

– compressed air pressure p_2 expressed in hPa,
– compressed air temperature T_2 expressed in °C,
– relative compressed air humidity φ_2 expressed in %,

Based on the Enthalpy–entropy chart (Mollier diagram) and the values of the parameters of compressed air pressure p_2, compressed air temperature T_2, relative compressed air humidity φ_2 should be determined:

– humidity content in compressed air x_2 expressed in $\frac{g}{kg}$.

Water vapor in compressed humid air

Compression of air by the compressor raises the temperature of the compressed air and lowers the relative humidity of the air. In the cooler, the temperature of the compressed air is lowered and condensate is condensed.

In the first step, determine the amount of condensed water behind the cooler. Determine the difference Δx of the humidity content in atmospheric air x_1 and humidity content in compressed air x_2 expressed in $\frac{g}{kg}$:

$$\Delta x = x_1 - x_2 \tag{3}$$

Then calculate the mass flow rate of condensed water behind the cooler $m_{H_2O(1)}$ expressed in $\frac{kg}{h}$:

$$\dot{m}_{H_2O(1)} = \Delta x \cdot \dot{m}_p \tag{4}$$

where Δx is difference of the humidity content in atmospheric air x_1 and humidity content in compressed air x_2 and $\dot{m}_p$ is mass flow rate of atmospheric air intake by a compressor.

Water vapor remaining in compressed humid air $\dot{m}_{H_2O(p1)}$ is calculated as the difference mass flow rate of water vapor in the intake atmospheric air $\dot{m}_{H_2O(p)}$ and mass flow rate of condensed water behind the cooler $m_{H_2O(1)}$:

$$\dot{m}_{H_2O(p1)} = \dot{m}_{H_2O(p)} - \dot{m}_{H_2O(1)} \tag{5}$$

Maximum adsorption capacity of the dryer

The adsorption capacity of an adsorbent depends on the properties of the adsorbent and the capacity of the vessel in which it is placed. To calculate the adsorption capacity, the following data are required:

– capacity of the vessel filled with the adsorbent V_0 expressed in m^3,
– adsorbent density ρ_a expressed in $\frac{kg}{m^3}$,
– adsorbent capacity $V_{H_2O(k)}$ expressed in $\frac{kg\ H_2O}{100\ kg\ adsorbent}$.

The mass of the adsorbent in vessel is calculated as follows:

$$m_{H_2O(k)} = V_0 \cdot \rho_a \cdot V_{H_2O(k)} \tag{6}$$

A single drying cycle takes about 4 min. The maximum adsorption capacity of the dryer $\dot{m}_{H_2O(k)}$ can be calculated. It is determined by mass flow rate and expressed in $\frac{kg}{h}$:

$$\dot{m}_{H_2O(k)} = \frac{m_{H_2O(k)}}{4\ min} \tag{7}$$

where $m_{H_2O(k)}$ is mass of the adsorbent in vessel.

Required adsorption capacity of the dryer

In the order to check whether the purity of the compressed air is sufficient, the condition according to which the value of the maximum adsorption capacity of the dryer $\dot{m}_{H_2O(k)}$ is greater than the value of the condensed mass flow water vapor remaining in compressed humid air $m_{H_2O(p1)}$ must be met:

$$\dot{m}_{H_2O(k)} > \dot{m}_{H_2O(p1)} \tag{8}$$

Fulfillment of the above condition indicates correct operation of the dryer.

8. Research and simulations

Tests and calculations were carried out to verify the correctness of the structure of prototype.

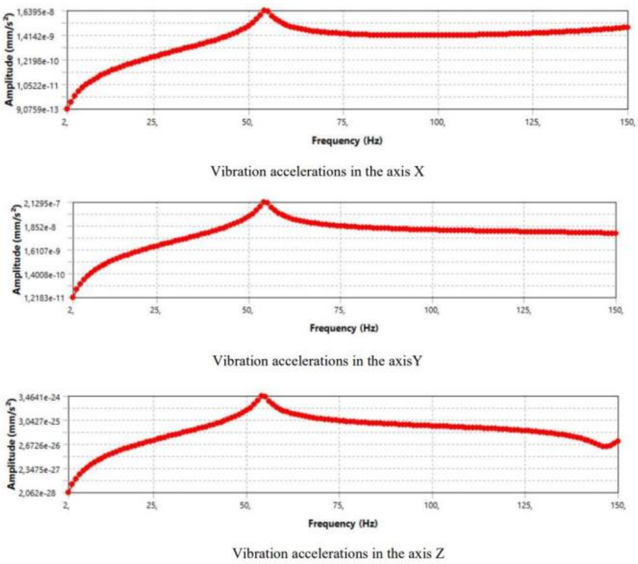

Fig. 7. Vibration accelerations in the axis X, Y, Z

A numerical strength test was carried out – modal analysis of free vibrations of the external rod. Finite element method was used to perform a modal analysis. The test concerned the flaccid external rod connecting the upper plate with the lower plate. This the most exposed element to the negative effects of vibrations. Failure to meet the requirements for resistance to vibrations may cause unwanted noise and resonance, which in turn may lead to damage to the dryer components.

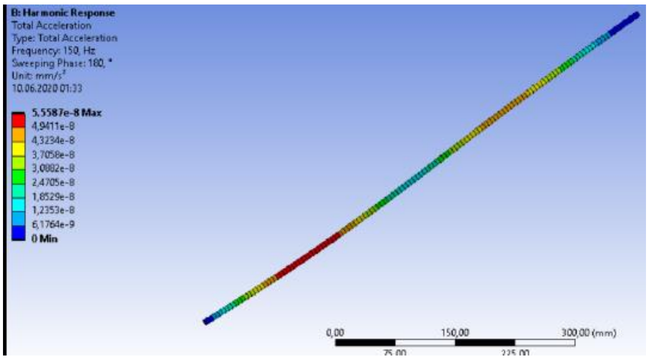

Fig. 8. Modal analysis for 150 Hz

The obtained results meet the requirements of the PN-EN 61373 standard [14]. Modal analysis results indicate a high durability of the device [17].

As part of the prototype, tests were carried out on the adsorbent. The basic quantities necessary for the correct operation of the device were checked:

- selection of dryer operating parameters,
- assessment of adsorption capacity,
- pressure dew point test.

8.1. Selecting key algorithm parameters

The parameters of the dryer operation algorithm were selected based on the determination of the times of individual dryer cycles. These parameters ensure proper drying of the compressed air in the drying column and regeneration of the adsorbent in the regeneration column. The test allowed to determine the operation time of a single drying cycle, the adsorbent drying time and the adsorbent regeneration time.

8.2. Assessment of the required adsorption capacity

In order to determine whether the dryer properly removes water from compressed air, it should be checked whether the adsorption capacity of the dryer is higher than the amount of water vapour remaining in the pre-dried air. Using the Mollier graphs (H-X), the properties of air saturated with water vapour intake by a compressor were determined:

- pressure: $p_1 = 1013.25$ kPa,
- temperature: $T_1 = 30°C$,
- relative air humidity: $\varphi_1 = 100\%$,
- air density: $\rho_1 = 1.15 \frac{kg}{m^3}$,
- humidity content in air: $x_1 = 27.1 \frac{g}{kg}$.

Based on the above data and the assumed compressor capacity of $\dot{V}_s = 62 \frac{m^3}{h}$, the air mass flow was calculated:

$$\dot{m}_p = \dot{V}_s \cdot \rho_1 = 62 \frac{m^3}{h} \cdot 1.15 \frac{kg}{m^3} = 71.3 \frac{kg}{h} \tag{9}$$

The water vapour mass flow contained in the intake air was calculated:

$$\dot{m}_{H_2O(p)} = x_1 \cdot \dot{m}_p = 27.1 \frac{g}{kg} \cdot 71.3 \frac{kg}{h} = 1.932 \frac{kg}{h} \tag{10}$$

In the next stage, the content of water vapour in the compressed air was determined. For this purpose, the properties of compressed air saturated with water vapour were determined:

- pressure: $p_2 = 9$ bar $= 9000$ kPa,
- temperature: $T_2 = 50°$ C,
- relative air humidity: $\varphi_2 = 100\%$,
- air density: $\rho_2 = 9.65 \frac{kg}{m^3}$,
- humidity content in air: $x_2 = 8.6 \frac{g}{kg}$.

Then, the difference in the humidity content of air intake from the atmosphere and compressed air was determined:

$$\Delta x = x_1 - x_2 = 27.1 \frac{g}{kg} - 8.6 \frac{g}{kg} = 18.5 \frac{g}{kg} \tag{11}$$

Based on the different values for the humidity content of air intake from the atmosphere, compressed air and the calculated mass flow of the intake air, the amount of condensed water behind the cooler was determined:

$$\dot{m}_{H_2O(1)} = \Delta x \cdot \dot{m}_p = 18.5 \frac{g}{kg} \cdot 71.3 \frac{kg}{h} = 1.326 \frac{kg}{h} \tag{12}$$

The residual water vapour content in the compressed humid air was calculated:

$$\dot{M}_{H_2O(p1)} = \dot{m}_{H_2O(p)} - \dot{m}_{H_2O(1)} = 1.932 \frac{kg}{h} - 1.326 \frac{kg}{h} = 0.606 \frac{kg}{h} \tag{13}$$

The adsorption capacity of the dryer was then determined. It should be higher than the calculated amount of water vapour that is remained in the compressed humid air. The calculations were performed for the following data:

- inner diameter of the dryer column: $d_k = 116$ mm,
- height of the dryer column: $h_k = 519$ mm,
- adsorbent density: $\rho_a = 800 \frac{kg}{m^3}$,
- adsorbent capacity: $V_{H_2O(k)} = 19.5 \frac{kg\ H_2O}{100\ kg\ adsorbent}$.

Capacity of single dryer column:

$$V_0 = \pi \cdot \left(\frac{d_k}{2}\right)^2 \cdot h_k = \pi \cdot \left(\frac{116\ mm}{2}\right)^2 \cdot 519\ mm = 0.00548\ m^3 \tag{14}$$

Adsorption capacity of the adsorbent contained in the column

$$M_{H_2O(k)} = V_0 \cdot \rho_a \cdot V_{H_2O(k)} = 0.00548\ m^3 \cdot 800\,\frac{kg}{m^3} \cdot \frac{19.5\ kg}{100\ kg} = 0.854\ kg \quad (15)$$

A single drying cycle takes about 4 min, so the vapour adsorption capacity of the new dryer is:

$$\dot{M}_{H_2O(k)} = \frac{m_{H_2O(k)}}{4\ min} = \frac{0{,}854\ kg}{4\ min} = 12.78\ h > \dot{m}_{H_2O(p1)} = 0.606\,\frac{kg}{h} \quad (16)$$

The water vapour adsorption capacity of the adsorbent is sufficient for the proper operation of the device. During compression in the compressor small amounts of oil enters the dryer column. This clogs the pores of the molecular sieve and reduces the adsorption capacity of the adsorbent. A much higher value of the adsorption capacity ensures reliable operation of the device and the maintenance of correct operating parameters over a long period of time (1–2 years of operation).

8.3. Pressure dew point test

The pressure dew point test consists in measuring the pressure dew point temperature of the dried air coming out from dryer. The measurement is made with a specialized device.

In railway practice, the pressure dew point temperature should be at least 30°C lower than the ambient temperature. The test lasted 5 minutes and was carried out for the new dryer and regularly during its operation. Measurements for the described dryer were carried out using a portable CS INSTRUMENTS DP 510 meter. The tests showed that the new dryer achieves a pressure dew point of –70°C, while during operation the observed dew point is from –60°C to –40°C. These values meet the requirements of ISO 8573-1. The achieved dew point value guarantees high-purity compressed air and ensures proper operation of the dryer, even when part of the adsorbent bed is worn.

9. Summary

In traction vehicles, compressed air is essential medium for proper operation. Ensuring proper purity, and in particular removing contaminants such as humidity and water, is essential for correct vehicle operation.

In the dryer market there are many designs with different drying methods. Adsorption dryers and membrane dryers are used in traction vehicles.

The adsorption dryer prototype designed by the Railway Vehicles Institute "TABOR" meets the requirements of railroad standards, UIC cards, as well as requirements for installation and serviceability.

The prototype was subjected to bench tests and calculations. Tests showed that the device was properly designed and meets the requirements. Modal analysis of the normal mode of the outer bar proved that the values of vibration acceleration are lower than the values allowed by the standard.

Selection of the dryer operating parameters made it possible to determine the working cycle times of the dryer. The determined working cycle times allow for proper drying of compressed air and regeneration of adsorbent. The evaluation of the required adsorption capacity proved that the amount of adsorbent in the column is sufficient for proper operation of the device for at least one year. The conclusion of the pressure dew point test is that the pressure dew point value increases during operation.

The adsorption capacity of the desiccant decreases during operation because the pores of the adsorbent are clogged with oil and dust from the abraded adsorbent.

In the future, the dryer designed by the Institute of Railway Vehicles "TABOR" can be modified or new elements can be added. Further work should be oriented towards:

- adding a device for measuring the humidity of dried compressed air,
- looking for a new adsorbent.

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