Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 187 (2017) 672 – 679

Procedia Engineering

www.elsevier.com/locate/procedia

10th International Scientific Conference Transbaltica 2017:
Transportation Science and Technology

Railway Rolling Stock Compressors Capacity and Main Reservoirs Volume Calculation Methods

Viačeslav Petrenko*

Vilnius Gediminas Technical University, Lithuania

Abstract

Existing railway rolling stock compressors capacity and main reservoirs volume calculations methods were created in 1960–1970 and do not take into account the achievements of modern railway pneumatic technologies and the results of calculations of compressor capacity and main reservoir volume is inaccurate. The new calculation technology begins from total compressed air consumption for braking processes, air leaks and auxiliary needs definition. Knowing all compressed air consumption possibilities, compressor capacity is calculated. Then it is possible to calculate compressed air production system main reservoirs volume. Calculated compressor capacity and main reservoirs volume should be equal to air consumption for train brakes release and charge after service or emergency braking, for this purpose balance equation between produced and charged air is used. If railway rolling stock is operated in high humidity conditions without composed air dehumidification system main reservoirs useful volume decreasing. For that specific climate conditions compressor capacity should be corrected.

© 2017 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the organizing committee of the 10th International Scientific Conference Transbaltica 2017

Keywords: railway vehicle, compressors capacity, main reservoirs volume, new calculation methods

1. Introduction

Railway rolling stock compressed air production system provides compressed air to the braking system, sand system, wheels flange lubrication system, sound signals, electric pneumatic devices (contactors, pantographs,

* Corresponding author.
E-mail address: viaceslav.petrenko@vgtu.lt

1877-7058 © 2017 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the organizing committee of the 10th International Scientific Conference Transbaltica 2017
doi:10.1016/j.proeng.2017.04.430

reversers), pneumatic suspension system, fire extinguishing system and other systems and devices. So the requirements for compressed air quality are very high, according ISO 8573-1 “Compressed air: Contaminants and purity classes”, air quality could be 2-2-2 class or according GOST 17433-80 “Industries purity. Compressed air grades of contamination” air quality must be at least 6 class (Table 1).

Compressed air production system (Fig. 1) consists of air compressor, main reservoirs, safety and backward valves, pressure regulators, air filtration, cooling and dehumidification devices.

Table 1. Railway rolling stock compressed air quality requirements [1, 2].

Compressed air parameters	Standards requirements	
	ISO 8573-1	GOST 17433-80
Quality class	2-2-2	6
Dirt participle size, µm	1	25
Dirt participle maximal concentration, mg/m³	1	2
Water pressure dew point, °C	−40	–
Water maximal concentration, mg/m³	–	800
Oil maximal concentration, mg/m³	0.1	16

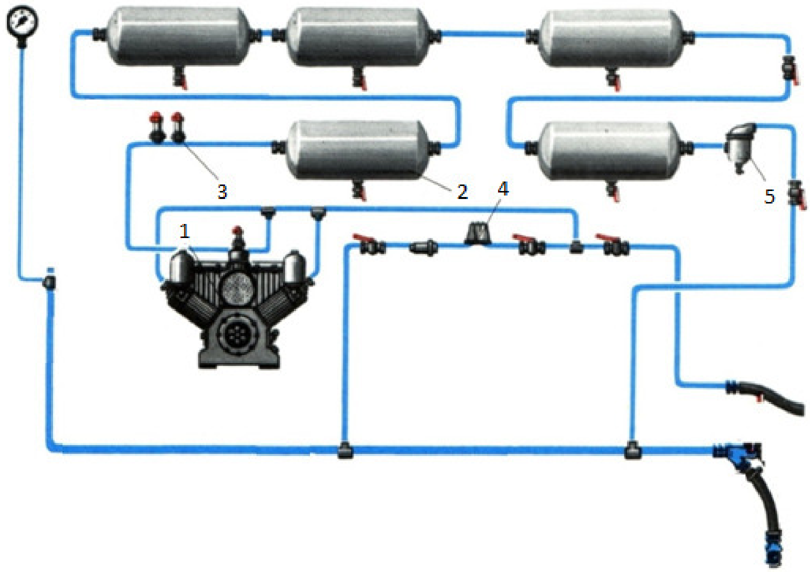

Fig. 1. Railway rolling stock compressed air production system:
1 – air compressor; 2 − main reservoirs; 3 – safety valves; 4 − pressure regulator; 5 − compressed air filtration devices (oil separators, dehumidification system).

The main reservoir accumulates pressed air and during cooling condensate (mix of water and oil) is separated. Main reservoirs must be connected in series and reservoir’s volume must comply with safety standards (Table 2). Modern locomotives are equipped with at least two main reservoirs.

Pressure regulators controls compressors, switching them on or off when pressure in the main reservoirs is changing within minimal and maximal limits (0.10–0.15 MPa). The safety valves (Fig. 1) stops uncontrolled pressure increase in case of the pressure regulators malfunctions,

Railway rolling stock compressors supply compressed air for all pneumatic systems and compressors capacity and number must comply strict safety standards. For example the Railway rolling stock compressed air production system requirements of the Organization for Co-Operation between Railways (Table 2).

Table 2. Railway rolling stock compressed air production system requirements [2].

Rolling stock types	Compressor		Main reservoirs	
	Capacity, m^3/min	Number	Pressure, MPa	Volume, l
Freight and universal diesel locomotives	4.0–6.0	1	1.0	1000–1500
Shunting locomotives	4.0–6.0	1	1.0	1000–1200
Freight and universal electric locomotives	4.5	2	1.0	1200–1500
Passenger electric locomotives	2.0–4.0	2	1.0	1000–1200
EMU* (for 2 wagons)	1.0	1	0.8	340–680
DMU** (with compressor's mechanic transmission)	2.0	1	0.8	340–800
DMU (with compressor's electric transmission)	1.0	1	0.8	340–800

* EMU – electric motive units; **DMU – diesel motive units.

Compressors and main reservoirs should fully ensure the need for compressed air for the all train pneumatic systems at the maximum air flow rate. Compressors must have the necessary capacity to create the required pressure in the main reservoirs within a set time. Designing rolling stock or creating technical requirements compressors capacity and main reservoirs volume should be calculated.

2. Railway rolling stock compressors capacity and main reservoirs volume calculation

Already existing railway rolling stock compressors capacity and main reservoirs volume calculations methods [3, 4, 6, 7] do not take into account the achievements of modern railway pneumatic technologies [8, 9]:

- modern compressors don't need stopping for cooling;
- compressed air production system practically always have dehumidification system;
- in some cases locomotives is equipped with double compressor modules;
- increased the number of users of the compressed air;
- improved hermeticity of train's pneumatic braking net.

The new railway rolling stock compressors main reservoirs and compressors capacity calculation technology consists of the following stages:

- total compressed air consumption definition;
- compressor capacity calculation;
- main reservoirs volume estimation;
- calculated compressor capacity and main reservoirs volume checking for train brakes release and charge after braking;
- compressor capacity correction for high atmosphere air humidity regions.

Total compressed air one hour consumption for all main needs in the train Q_t, m^3/h [4]:

$$Q_t = Q_b + Q_l + Q_c + Q_a , \tag{1}$$

where: Q_b – air consumption for braking processes, m^3/h; Q_l – air leaks from train braking system, m^3/h; Q_c – air leaks from compressed air production system, m^3/h; Q_a – air consumption for auxiliary needs, m^3/h.

Air consumption for braking processes Q_b :

$$Q_b = \Delta p_{bp} V_{bp} n_b , \tag{2}$$

where: Δp_{bp} − brake pipe pressure discharge "depth" during service braking, MPa; V_{bp} – braking pipe capacity, m^3; n_b – the average number of service braking for one hour.

Brake pipe pressure discharge during service braking could be settled according national brakes operation rules. For example, according JSC Lithuanian Railways rules [5] the biggest service braking brake pipe maximal discharge is 0.15–0.17 MPa.

Train braking pipe capacity must be calculated for trains braking system configuration (Fig. 2):

$$V_{bp} = V_p + V_{ar} + V_{dc} + V_{ap}\,, \tag{3}$$

where: V_p – brake pipe volume, m^3; V_{ar} – train's auxiliary reservoirs volume, m^3; V_{dc} – brake distributers chambers volume; V_{ap} – pneumatic scheme connecting pipes volume, m^3.

Freight or passenger wagons and locomotives brake pipe, auxiliary reservoirs and distributer chambers volumes is different (Table 3).

Table 3. Rolling stock brake systems parts volume [6].

Type of rolling stock	Volume, m^3			
	V_p	V_{ar}	V_{dc}	V_{bp}*
Four axels cistern wagon	11.1	78	12	101.1
Eight axels cistern wagon	19.4	135	12	166.4
Passenger wagon	22.5	55	3	80.5
2M62M freight locomotive	37.4	110	24	171.4

* – without V_{ap}.

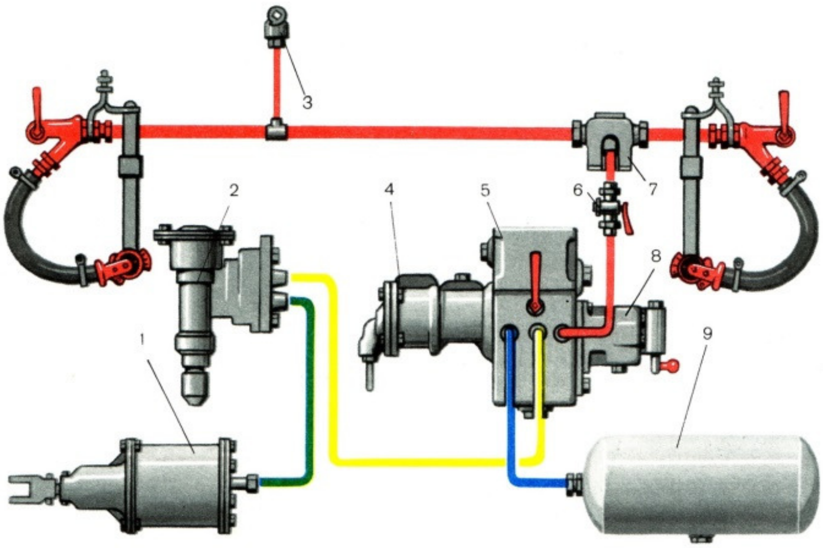

Fig. 2. Freight wagon pneumatic brake system [7]:
1 − brake cylinder; 2 – automatic regulator; 3 – emergency bracing valve; 4, 5, 8 – brake distributor chambers; 6 – cock, 7 – dirt collector, 9 – auxiliary reservoir.

Any pneumatic braking system has air leaks:

$$Q_l = \Delta p_l V_{bp}\,, \tag{4}$$

where: Δp_l – maximal brake pipe pressure reduction rate because of air leaks, MPa/min.

Pressure reduction rate because of air leaks can be equated to brake distributers “no response” pressure (the biggest air lake rate) reduction rate 0.02–0.03 MPa/min.

Air leaks from compressed air production system:

$$Q_l = \Delta p_{lc} V_c , \tag{5}$$

where: Δp_{lc} – maximal pressed air production system pressure reduction rate because of air leaks, MPa/min; V_c – pressed air production system volume, m^3.

Maximal pressed air production system pressure reduction rate should be described in national railway brakes regulations and according JSC Lithuanian Railways rules [5] it must be no more than 0.02 MPa per 2.5 min or 0.05 MPa per 6.5 min. Compressed air production system volume:

$$V_c = V_{dh} + V_{mr} + V_{cp} + V_{cap} , \tag{6}$$

where: V_{dh} – air dehumidification tanks volume, m^3; V_{mr} – main reservoirs volume, m^3; V_{cp} – compressor main pipe volume; V_{cap} – compressor pneumatic scheme connecting pipes volume, m^3.

Air consumption for rolling stock auxiliary needs includes all pneumatic systems air consumptions:

$$Q_a = Q_{ss} + Q_s + Q_{wl} + Q_{ep} + Q_{ps} + Q_o , \tag{7}$$

where: Q_{ss} – sound signals, m^3/h; Q_s – sand system, m^3/h; Q_{wl} – wheels flange lubrication system, m^3/h; Q_{ep} – electric pneumatic devises, m^3/h; Q_{ps} – pneumatic suspension system, m^3/h; Q_o – other systems, m^3/h.

Compressed air is used in various modern rolling stock devices and systems:

- pantographs suspension;
- doors mechanisms;
- vacuum toilets;
- fire extinguishing systems;
- freight wagons body lifting devices;
- automatic coupler gear.

The air auxiliary needs should be calculated considering concrete rolling stock futures.

Knowing all compressed air consumption possibilities, compressor capacity could be calculated Q_{com}, m^3/min:

$$Q_{com} = \mu \varphi Q_t / 60 , \tag{8}$$

where: Q_t – total air consumption, m^3/h; μ – coefficient taking into account compressor cooling time φ – compressed air consumption ratio for dehumidification.

Coefficient taking into account compressor cooling time depends on what compressor type will be used. Modern piston oil-free or screw compressor don’t need time for cooling, so $\mu = 1$, but typical piston compressor needs time for cooling, so in that case $\mu = 1.3–1.5$ [4].

Air consumption for air dehumidification depends on which dehumidification system is used: one column or two columns. In modern railway rolling stock compressed air production system air consumption ratio for dehumidification varies within 5–20% ($\varphi = 1.05–1.20$).

Then compressor or compressors with capacity bigger, than calculated by (8) equation are select.

Knowing main compressor capacity, it is possible to calculate main reservoirs volume:

$$V_{mr} = \frac{V_{bp}\left(\Delta p_{bp} + at\right) + Q_{com} t_r p_a}{p_1 - p_2 - at} , \tag{9}$$

where: V_{bp} – train braking pipe capacity, m^3; Δp_{bp} – brake pipe pressure reduction during braking, MPa; a – brake pipe leaks, MPa/min; Q_{com} – compressor capacity, m^3/min; t_r – train brakes release time, min; p_1 – main reservoirs pressure before brake release, MPa; p_2 – main reservoirs minimal pressure during brake release, MPa; p_a – atmosphere barometric pressure, MPa.

Calculated air compressor capacity must ensure train brake release and all wagons auxiliary reservoirs filling within a certain time. That time deepens on train's length (or axels number), type (passenger of freight), brake regime applicated before release, train operation season. Filling time is strictly controlled and described in railway brakes operation rules (Tables 4–6).

Table 4. Passenger trains brake release time [5].

Braking regime	Brakes release time, at least, min	
	Till 20 wagons	From 20 wagons
After service and full breakings	1.0	2.0
After emergency braking	4.0	6.0

Table 5. Freight trains brake release time [5].

Braking regime	Brakes release time, at least, min	
	Plains regime	Hills regime
After one breaking step	1.5	2.0
After service breaking	2.0	3.5
After emergency braking, train till 100 axels	4.0	4.0
After emergency braking, train more than 100 axels	6.0	6.0

Table 6. Long and heavy freight trains brake release time [5].

Braking regime	Minimal brakes release time, min	
	Summer time	Winter time
After service breaking	3	4.5
After forced service breaking	4	6.0
After emergency braking	8	12.0

In this case calculated compressor capacity and main reservoirs volume should be equal to air consumption for train brakes release and charge after service or emergency braking during certain time (Tables 4–6), or:

$$Q_{com} + Q_{mr} \geq Q_{bp} + Q_{bd} + Q_{ar} + Q_l \, , \tag{10}$$

where: Q_{com} – volume of air produced by the compressor, m^3; Q_{mr} – main reservoirs minimal practical volume, m^3; Q_{bp} – brake pipe air consumption volume during release and charge, m^3; Q_{bd} – brake valves air consumption volume during release and charge, m^3; Q_{ar} – auxiliary reservoirs air consumption volume during release and charge, m^3; Q_l – air leaks volume during release and charge, m^3.

Or in the expanded form:

$$Q_{com}t_r + \frac{\Delta P_{mr}}{P_a}V_{mr} \geq \frac{\Delta P_{bp}}{P_a}V_{bp} + \frac{\Delta P_{bv}}{P_a}\sum V_{bv} + \frac{\Delta P_{ar}}{P_a}\sum V_{ar} + \frac{\Delta P_l}{P_a}\sum V_{bp}t_r \, , \tag{11}$$

where: t_r – brakes release and auxiliary reservoirs charging time, min; ΔP_{mr} – main reservoirs pressure decrease during service braking, MPa; ΔP_{bp} – brake pipe pressure decrease, MPa; ΔP_{bv} – brake valves chambers pressure decrease, MPa; ΔV_{bv} – brake valves chambers volume, m^3; ΔP_{ar} – auxiliary reservoirs pressure decrease, MPa; ΔV_{ar} – auxiliary reservoirs volume, m^3; ΔP_l – air leaks pressure decrease, MPa.

Solving that equation for Q_{com}, compressor capacity is calculated and compared with the capacity (calculated by Equation 8) for the already selected compressor. Q_{com} should be bigger than selected compressor capacity, otherwise it is necessary to choose another compressor with bigger capacity.

Atmosphere air always contains some quantity of water vapour. It is obvious, that water vapour are sucked into the main reservoirs and condensed. Some railway rolling stock units have compressed dehumidification system and almost all water vapour is separated in the dehumidification system tanks. But there is still in usage rolling stock with only main reservoirs system. In the main reservoirs also take place natural water vapour condensation and about 70–75% of atmosphere water is separated in the main reservoirs [10]. It means, that condensed water vapours decrease main reservoirs useful volume and in some cases main reservoirs useful volume decreasing reaches 15% [11].

If railway rolling stock is operated in high humidity conditions without composed air dehumidification system main reservoirs useful volume decreasing should be considered:

$$m_w = Q_{com} t \varphi P_v \,, \qquad (12)$$

where: Q_{com} – compressor capacity, m^3; t − compressor working time, min; φ − specific atmosphere air humidity; P_v – relative humidity, g/m^3.

According statistical data [12] in Lithuania during October–November period relative average atmosphere air humidity is about 88%.

The water vapour capacity depends on the temperature of the atmosphere air (Table 7).

Table 7. Relative humidity of a kilogram of air at average sea level pressure.

Air temperature, ºC	−40	−30	−20	−10	0	+10	+20	+30	+40
Relative humidity, g/m^3	0.1	0.3	0.75	1.8	3.8	7.8	15.0	27.7	49.8

One typical locomotive compressor with 5.3 m^3/min capacity in hot summer conditions (+30 ^{0}C temperature, 80% humidity) compress air for one hour with water vapour:

$$m_w = 5.3 \cdot 60 \cdot 0.8 \cdot 27.7 = 7047 \text{ g} .$$

One hour of compressor work creates sufficient amount of condescend water in main reservoirs. For that specific climate conditions compressor capacity should be corrected:

$$Q'_{com} = \left(1 - t_{com} \varphi P_v\right) Q_{com} k_{com} \,, \qquad (13)$$

where: t_{com} − compressor working time between main reservoirs maintenance operations, min; k_{com} – compressors number.

The new railway rolling stock compressor capacity and main reservoirs volume calculation methods allows to design rolling stock or create technical requirements taking into account the achievements of modern pneumatic technologies.

3. Conclusions

1. Existing railway rolling stock compressors capacity and main reservoirs volume calculations methods do not take into account the achievements of modern railway pneumatic technologies and the results of calculations of compressor capacity and main reservoir volume is inaccurate.
2. The article suggests corrected compressed air consumption for braking processes, air leaks and auxiliary needs calculation methods and it allows to determine locomotive compressor capacity and main reservoir volume.

3. The new railway rolling stock compressor capacity and main reservoirs volume calculation methods allows to design rolling stock or create technical requirements taking into account the achievements of modern pneumatic technologies.

References

[1] ISO 8573-1: 2010 (E) Compressed air – Part 1: Contaminants and purity classes.
[2] ГОСТ 17433-80 Промышленная чистота. Сжатый воздух. Классы загрязненности [Industries purity. Compressed air grades of contamination].
[3] В. Г. Иноземцев, Тормоза железнодорожного подвижного состава. Москва, 1979 [V. G. Inozemcev, Railway rolling stock brakes].
[4] В. Р. Асадченко, Автоматические тормоза подвижного состава железнодорожного транспорта. Москва, 2002 [V. R. Asadcenko, Railway rolling stock automatic brakes].
[5] Geležinkelio riedmenų stabdžių naudojimo taisyklės, Vilnius: AB Lietuvos geležinkeliai, 2015 [Railway rolling stock brakes operation rules].
[6] В. И. Крылов, Тормозное оборудование железнодорожного подвижного состава: Справочник. Москва, Транспорт, 1989 [V. I. Krylov, Railway rolling stock braking equipment].
[7] Крылов В. И. Тормоза подвижного состава: Справочник. Москва, Транспорт, 1979 [V. I. Krylov, Railway rolling stock brakes].
[8] J. E. Beaver, K. Hering, The next generation of air supply units, in: Proceedings of the 2004 ASME/IEEE joint rail conference, Baltimore. 2004, pp. 163–166,
[9] M. Hartl, F. Meyer, S. Schneider, Oil-free low-vibration piston compressor in railway applications, International Conference on Compressors and their Systems, in: Imeche conference transactions, London. 2001, pp. 177–188.
[10] В. Г. Иноземцев, Тормоза железнодорожного подвижного состава: Вопросы и ответы. Москва, 1987 [V. G. Inozemcev, Railway rolling stock brakes: Questions and answers].
[11] Ю. И. Матяш, Е. М. Кириленко, Усовершенствованная система очистки сжатого воздуха. Вагоны и вагонное хозяйство. Москва, 2016 [U. I. Matiash, E. M. Kirilenko, Improved compressed air cleaning system], pp. 36–38.
[12] Norwegian Meteorological Institute and Lithuanian Road Administration weather conditions stops data [Online]. Available from Internet: http://www.yr.no/place/Lithuania/Kaunas/Kaunas~598318/