UDC 629.424.2
DOI https://doi.org/10.32782/2663-5941/2025.3.1/52

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CLASSIFICATION OF POSITIVE-ACTION COMPRESSORS FOR RAILWAY ROLLING STOCK

The article considers the classification of positive displacement compressors, which are widely used in pneumatic systems of traction and railcar rolling stock. An analysis of modern technical solutions in the field of compressor construction, as well as current classifications used in scientific and industrial literature, is carried out. The main attention is paid to the systematization of compressors depending on the design features, operating mode, number of compression stages, type of drive, availability of lubricant, as well as the scope of application (*locomotives, electric trains, diesel trains, subway cars, etc.*).

The need to build a generalized classification scheme is formulated, which considers both traditional and modern technical solutions used in modern railway transport. A multi-level classification structure of positive displacement compressors has been developed, covering their main types – piston, diaphragm, screw and others, with a detailed consideration of the design and operational characteristics of each of them. The advantages and disadvantages of different types of compressors were determined in terms of their operating conditions, maintainability, energy efficiency and maintenance costs.

The study considered data from technical documentation and catalogs of leading manufacturers of compressor equipment, such as Poltava Turbomechanical Plant, Transpneumatics, Atlas Copco, CKD, etc. The prospects for the application of modern energy-saving technologies in compressor installations, in particular, inverter control of productivity and oil-free systems, were analyzed. Conclusions were drawn on the feasibility of introducing a single classification system into the regulatory and technical framework to facilitate the selection of compressor equipment at the stages of design and operation of rolling stock.

It is noted that the results of the study can be used in the practice of engineering design, maintenance, modernization of pneumatic systems of rolling stock and serve as the basis for further scientific research aimed at optimizing the design and increasing the efficiency of compressor units for railway transport.

Key words: *transportation, mechanics, railway transport, transport technologies, rolling stock, repair, operation, reliability, compressors.*

Formulation of the problem. The growth of railway traffic in Ukraine requires increasing the reliability and efficiency of rolling stock. One of the key systems that ensures the safety and functionality of trains is the pneumatic system, the heart of which is the compressor. Currently, the most widespread in air supply systems are positive displacement compressors, the effective operation of which has a direct impact on the functioning of the brake system, pneumatic drives and other auxiliary mechanisms.

Today, there are a variety of designs of positive displacement compressors used in railway rolling stock. However, there is no clear and systematic classification of these units considering their design features, technical characteristics and areas of application on different types of rolling stock.

Insufficient systematization complicates the process of selecting the optimal type of compressor for specific operating conditions and technical requirements. This leads to difficulties in designing new and modernizing existing pneumatic systems of rolling stock. In addition, the lack of a unified classification complicates the analysis of their reliability, maintenance and development of effective repair strategies.

Thus, there is an urgent need to develop a scientifically based classification of positive displacement compressors used in railway rolling stock. Such a classification will help optimize the choice of compressor equipment, increase the efficiency and reliability of pneumatic systems, and simplify the processes of their operation and maintenance. Solving this scientific and applied problem is of great importance for the further development of railway transport in Ukraine.

Analysis of recent research and publications. The study [1] proposes an innovative method for classifying the condition of diesel-electric locomotive compressors based on vibration signal analysis using machine learning. The authors developed an algorithm that shows 5 main types of faults with 94% accuracy, including cylinder wear and valve defects. The results are especially relevant for freight transportation, where compressor reliability is critical.

In the article [2], a comprehensive thermodynamic analysis of the operation of screw compressors in pneumatic systems of high-speed trains is presented. The authors found that changing the geometry of the screws by 5° increases the efficiency by 7–8% when operating at high speeds. The work is of great importance for the development of new generations of compressors for high-speed lines.

A study [3] analyzed the failure statistics of brake compressors using Weibull distribution based on data from 43 railway depots. The authors proposed a modified preventive maintenance schedule that reduces the probability of failure by 25%. The results have already been implemented in some parts of India, demonstrating significant cost savings.

The work [4] is devoted to the optimization of the design of twin-screw compressors for energy-efficient metro trains. Using multi-criteria optimization methods, the authors achieved a 15% reduction in energy consumption while maintaining performance. The study is especially relevant for cities with intensive metro traffic, where energy saving is a critical factor.

In the article [5], a comprehensive comparison of the efficiency of traditional lubricated and lubricated-free compressors in urban rail transport conditions is carried out. The study contains recommendations for choosing the type of compressor depending on the operating conditions and environmental requirements.

The study [6] introduces an innovative predictive maintenance system for reciprocating compressors in freight trains using artificial intelligence. The developed algorithm based on a neural network analyzes vibration sensor data in real time, achieving a failure prediction accuracy of 91%.

In the article [7], a new method for detecting faults in scroll compressors using acoustic emission analysis is presented. The system is particularly effective for detecting microcracks in scroll elements. The study offers a new approach to monitoring high-precision compressor systems.

In the work [8], the strength of the supporting structure of a freight car made of round pipes during sea transportation is investigated. Experimental data were obtained during real voyages in the Black Sea. The study is of great importance for the safety of combined rail-sea transportation.

Continuing the previous study, the work [9] focuses on the analysis of fastening of gondola cars using viscous couplings. The authors developed recommendations for the optimal number and location of fasteners. The results have already been implemented in the operational practice of some shipping companies, increasing the safety of transportation.

The study [10] proposes an innovative system for utilizing waste heat from compressors in railway rolling stock. Particular attention is paid to adapting the system to the existing infrastructure. The results open new opportunities for increasing the energy efficiency of railway transport.

The study [11] conducts a comprehensive comparative analysis of the life cycle costs of different types of compressors in regional trains. The authors developed a unique cost estimation model that takes into account energy efficiency, maintenance costs and environmental impact.

Experimental work [12] analyzes the efficiency of variable speed compressors in hybrid trains. The results show a reduction in energy consumption by 18–22% compared to traditional systems under variable loads. A feature of the study is a comprehensive assessment of the impact of rotation speed on the resource of the unit.

An innovative study [13] uses CFD methods to analyze air flows in piston compressors of high-speed trains. The authors developed a three-dimensional model that accurately reproduces the processes in the compression chamber with an error of less than 3%. The results open new opportunities for optimizing the energy efficiency of compressor systems.

The study [14] is devoted to determining the optimal parameters of on-board energy storage systems for metro rolling stock. The authors developed a unique capacity calculation method that considers the line profile and the schedule of movement.

Of value is the analysis of the interaction of the storage system with the traction drive. The results have already been implemented on some lines of the Ukrainian metro.

Continuing the previous study, the work [15] focuses on determining the rational parameters of capacitive systems for underground transport. The authors proposed a new charging/discharging control algorithm that increases the efficiency by 8–10%. The results of the study are important for the development of energy-efficient technologies in urban transport.

The study [16] introduces an innovative IoT system for real-time monitoring of the condition of railway compressors. The system is particularly effective for remote depots with limited access to specialists. The results open up new opportunities for the digital transformation of railway infrastructure.

In the article [17], a comprehensive solution for noise reduction (up to 8 dB) and vibration in piston compressors of suburban trains is presented. The study offers a unique methodology for balancing efficiency and cost of modernization.

The work [18] presents a systematic analysis of 12 modern sealing technologies for rotary compressors, including: polymeric materials (lifetime up to 50,000 hours); laser surface texturing (wear – 30%); magnetic seals (for oil-free systems). The review contains unique data on the influence of microtextured on tightness.

Innovative research [19] presents a new generation of lightweight and environmentally friendly materials for compressors: aluminum foam structures; biopolymer composites; carbon nanotubes in a matrix. The results are in line with the EU's goals for decarbonizing transport by 2050.

The analysis of the literature clearly shows that insufficient attention is paid to the issue of classifying positive displacement compressors used in railway rolling stock. Existing approaches are often fragmentary and do not cover all important aspects of the functioning of these units. The lack of a single, clearly structured classification complicates the comparative analysis of different types of compressors. It also prevents the systematization of knowledge about their design features, operational characteristics and areas of application in railway transport. This situation can lead to inefficient equipment selection and complicate the development of optimal air supply systems for rolling stock. Therefore, the need for in-depth and comprehensive research to develop a comprehensive classification is obvious and urgent.

Analysis of existing technical documentation and regulations allowed to identify current standards and approaches to the classification of compressor equipment in railway transport. Systematization and generalization of literary sources provided a theoretical basis for the development of an improved classification, considering various design features and functional characteristics of compressors. A comparative analysis of the technical characteristics and principles of operation of different types of positive displacement compressors used in rolling stock revealed their advantages and disadvantages. Development of a structural classification scheme based on certain criteria (for example, principle of operation, number of compression stages, type of drive) contributed to a clear and logical division of compressors into groups. An expert survey of specialists in the field of railway transport and compressor equipment production helped to verify the proposed classification and consider practical operating experience. Practical testing of the developed classification on the example of specific models of compressors used in rolling stock of Ukrainian railways confirmed its versatility and practical value.

Task statement. The purpose of the study is to systematize existing types of compressors to optimize their selection and application, according to the main design and functional features. The developed multi-level hierarchical classification structure allows to systematize existing and new types of compressors. The results of the study can be used to develop recommendations for improving the efficiency of pneumatic systems of railway transport. They are a theoretical basis for optimizing the selection and design of compressor equipment for railway transport.

Outline of the main material of the study. The main components of compressor units installed on modern railway rolling stock and subway cars (Fig. 1) are: compressor – 1; air dryer with built-in pre-cleaning filter – 2; device for collecting and removing condensate – 3; fine oil filter – 4; safety valves – 5 and 6, which prevent the occurrence of unacceptably high pressure in the event of various malfunctions; receiver – 7. After the compressor, the air compressed to 8.5–10 bar, which contains oil and water in the form of drops or steam, is subjected to special treatment to prevent them from entering pneumatic networks.

After the compressor, the air enters the air dryer, where the main part of the impurities created by the droplets is precipitated mechanically, and the remaining part is removed by special moisture absorbers. If necessary, the compressed air is additionally cooled and passed through a fine oil filter. The condensate accumulated in the air dryer must be collected for further disposal. It should be noted that in oil-free compressors, the need for a condensate collection and removal system, as well as a fine oil filter, is eliminated.

Research of scientific and technical documentation and operating experience have allowed to formulate the main requirements for compressors of modern rolling stock: compressors must fully satisfy the needs of the train in compressed air at its highest consumption; their performance must be at the level necessary to create the set pressure in the main tank for a certain time; the reliability of the compressors must correspond to 0.003 failures per thousand hours of operation; power consumption at the level of 8 kW per compression of 1 m^3/min; specific gravity not more than 70 kg (without engine) per 1 m^3/min of compressor supply.

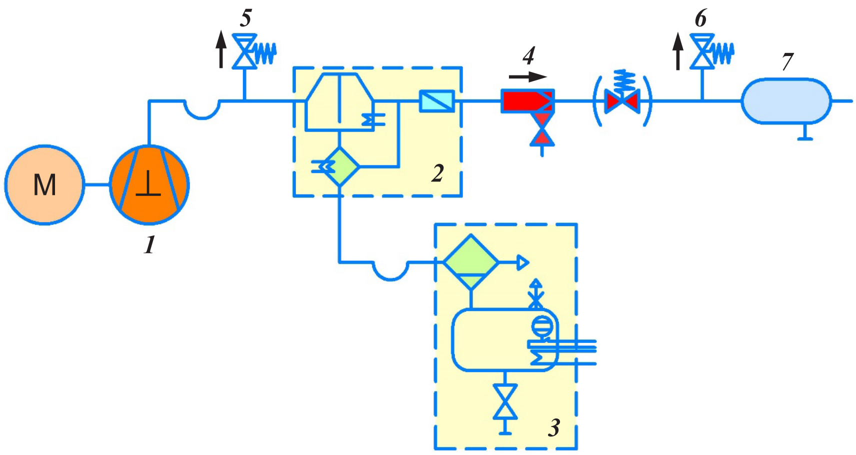

Fig. 1. Scheme of the compressor installation

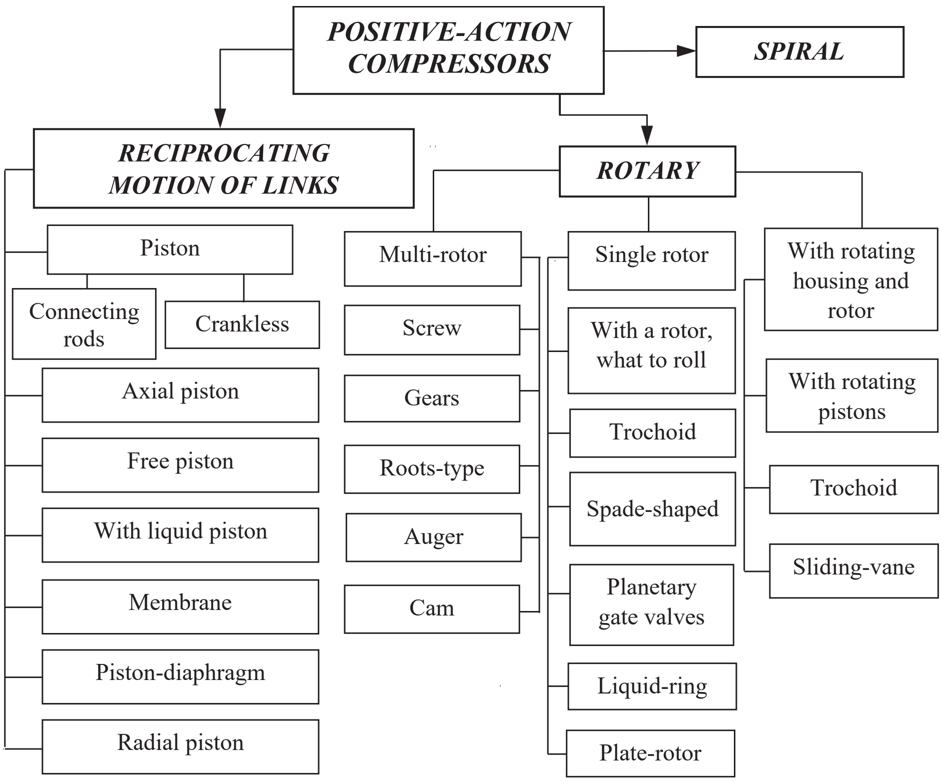

Fig. 2. Classification of positive displacement compressors

Analysis of scientific and technical literature allowed us to develop a classification scheme for existing positive displacement compressors (Fig. 2), which can be used in air supply systems and installed on traction units (diesel locomotives, electric locomotives, electric trains, diesel trains, railcars, and subway cars) to provide compressed air to automatic braking devices, control devices, and auxiliary mechanisms.

Below in Table 1 (DL – diesel locomotive, EL – electric locomotive, DT – diesel train, MC – metro car, ERS – Electric Rolling Stock) technical characteristics of some of the listed compressors are given, the analysis of which allows to assess the compliance of piston compressors with the above requirements.

From the analysis of the data in Table 1, the air supply systems of modern traction and railcar rolling stock in difficult operating conditions (significant vibrations and significant fluctuations in the external temperature) are mainly based on piston compressors (). Their design features determine their significant weight and size indicators and significant power consumption for the drive (for example, according to research results: the working volume of the KT-7 compressor exceeds 1 m^3, the mass is 646 kg, the power consumption for the drive is 44 kW – 2% of the effective power of the locomotive power plant), and the differences in the operating conditions of compressors on diesel and electric locomotives determine their differences in design.

As the conducted studies have shown, the piston compressors of modern traction and multi-rail rolling stock of Ukrzaliznytsia, with sufficient productivity and satisfactory operational reliability, are characterized by rather large mass-dimensional

Table 1

Technical characteristics of compressors of modern traction rolling stock

Indicator \ Compressor type	КТ6,7	КТ6ЭЛ	К3	ПК-5,25	ПК-3,5
Rolling stock type	DL	EL	EL	DL	DL
Productivity, м^3/min	5,3	5,3/2,75	4,1	5,25	3,5
Number of revolutions, rpm	850	850/440	1250	1450	1450
Power consumption, kW	44	44	37	37	27,5
Discharge pressure, MPa	0,9	0,9	1,0	0,9	0,9
Number of compression stages	2	2	2	2	2
Weight of the compressor, kg	646	630	410	310	200
Cylinder position	W	W	W	V	V
Overall dimensions, mm					
- length	760	760	1043	805	625
- width	1320	1255	867	835	835
- height	1105	1105	911	670	670

Continuation of table 1

Indicator \ Compressor type	ПК-1,75	Э-500	ВП3-4/9	ВВ-1,5/9
Rolling stock type	DL	EL, DL	DL	DL, DT
Productivity, м^3/min	1,75	1,75	3	1,5
Number of revolutions, rpm	1450	200	1000	1000
Power consumption, kW	13,3	15	21	15
Discharge pressure, MPa	0,9	0,9	0,9	0,9
Number of compression stages	2	2	2	2
Weight of the compressor, kg	125	670	344	238
Cylinder position	V	Horizontal	V	Vertical
Overall dimensions, mm				
- length	460	717	526	535
- width	775	1299	1071	462
- height	665	629	1070	235

Continuation of table 1

Indicator \ Compressor type	ПК-35	ЭК-7Б	ЭК-7В	ЭК-4
Rolling stock type	DL	ERS	ERS	MC
Productivity, $м^3$/min	3,5	0,62	0,58	0,43
Number of revolutions, rpm	1450	560	540	320
Power consumption, kW	32	5,0	4,7	4,3
Discharge pressure, MPa	0,9	0,8	0,8	0,8
Number of compression stages	2	1	1	1
Weight of the compressor, kg	380	118	118	140
Cylinder position	V	Horizontal	Horizontal	Horizontal
Overall dimensions, mm - length - width - height	685 860 968	520 604 440	520 604 440	520 583 465

Continuation of table 1

Indicator \ Compressor type	ВГ-0,42/8-400	ЭК4Б-М	К-1	К-2
Rolling stock type	MC	MC	DL, EL	EL
Productivity, $м^3$/min	0,42	0,42	2,0	2,63
Number of revolutions, rpm	400	400	700	720
Power consumption, kW	-	4,5	17,6	18,7
Discharge pressure, MPa	0,8	0,8	0,8	0,9
Number of compression stages	1	1	2	2
Weight of the compressor, kg	130	310	220	360
Cylinder position	Horizontal	Horizontal	V	W
Overall dimensions, mm - length - width - height	605 627 500	1028 674 500	600 860 667	1043 867 911

indicators and high levels of vibrations, which have a negative impact on people, as well as the reliability and durability of both the compressors themselves and the supporting elements of the rolling stock. Therefore, a rational direction for ensuring the required operational characteristics of air supply systems of modern rolling stock is to eliminate the indicated disadvantages of piston compressors by using rotary compressors (screw, single-rotor vane, trochoidal, etc.). The main advantages of rotary compressors include reduced vibration levels compared to piston compressors, reduced power consumption and mass-dimensional indicators.

Conclusions. The developed classification of positive displacement compressors for railway rolling stock systematizes existing types according to key design and functional features, which simplifies their selection and application. The main classification criteria are determined, including the principle of operation (piston, screw, plate, scroll), number of compression stages, type of drive, cooling method, and features of application on various types of rolling stock.

It was found that piston compressors remain the most common due to their versatility and ability to provide high pressure but have a higher level of vibration and require more frequent maintenance. At the same time, rotary compressors demonstrate better energy efficiency and lower noise levels compared to piston compressors, which makes them promise for modern rolling stock.

The classification of compressors presented in the article allows you to structure them by purpose (braking systems, pneumatic drives, auxiliary systems), which further allows you to more accurately select equipment considering the specific requirements of each system. It can serve as the basis for further scientific research aimed at optimizing the design and increasing the efficiency of compressor units for railway transport.

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Фомін О.В., Логвіненко О.А., Кузьменко С.В., Заверкін А.В. КЛАСИФІКАЦІЯ КОМПРЕСОРІВ ОБ'ЄМНОЇ ДІЇ РУХОМОГО СКЛАДУ ЗАЛІЗНИЦЬ

У статті розглянуто класифікацію компресорів об'ємної дії, які широко використовуються в пневматичних системах тягового та моторвагонного рухомого складу. Проведено аналіз сучасних технічних рішень у галузі компресоробудування, а також чинних класифікацій, що використовуються в науковій та виробничій літературі. Основну увагу приділено систематизації компресорів залежно від конструктивних ознак, режиму роботи, кількості ступенів стискання, типу приводу, наявності мастила, а також сфери застосування (локомотиви, електропоїзди, дизель-поїзди, вагони метрополітену тощо).

Сформульовано необхідність побудови узагальненої класифікаційної схеми, яка враховує як традиційні, так і новітні технічні рішення, що застосовуються у сучасному залізничному транспорті. Розроблено багаторівневу структуру класифікації компресорів об'ємної дії, що охоплює їх основні типи – поршневі, мембранні, гвинтові та інші, з детальним розглядом конструктивних та експлуатаційних *характеристик кожного з них. Визначено переваги й недоліки різних типів компресорів з огляду на умови їх експлуатації, ремонтопридатність, енергоефективність та вартість обслуговування.*

У ході дослідження враховано дані з технічної документації та каталогів провідних виробників компресорного обладнання, таких як ОАО «Полтавський турбомеханічний завод», ВАТ «Транспневматика», Atlas Copco, CKD та ін. Проаналізовано перспективи застосування сучасних енергозберігаючих технологій у компресорних установках, зокрема інверторного регулювання продуктивності та безмасляних систем. Зроблено висновки щодо доцільності впровадження єдиної класифікаційної системи у нормативно-технічну базу для полегшення вибору компресорного обладнання на етапах проектування та експлуатації рухомого складу.

Зазначено, що результати дослідження можуть бути використані в практиці інженерного проектування, технічного обслуговування, модернізації пневматичних систем рухомого складу та слугувати основою для подальших наукових досліджень, спрямованих на оптимізацію конструкції та підвищення ефективності компресорних установок для залізничного транспорту.

Ключові слова: *перевезення, механіка, залізничний транспорт, транспортні технології, рухомий склад, ремонт, експлуатація, надійність, компресори.*