«AT THE TIME OF BURNING MOTION IS TRANSMITTED»

***Grigoriev, Nikolai D.**, Russian University of Transport, Moscow, Russia.*

ABSTRACT

«The facts relating to the ballistic properties of rockets are the result of observation, but they indicate the possibility of a mathematical theory of the design of rockets, – in a word, the possibility of rocket ballistics. But this science, which still needs to be created…», – wrote K. I. Konstantinov, a scientist and inventor in the field of rocketry and artillery. He made changes to the design of rockets and launchers, studied various powder compositions. Thanks to him, the production of all types of combat missiles was standardized and took to the assembly line. The range of Konstantinov rockets was four times greater than the old samples. His inventions include Konstantinov pendulum, an electroballistic installation, a chronoscope, a time relay. The famous Russian «Katyushas», which terrified the enemy in the Second World War, are the distant descendants of the rockets created at the Petersburg rocket establishment under the leadership of General Konstantinov.

Keywords: theory of ballistics, rocket, artillery, chronoscope, electroballistic installation, Konstantinov pendulum, history.

Background. *A prominent military engineer, scientist, inventor, Lieutenant-General Konstantin Ivanovich Konstantinov was born on December 20, 1818 (January 1, 1819 in a new style) in Warsaw. Although for a long time there were discrepancies regarding his day, month, and year of birth, since the «high order» circumstance existed in the rocket specialist's family tree. As it later became known, in fact, he was the illegitimate son of the Grand Duke, Tsarevich Konstantin Pavlovich Romanov, governor of the Kingdom of Poland, then in the Russian Empire. The mother was a Parisian actress and singer Clara-Anna de Laurent.*

At the request of the father, the baby was given the name Konstantin. At that time, when making a metric record, an extramarital [1–6, 14, 15] child (born by an unmarried woman) was given a patronymic and surname according to the name of his godfather. The godfather at baptism in the church was the Grand Duke, and therefore, the newborn became Konstantin Konstantinovich Konstantinov.

After the death of cholera of Konstantin Pavlovich in 1831, the boy was considered an adopted child (foster-son) of Knyaz Ivan Alexandrovich Golitsyn, adjutant of Tsarevich. For this reason, in 1837, his patronymic changed from Konstantinovich to Ivanovich.

Objective. *The objective of the author is to consider life and scientific achievements of a prominent military engineer, scientist, inventor, Lieutenant-General Konstantin Ivanovich Konstantinov.*

Methods. *The author uses general scientific methods, historical-retrospective method, scientific description.*

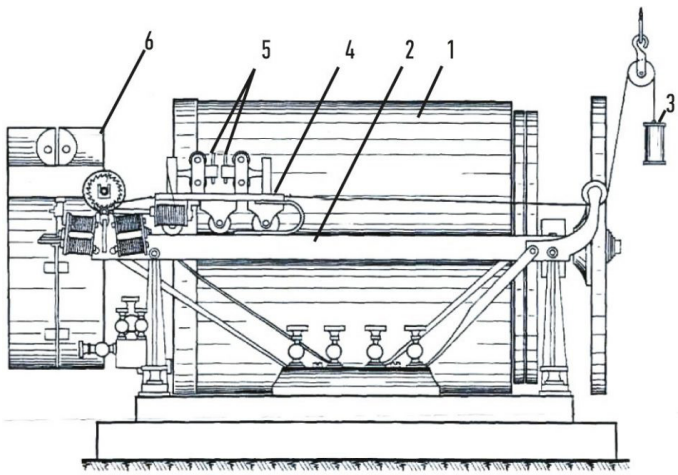
Results.

Artillery Universities

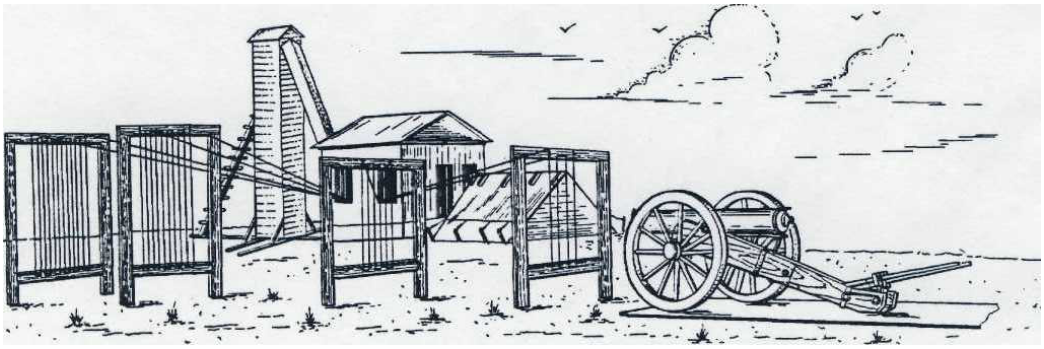
In 1834, fulfilling the will of the late grand duke, a boy under the guise of the son of a merchant of the second guild of Chernigov province, was sent by Golitsyn as an elder to the elite (prestigious for scientific potential) to St. Petersburg Mikhailovsky Artillery School (in the future artillery academy). People from noble or merchant families were taken there, and it was necessary to «conform».

The fact that the school was founded in 1820 by Konstantin Pavlovich's brother and also Grand Duke Mikhail Pavlovich, whose name was carried by this military educational institution that trained artillery officers, is not a minor detail in this situation.

The second important detail, a kind of luck for the newly minted Junker, was appearance in the curricula of the senior officer class of applied mechanics – an extremely important subject in rocket science. Moreover, the students of Konstantinov's call-in were especially lucky that the hydraulics, engines, transmission and actuating mechanisms that were part of the subject, as well as the initial course on the nascent railway transport were taught by none other than Professor P. P. Melnikov, the author of the first scientific work «On Railways» (1835), later supervising the construction of Petersburg–Moscow highway and becoming the first Russian Minister of Railways.



Ballistic installation of Konstantinov.



General view of the ballistic installation of K. I. Konstantinov.

As a mechanical engineer and a brilliant engineer, Melnikov attached great importance to ensuring that the theoretical knowledge obtained was logically linked to the practical training of officers who were assigned to work independently in artillery production and mining plants. Reports of the officers-interns were then printed at public expense and made up two impressive volumes. They turned out to be the only ones for their time and very thorough descriptions of the factory business in Russia. For Konstantinov, they played in addition to the classes that the professor led, the role of the university pantry, the data bank, which helped him in tireless innovation. An excellent training in the field of mechanics was very useful for a graduate of Mikhailovsky School, making him later one of the most prominent military engineers.

In 1836, Konstantinov remained in school for additional improvement of his knowledge in higher grades and scientific work. He began to work on creation of an automatic installation for measuring the speed of a gun-projectile. First of all, he needed a device capable of measuring very small periods of time with great accuracy. Research activities that required constant efforts began, each new step in which brought new knowledge and experience.

In 1837, with the rank of warrant officer, he was enlisted in the Guards artillery battery. There he designed a mobile sight, which was later widely used in Russian artillery.

In 1838, the final graduation of a young man from the school with the rank of second lieutenant took place. He became a teacher at the division fireworks school and was appointed commander of the school of masters and apprentices of gunpowder, saltpeter and sulfuric affairs (later a pyrotechnic school) at Okhta powder factory, and two years later he became an assistant to the head of the educational laboratory team of St. Petersburg. The officer studied in detail the effect of various types of gunpowder, which later came in handy when improving combat missiles.

In 1840, Konstantinov was sent for four years to Europe to familiarize himself with the state of the artillery arts. He managed to visit England, France, Belgium, Holland, Prussia and Austria-Hungary.

In 1842, while in London, he had the opportunity to implement the idea of a chronoscope for analyzing movements of a gun-projectile, which took place in a hundred-thousandth of a second. The first version of the device developed by him consisted of a horizontal copper cylinder, driven into rotation by a load suspended on a silk thread, the other end of which was wound on the horizontal axis of the swipe. The swipe was located perpendicular to the cylinder and was connected to it by a system of gear wheels. At one turn of the swipe, the cylinder made 30 turns. To ensure a uniform rotation of the cylinder and to increase the measurement accuracy, Konstantinov proposed an air brake in the form of wings mounted on the cylinder axis, the inner sides of which, with the aim of increasing air resistance during rotation, represented logarithmic surfaces. At his request, an English physicist, owner of a precision instrument workshop, Charles Wheatstone, made this version of the chronoscope and later tried to appropriate the invention to himself.

Having experienced the first version of the chronoscope performed by Wheatstone, Konstantinov recognized it unsuitable for use. In Paris, he developed the second version of the chronometric device, the manufacture of which he ordered in the workshop of the French physicist L. Breguet. However, many parts of this device were damaged during transportation to St. Petersburg, and it was impossible to use the chronoscope. In 1844, a stubborn inventor created a more advanced electro-ballistic installation. It was successfully tested on Volkov field in St. Petersburg [7–10]. The third version of the chronoscope allowed to determine the intervals required for the cannonball to pass through electrically connected metal shields, and automatically register these signals on a millimeter grid deposited on the surface of a uniformly rotating cylinder. A special switch and an electromagnetic pendulum relay provided automatic control over the uniform speed of rotation of the cylinder. The electric ballistic installation recorded the speed of the projectile with an accuracy of 0,00006 seconds, which was an unsurpassed record for those years. In an effort to measure accuracy in time, an artillery officer, for the first time in measuring equipment, justified the question of calibrating instrument readings[1].

At the suggestion of the Russian Academy of Sciences, Konstantinov's electro-ballistic facility was recognized as an outstanding achievement of science and technology, which allows determining the initial speed of a cannonball gun flying out of a barrel. In 1846, the inventor was awarded the Order of

[1] Currently, according to the federal law No. 102 of July 20, 2008 «On ensuring the uniformity of measurements», verification or calibration of measuring devices in order to achieve reliability of measurement results of physical quantities are performed by the metrological services of a country or enterprise (as decided by its chief metrologist). Measuring devices that have not passed the next (planned) verification or calibration are not allowed to be used and their readings cannot be taken as reliable data.

St. Vladimir of the 4th degree, received 2000 rubles in silver and was awarded the recently established Mikhailov Prize.

In 1845, Konstantinov developed an electromechanical circuit breaker and circuit switch, which he called an auxiliary device. A two-stage wooden cylinder was driven into rotation by a load. With the passage of electric current through the electromagnet, the brake lever, mounted on the axle, kept the cylinder from rotating. After the shot of the gun, the projectile broke the wire of the first shield and the electromagnet circuit – the source of electric current – opened. The coil spring deflected the braking lever from the cylinder, which, under the influence of the load, began to rotate. It rotated until the contact plate was connected to the spring of the next shield. The electromagnet circuit was closed again. After the electromagnet triggered, subsequent shields were switched. The device, created by the inventor, automatically signaled and recorded the moment of passage of the projectile through the shield. The new device has become the prototype of modern automatic switches and distributors of electrical circuits of telemechanical installations in a given order.

At the same time, he made several improvements in the technique of fireworks. A new form of parachutes for lighting rockets, a pyrotechnic photometer, pruned banners, a method for comparing force compounds, etc. were created.

Rocket ballistic pendulum

From a trip abroad, Konstantin Ivanovich brought a lot of materials relating to production and use of combat missiles. In St. Petersburg, he systematized the collected and very thoroughly stated in a report to the Artillery Branch of the Military Accounting Committee his proposals for improving domestic rocket production. And he was heard by the military authorities.

In 1846, Konstantinov was seconded to the headquarters of the General Feldtseyhmeister (the chief commander in artillery of the Russian army) and in 1846–1847 he was engaged in research of rocket technology in the rocket establishment of Colonel I. F. Kostyko.

Konstantinov undertook to carry out the order of the Artillery Branch to come to grips with investigation of the missiles with full enthusiasm. He understood that his predecessors possessed only initial information about the process of developing «reactive power», the behavior of a rocket in flight, and the laws of their dispersion. The first task was to create a scientific or, as he wrote, «mathematical theory of construction and firing of rockets». For this it was necessary to find the possibility of an analytical study of the processes occurring in the rocket chamber, to establish the patterns to which they obey. According to his program of experiments on missiles, he began a comparative study of combat missiles, and a detailed cooperation was made for their production [14].

The then-known French artillery researcher Moren used the conventional dynamometer to measure the traction of the powder engine, and the Austrian baron Augustin, the creator of a combat missile, used conventional lever weights for the same purpose. Konstantinov created a rocket ballistic pendulum to measure the thrust of a powder engine.

The swinging part of the pendulum was a sheer lever, linked with an upper end to the axis in the uprights. At the lower end of the lever was a receiver in which the test rocket was fixed. After ignition of the rocket charge under the action of the thrust force, the lever deviated from the initial position. The device registering this deviation in time was a cylinder whose axis was parallel to the swing plane of the pendulum. The cylinder was rotated manually using cable transmission. Parallel to the cylinder, two iron rails were placed one above the other, along which the bogie connected to the swinging part by a horizontal rod moved. The movements of the bogie were proportional to the sine of the angles of deflection of the pendulum. A wooden needle was fastened to the bogie, which traced a curve along the surface of the cylinder, covered with chalk paint before the experiment. As the rocket moved, the pendulum deflected and the needle, mounted on the bogie, struck out on the cylinder a curve by which it was possible to judge the speed of the rocket. The pendulum was built on a missile range on Volkov field in St. Petersburg and was tested in the presence of members of the Military Scientific Committee.

The pendulum, highly valued for measurement accuracy and ease of calculation, helped the artillery engineer to establish the law of the rocket's driving force variation over time and to investigate the influence of the form and design of the rocket on its ballistic properties. In essence, the scientific basis for calculating and designing missiles was laid. For many years, the pendulum remained the most perfect tool for estimating the propulsion parameters of a rocket engine. The methodology for studying the intraballistic characteristics of rockets, then proposed by Konstantinov, is a prototype of modern fire tests. The principles and design principles tested by him were used at the Institute of Physical Chemistry of the Academy of Sciences of the USSR in the study of the specific impulse of solid propellant Russian rocket engines created in the late 1940s.

In 1848, Konstantinov produced an electromagnetic telegraph for quick and uninterrupted verbal intercourse between the operators of the main elements of the electroballistic installation (a tool and an electroballistic device were located at a considerable distance from each other). The telegraph consisted of two identical apparatus that served to send and receive dispatches (urgent notifications). The dial of the device had 12 characters and an index hand. When pressing the

key of one of the devices, the metal rod fell into a cup with mercury. The electrical circuit is closed. In the receiving device, an electromagnet actuated a lever that turned one of the gears. When the key was released, another gear wheel turned. As a result, the hand connected to the gears moved to one twelfth part of the circle, passed from one sign to another and was duplicated on the transmitter, which provided control of information transfer. The dispatch (telegram) was decrypted using a special code.

Speaking in modern language, the Russian officer, in the first half of 19th century, invented a prototype of the current automatic switches and step regulators, created a time relay (timer), which in 20th century became a model of the American technology of automatic control of production processes on the principle of time span, took part in development of feedback in systems with automatic controllers.

The following year, Konstantin Ivanovich was promoted to colonel and appointed head of Okhta capsule establishment, and in 1850, commander of St. Petersburg Rocket Plant, the first industrial enterprise in Russia for production of combat missiles [11]. From 1852 he became a member of Artillery Division of the Military Scientific Committee.

The plant commander conducted experiments to optimize rocket parameters, stabilize them in flight, experimented with rocket powder compositions, improved launchers, mechanization and automation of production equipment, and search for new modifications of combat rocket designs with an increased range to 4–5 km, improved drop accuracy. He constantly cared about the technology of production and assembly of rockets, safety of their manufacture.

Before him, for stability of the energy characteristics and achievement of homogeneity of the composition, black powder was mixed in barrels with a horizontal axis of rotation with a manual drive. But the stirring barrels often served as the cause of explosions and fires, since copper bullets were poured in for the better grinding of the components, causing sparks to appear. In 1855, he offered barrels with an inclined axis of rotation, in which the mixing of powder occurred better, and the force of blows of copper bullets one against the other became much less. According to his technology in 1853–1856, the plant produced several thousand combat missiles for the needs of Crimean (Eastern) Russian-Turkish War. He was declared «the royal favor».

Shooting guns in time with drums

In the summer of 1856, coronation celebrations took place with a grand firework and musical performance on the occasion of the ascension to the throne of Emperor Alexander II. The preparation and holding of the celebrations were entrusted to Konstantinov as a well-known specialist in the field of pyrotechnics, electrical automation and rocket science. To illuminate the huge square in front of Ekaterinisky Palace, according to his proposal, ten powerful electric arc lamps (electric suns), invented by the Russian electrical engineer A. I. Shpakovsky, and never used before anywhere in the world, were installed at the roof of the building. Electromagnetic and electromechanical regulators ensured the brightness of lighting and the reliability of their work. The lamps made a real sensation, were a resounding success and general approval.

At the celebrations, the choir and orchestra, bringing together about 3 thousand people, were to perform the national anthem. But during the rehearsal it turned out that the drum beat was weakened by the sounds of copper pipes and the effect of the orchestra's solemn sound was noticeably reduced. Konstantinov quickly found the original solution: electro-automatic remote control of shooting with the help of clavichord.

The clavicord was installed on the conductor's console, connected to galvanic batteries and connected with wires with metal fuses installed in cannons located at a distance of about 1 km from the square. When the conductor pressed the clavichord key, the electric current from the galvanic batteries installed in the square heated up the fuses and a shot from the guns was heard to the drums, which sharply intensified and emphasized drumming. A communication scheme was developed for serially connecting the guns to the same galvanic battery, as well as a special device that protected the keys from accidental touch and a possible premature shot. The effect of the remote control of firing guns that intensified the beat of the drums was amazing. Electric clavichord was not just original, but was a new word in communication technology and control of various objects at a distance.

However, the effects of the clavichord sound synchronization turned out to be no less impressive for the career growth of the author of the invention. In August 1856, he was given the military rank of major general.

In 1853, Konstantinov published an article entitled «Making, Preparing and Using Balloons» in the «Artillery Magazine», and in 1856 published the work «Ballooning», which for the first time in the Russian press set out the history of this area of science and for the first time in the world considered the idea of the use of rocket engines for movement of the air apparatus and control of the balloon.

In 1857, in «Sea Collection», Konstantinov made an analysis of proposals related to scuba diving, including giving an example and commenting on the idea of the Russian engineer Adjutant General (adjutant in the rank of general under the emperor) K. A. Schilder on the use of combat missiles on the world's first all-metal submarine.

In 1859 he was awarded the Order of St. Stanislav I degree for improvement of combat missiles and was appointed head of the Special Directorate for Preparation and Use of Combat Missiles at the headquarters of the General Feldtseyhmeister.

In 1857–1860, he repeatedly traveled to France on business trips, where he studied the state of rocket technology and placed orders for factory equipment.

The foreshadowing of «Tsiolkovsky formula»

In 1860 Konstantinov gave a course of lectures «On Military Missiles» at Mikhailovsky Artillery Academy. Prepared with the inherent thoroughness of their author, these texts, as it later became apparent, were the most comprehensive overview of the achievements of rocket technology in Russia and the rest of the world, the scientific and technical level, the methodological and technological aspects of the materials, the attached calculations and drawings produced impression on any audience, and especially on military experts.

Being in Paris the same year, the general requested permission from the Russian authorities to publish his lectures in French. The reason was businesslike and mutually beneficial: the French military department agreed to share the secrets of making combat missiles, but only in exchange for information about these weapons possessed by

Konstantinov. Emperor Alexander II agreed to the publication of the lectures of Major General.

The published book included a detailed analysis of development of rocket technology as a weapon system, as well as an atlas of drawings explaining the text. In 1864, in reverse translation into Russian, it was published in Petersburg and again had a serious public response.

The conference of Artillery Academy on awarding the Mikhailovsky Prize marked the book as «a complete and distinct treatise on missiles, which so far did not exist either in Russian or in a foreign language».

The Austrian newspaper «Allgemeine Militärzeitung» stated: «The explanations in this work should be considered as an important event in military literature, because it contains with scientific thoroughness and in a public way the subject about which (if the previous works of the same author were excluded) only insufficient and superficial information has been printed until now» [14, p. 228].

Undoubtedly, in the middle of 19th century, Konstantinov, in his lectures, was the first of the rocket specialists to come up very close to one of the main laws of rocket movement: «The mathematical form of this law, as is known, was given by another domestic scientist, the founder of cosmonautics, and therefore it bears his name: «Tsiolkovsky's formula» [14, p. 231].

In 1864, Konstantinov was promoted to the rank of lieutenant general. The following year, he became an honorary member of Marine Scientific Committee and the construction manager of Nikolaev Rocket Plant designed by him. In 1867 he moved to live in the city of Nikolaev, where he organized a branch of the Russian Chemical Society and was elected its first chairman.

In «Nikolayevsky Vestnik», articles «On improving the supply of Nikolaev market», «On improving the national food of Russia in economic and hygienic terms» and a number of other publications soon appeared. They addressed the issues of using achievements in the field of electrical automation to improve and ensure production processes directly related to human life: when creating food products, artificially freezing them, cooling them and storing them in airless space.

At the end of the 1860s in Nikolaev, Konstantinov created a huge rectangular-shaped kite, popular among Russian boys, in contrast to the triangular shape, common in the West. The kite weighed about 4 kg, with an average wind it could lift to a height of more than 1 km the weight of 4 pounds (about 1,638 kg) and was adapted for transmitting signals and written messages. In the last years of his life, he took up the problems of the practical use of balloons, considering that they require the lightest propulsive devices and control systems for them.

Conclusion. *Konstantin Ivanovich Konstantinov died on January 24 (12 in the old style) 1871 after a severe and debilitating illness at the age of 51 in Nikolaev. He was buried in the village of Nivnoe of Mglinsky district of the Chernigov province (now Surazhsky district of Bryansk region) in the family crypt of a merchant, whose son at that time he was considered following the legend created by Golitsyn.*

The rocket plant in Nikolaev was completed and opened without him, then was transferred to Shostka and produced combat, signal, lighting and rescue rockets.

He is the author of more than 100 scientific papers and essays, he has 20 inventions in various fields of electric, electrical instrument making, rocketry, artillery, handguns, pyrotechnics, gunpowder, aeronautics.

In addition to Russian awards for his scholarly works and inventions, he was awarded Prussian, French, Würtemberg, Dutch and Spanish orders.

In the era of gunpowder, the general was rightfully considered the main missileman of the Russian Empire. And the story pays tribute to him.

REFERENCES

1. Konstantinov Konstantin Ivanovich. New Russian Encyclopedia. Vol. VIII (2). Moscow, Encyclopedia, Infra-M, 2011, pp. 274–275.

2. Konstantinov Konstantin Ivanovich. Great Soviet Encyclopedia. Vol. 13. Moscow, Soviet Encyclopedia, 1973, p. 47.

3. Konstantinov Konstantin Ivanovich. Great Soviet Encyclopedia. Vol. 22. Moscow, Great Soviet Encyclopedia, 1953, p. 420.

4. Konstantinov Konstantin Ivanovich. Soviet military encyclopedia. Vol. 4. Moscow, Voenizdat, 1977, p. 310.

5. Konstantinov Konstantin Ivanovich. Russian encyclopedic dictionary. Moscow, Great Russian Encyclopedia, 2003, p. 727.

6. Mazing, G. Yu., Kachur, P. I. Konstantin Ivanovich Konstantinov. 1818–1871. Moscow, Nauka publ., 1995, 175 p.

7. Khramoy, A. V. Konstantinov Konstantin Ivanovich (1817–1871). Moscow, Gosenergoizdat publ., 1951, 115 p.

8. Khramoy, A. V. Essay on the history of development of automation in the USSR. Pre-October period [*Ocherk istorii razvitiya avtomatiki v SSSR. Dooktyabrskiy period*]. Moscow, Publishing House of the Academy of Sciences of the USSR, 1950, 221 p.

9. Khramoy, A. V. K. I. Konstantinov – a pioneer of electric automatics [*Konstantinov – pioner elektroavtomatiki*]. *Elektrichestvo*, 1950, Iss. 2, pp. 82–84.

10. Veselovsky, O. N., Schneiberg, Ya. A. Essays on the history of electrical engineering [*Ocherki po istorii elektrotekhniki*]. Moscow, Izd-vo MEI, 1993, 252 p.

11. Shipov, B. V. Domestic rocket science [*Otechestvennoe raketostroenie*]. Moscow, Voenizdat publ., 1967, 112 p.

12. Grigoriev, N. D. Compass tore around – people went wild. *World of Transport and Transportation*, Vol.15, 2017, Iss. 1, pp. 256–268.

13. Chizhevsky Leonid Vasilievich. Great Soviet Encyclopedia. Vol. 29. Moscow, Soviet Encyclopedia, 1978, p. 188.

14. Kachur, P. I. Chief missileman of the Russian Empire [*Glavniy raketchik Rossiiskoi imperii*]. Moscow, Publishing House «Arms and Technologies», 2013, 384 p.

15. Ryabukhin, B. K., Veber, V. F. For them, the monarchs are godparents [*Dlya nih monarhi – krestnye otsy*]. Ryazan, Litera M, 2016, 432 p.

Information about the author:
Grigoriev, Nikolai D. – Ph.D. (Eng.), associate professor at the department of Electrical engineering of transport of Russian University of Transport, Moscow, Russia, +7 (495) 684–21–19.

Article received 14.06.2018, accepted 22.11.2018.