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Boris S. Jacobi

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ABSTRACT

185 years ago, in 1834 the first really working and sufficiently powerful electric motor was assembled by the young scientist, Moritz Herman von Jacobi in Königsberg (now Russian city of Kaliningrad).

The article is dedicated to the life and scientific achievements of the scientist who became known under the name of Boris Jacobi after he moved to Russia and took the Russian first name.

His merits, in particular, include development of a method of electroplating, that laid foundation for the entire field of applied electrochemistry. It's worth noting that the scientist revealed the results of the study in publicly available, or, in modern terms, open access publication.

Jacobi worked in different fields. He invented a series of devices to measure electric resistance, called by him voltagometer (rheochord, or slide-wire). His research activities were also successful in the field of telegraphy, he invented synchronously acting telegraph device with direct (without further decoding) indication of the letters and numbers at the receiver and first ever letter-printing telegraph device, he administered the project of construction of first cable lines in St. Petersburg and between St. Petersburg and Tsarskoe selo (Emperors' residence). Jacobi developed galvanic batteries, anti-ship mines of new type, initiated creation of galvanic teams within pioneer units of the Russian army. Boris Jacobi initiated and managed unitage, establishment of metric system, and of weight and measure standards in Russia.

Thanks to numerous scientific achievements Jacobi received well-deserved recognition of his contemporaries.

Keywords: *Jacobi, history of transport, electric motor, commutator, electromagnets, galvanic cell, electroplating, galvanoplasty, electrotyping, electrodeposition, mechanical generators, magnetoelectric generator, Jacobi telegraph apparatus.*

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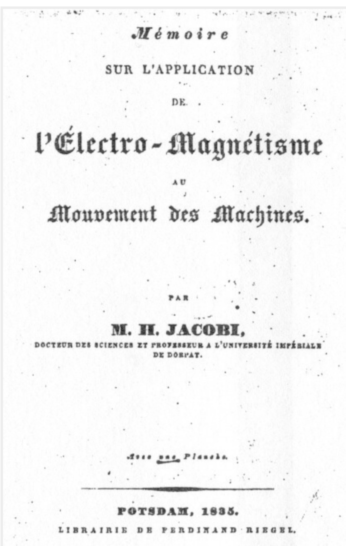
The *objective* of the proposed essay is, using *historical-retrospective and scientific analysis*, to describe life and main research oeuvres of Boris (Moritz Hermann von) Jacobi, prominent scientist in the field of electrical engineering, inventor of the first really working electric motor.

Early years

Future scientist in the field of electrical engineering, academician of the Imperial Saint Petersburg Academy of Sciences Moritz Herman von Jacobi (since 1837 his name changed for Boris Semyonovich Jacobi) was born on September 21, 1801 in Potsdam (Germany) in a wealthy family of the personal banker of the Kaiser (king) of Prussia Friedrich Wilhelm III [1–9]. He received primary education at home and in the gymnasium. Being 19 years old, the young man entered the University of Berlin, and a year later he moved to the Faculty of Physics and Technology of the University of Göttingen. From 1823, after completing the course and after obtaining a diploma in civil engineering, he worked in Prussia's building department, designing large buildings and supervising their construction in Potsdam. He developed projects for a large road bridge and a canal to regulate river waters near the city of Oranienburg. In 1829, after his admission to the «Union for Promotion of Industrial Activities in Prussia», he was given the title of the architect.

Electric motors

In 1833, Jacobi moved to Königsberg (now Kaliningrad) and became interested in the theory and practice of electromagnetism, then quite a new branch of knowledge, that was developed thanks to the contribution of many famous and, regretfully, now less known scientists and inventors, comprising Alessandro Giuseppe Antonio Anastasio Gerolamo Umberto Volta, Dominique François Jean Arago, Michael Faraday, André-Marie Ampère, Hans Christian Oersted, Peter Barlow, William Sturgeon, Istvan (Ányos) Jedlik, Andreas von Baumgartner, Joseph Henry, Savatore dal Negro, Hippolyte Pixii, William Sturgeon, Heinrich Friedrich Emil Lenz, William Ritchie. It was just in 1833 that W. Ritchie in his article «Experimental Studies on Electromagnetism and Magnetoelectricity» described a device in which using a stationary horseshoe magnet he managed to obtain rotational movement around the vertical axis of the electromagnet (iron band wrapped in wire) during a pole shift. Jacobi expressed his opinion about one of similar devices, by saying that «such device will be only a toy for physics laboratories, it can't be used for wider range of purposes with whatever profitability».


Mémoire
SUR L'APPLICATION
DE
l'Électro-Magnétisme
AU
Mouvement des Machines.
PAR
M. H. JACOBI,
DOCTEUR DES SCIENCES ET PROFESSEUR A L'UNIVERSITÉ IMPÉRIALE DE DORPAT.
Avec une Planche.
POTSDAM, 1835.
LIBRAIRIE DE FERDINAND RIEGEL.

Lifetime edition of the work of B. Jacobi.

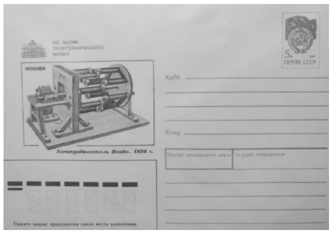
In 1834 Jacobi assembled electric motor (magnetic apparatus) of the original design with continuous rotation of the shaft at a frequency of 80–120 revolutions per minute and power of 15 W. This was of fundamental importance, since a scheme of reciprocating piston motion or jigging oscillations of a movable working part was customary for the design of steam and electrical installations common at that time. At that time, the inventors proposed using the engine to move oars or skulls, to replace rowers or create a moving mechanism that mimics movement of a horse's legs.

He first reported about his electric motor in 1834 in the works of Paris Academy of Sciences in «Note on a magnetic machine in which magnetism is used as a motor force», and a detailed description entitled «Memoirs on application of electromagnetic force to machine motion» was published in Potsdam and in the works of Russian Imperial Academy of Science.

His electric motor, based on the principle of gravitation and repulsion between sets of U-shaped electromagnets, worked from a battery of 69 galvanic cells invented by English scientist W. R. Grove and consisted of two groups of electromagnets with 8 rods of soft iron 7 inches (177,8 mm) long and 1 inch (25,4 mm) thick, wrapped with 320 feet (96 m) of copper wire with a diameter of onefourth line (3,17 mm) and located on two discs (one group was fixed on the frame, and the other rotated around axis). The groups were located at right angles and symmetrically one to the other in such a way that the poles opposed one another. The windings of stationary electromagnets were connected in series. The current in them had the same direction. For alternately changing polarity of the supplied current of moving electromagnets, Jacobi invented the commutator (circuit changer), the design principles of which are used up to now in the collector of traction electric motors for transport [10; 11, etc.].

The commutator consisted of four metal rings mounted on a shaft and isolated from it. Each ring with four cuts, one eighth of the circumference, filled with insulating inlays, was shifted by 45 degrees from the previous one. Along the smooth and polished circumference of the ring, a lever slid, which was a kind of brush, the second end of which was immersed in a vessel with mercury connected by conductors to a galvanic battery. Conductors, mounted on the motor shaft, departed from the rings to the windings of electromagnets of the rotating disk, connected in series. With the help of the commutator, during one revolution of the shaft, the direction of current and polarity changed eight times in mobile electromagnets, and they were alternately attracted and repelled by electromagnets of a fixed disk. This forced the rotating disk and the motor shaft connected to it to rotate. In his electric motor, the inventor for the first time applied three ideas: rotational movement of the shaft; commutator with rubbing contacts, without which it is impossible to ensure rotational movement of the moving winding; use of electromagnets, which, in comparison with permanent magnets, give a greater force of attraction and are not demagnetized in case of jolts and impacts. The acting model of his electric motor is currently located in Moscow Polytechnic Museum. On the recommendation of the Kaiser Friedrich Wilhelm III the University of Königsberg awarded him a Ph.D. for creation of an electric motor.

According to researchers, Jacobi is «undoubtedly the first to create a usable rotating electric motor» [12]. However, he expressly claimed in the memorandum of 1835 that «he was not the sole inventor of the electromagnetic motor itself», referring to the



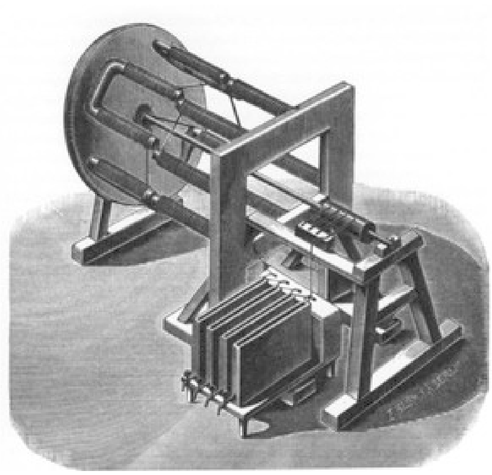
Post envelope with the image of Jacobi's motor from the collection of Moscow Polytechnic Museum.

«priority of the inventions of Guiseppe Domenico Botto and of S. Dal Negro» [12]. «The first electric motor set a world record in performance that stood for four years and was improved in September 1838 only by Jacobi himself. It was not before 1839–1840 when other developers worldwide managed to build motors of similar and later also of higher performance» [13].

In 1835, Jacobi moved to Dorpat (now Tartu, Estonia) and started working as a professor of civil architecture at the university.

In 1837, for his electric motor, he improved a galvanic cell of the English inventor John Frederick Daniell, who in 1836 placed a copper electrode in a solution of blue vitriol (copper sulfate), which does not interact with copper. Jacobi proposed to use for zinc electrode not a solution of sulfuric acid as an electrolyte, but a solution of zinc sulphate, which does not interact with zinc. The wooden box of Daniell–Jacobi galvanic cells, gummed with asphalt cement, was divided into two equal parts by a porous partition of weakly burned clay. In one compartment of the vessel, the copper electrode was in a solution of copper sulphate, in the other, zinc electrode was in a solution of zinc sulphate. The current in the electrical circuit was flowing from the zinc electrode to the copper electrode. In this case, the galvanic element gave not decreasing, but a stable constant voltage of almost one volt and found wide application in practice.

In 1837, Jacobi was naturalized in Russian Empire, changed the name and patronymic for Boris Semyonovich, and moved to St. Petersburg to work in the «Commission for production of experiments on adaptation of electromagnetic force to movement of machines following the method of Professor Jacobi», created at the request of the Minister of Education and President of the Imperial Saint Petersburg Academy of Sciences Sergey Uvarov.



First usable rotating electric motor of Jacobi [12; https://www.eti.kit.edu/english/1376.php].

New motor, electric boat, and future tram

In 1838 a vessel with 14 passengers made a seven-hour voyage for a distance of 14 km against the current and strong wind along the Neva and on the canals of St. Petersburg. Its rowing wheels for the first time were driven by «magnetism» of the vessel's electric 0,75 hp (552 W) motor created by Jacobi in St. Petersburg University. It was a combination of 40 small electric motors, structurally combined into one unit of 20 pieces on two shafts 1,2 m high, installed vertically in a wooden frame 0,9 m long and 0,77 m wide. The rotation of vertical axes with the help of bevel gears was transferred to the horizontal axis, to which the rowing wheels were attached. 320 galvanic cells were installed to power the windings of the electromagnets on a vessel called an «electric boat». Changing the direction of current in the windings of movable electromagnets was carried out by commutators, similar in design to those of his first electric motor [14].

Another embodiment of the electric motor could help to drive a person in a cart along the rails, that application of the electric motor after the works of the Russian inventor F. A. Pirotsky [15] appeared to be a prototype of the modern tram and electric train.

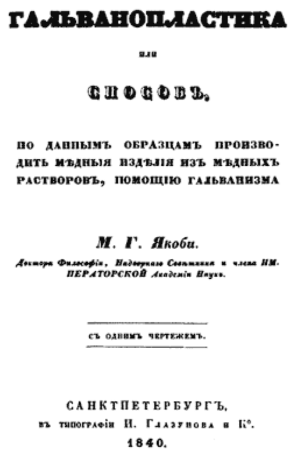
Experiments on the use of electromagnetism on a larger electrically driven vessel continued until 1840, until they led the scientist to conclude that the solution to the issue of widespread introduction of electric motors depends on creating a more capacious, reliable, economical and convenient current source than galvanic batteries could be at that time. Subsequently, after creation of mechanical generators, direct current electric motors began to be used in a regulated electric drive, in crane and lifting installations, as starter motors for internal combustion engines and for traction (on railway and sea transport, in the subway, for trams, trolley buses, submarines and electric cars). They have a large overload capacity, can provide smooth and economical regulation of the shaft rotational speed from tens to several thousand revolutions per minute, have a high starting torque value with a relatively small starting current ratio [16; 17 and others].

Galvanoplasty*

Jacobi studied and improved the galvanic cells used to power the electric motor. In 1836, while working with the cell, he paid attention to the fact that because of electrolysis, the laws of which were discovered in 1833–1834 by the English scientist Michael Faraday, a thin even layer of copper settles on the negative electrode, and that this layer could then be completely detached from the electrode. The shape of the surface of the copper leaf completely and exactly mirrored all the irregularities and surface features of the electrode. He applied an engraved plate, used to print his business card, as a negative electrode and saw that the leaf cut off from the electrode was a negative imprint of a plate with an inscription. Then, consciously and very successfully, he managed to make a copy of the metal coin, which he destroyed following the advice of his colleagues, so as not to be considered a counterfeiter. The researcher called this technique galvanoplasty and began to promote its dissemination and implementation.

In 1838, he presented to the Imperial St. Petersburg Academy of Sciences a memorandum on his discovery of galvanoplasty,

* The use of different terms referring to the topic of this chapter can be subject to further discussion and research as galvanoplasty is currently often referred to as galvanoplastics, electroplating, and depending on the sources those terms (and their derivatives, e.g. electrotyping, electroforming, electrodeposition) are assumed to be synonymous or to have nuances regarding their use. As this issue is not considered in the article, we do prefer to use the term «galvanoplasty» in the article as in historical context it is closer to the original Russian term initially used in Jacobi's works to describe the method to reproduce copies of engraved copper-plates by voltaic (galvanic) action (the term «galvanoplasty» or «galvanoplastics» in its Cyrillic form is used in Russian language till now), and the more modern term of electroplating. – *Ed. note.*



ГАЛЬВАНОПЛАСТИКА

или

СПОСОБЪ,

по даннымъ образцамъ производить мѣдныя издѣлія изъ мѣдныхъ растворовъ, помощію гальванизма

М. Г. Якоби.

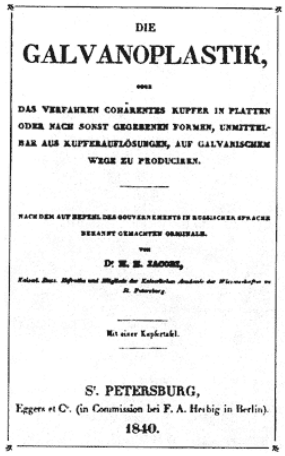
Доктора Философіи, Надворнаго Совѣтника и члена ИМПЕРАТОРСКОЙ Академіи Наукъ.

съ однимъ чертежемъ.

САНКТПЕТЕРБУРГЪ,

въ типографіи Н. Глазунова и К°.

1840.



DIE

GALVANOPLASTIK,

oder

DAS VERFAHREN COHÄRENTES KUPFER IN PLATTEN ODER NACH SONST GEGEBENEN FORMEN, UNMITTELBAR AUS KUPFERAUFLÖSUNGEN, AUF GALVANISCHEM WEGE ZU PRODUCIREN.

NACH DEM AUF BEFEHL DES GOUVERNEMENTS IN RUSSISCHER SPRACHE BEKANNT GEMACHTEN ORIGINALE.

von

Dr. M. H. JACOBI,

Kaiserl. Russ. Hofrathe und Mitgliede der Kaiserlichen Akademie der Wissenschaften zu St. Petersburg.

Mit einer Kupfertafel.

St. PETERSBURG,

Eggers et C°. (in Commission bei F. A. Herbig in Berlin).

1840.

Covers of scientific works of B. Jacobi.

which allows using galvanic effect (electrolysis of copper solutions) to obtain copper copies of the surface of objects. The Russian government bought from him the idea of galvanoplasty for 25,000 rubles in silver and offered to publish all the information received in the open accessed press so that it became accessible to everyone.

In 1840 his work «Galvanoplasty or the method of producing copper items using given samples from copper solutions using voltaic action» was published in the «Journal of Manufactures and Trade» (1840, No. 4), and then as a separate book.

It was a thorough practical guide, supplied with drawings and descriptions. Electrolytic deposition of metals immediately found practical application in printing, fabric printing, medal making, etc. It later became the basis for creating methods for coating the surface of metal, dielectric, gypsum, wax items with thin layer of reduced metal (copper, silver, gold, zinc, iron, nickel, chromium) in order to protect it from bad weather and other negative factors which further was called electrodeposition.

In the middle of the 19th century, large electroplating industrial enterprises arose in Russia and abroad, electroplating workshops were established at many factories, which marked the beginning of a new direction in applied electrochemistry. With the help of electroplating, Moscow and St. Petersburg's domes, statues and bas-reliefs of the Cathedral of Christ the Savior, St. Isaac's Cathedral, the Hermitage, the Winter Palace, the Peter and Paul Cathedral were later decorated with copper and gold. Copper copies were made from printing forms of state papers and banknotes, geographical maps, postage stamps, artistic engravings, which could not be achieved by engraving cliché (stereotypes). Electroplating was gradually introduced into printing and coinage, as well as into publishing of artistic products in the printing industry (heliography, galvanography (electrotyping), and galvanocautery). In recognition of his invention of galvanoplasty Jacobi was approved as adjunct (assistant professor) of the Imperial St. Petersburg Academy of Science in 1839, he was awarded with the prestigious Demidov Prize of 25 000 rubles (he was only ninth person to be awarded that prize) in 1840, and then he was elected extraordinary (supernumerary) academician in 1842.

In 1859, he was invited to study the methods for processing platinum by the method of hydro electrometallurgy (electrodeposition) and the electrolytic method of producing seamless copper pipes.

«Underwater experiments»

Jacobi from 1839 made part of the «Committee on Underwater Experiments» and developed anti-ship sea-mines of a new type for the Russian fleet and army (floating anchored mines with an air chamber in the hull, mines with self-igniting galvanized impactors and a fuse from an induction coil, which was the first high-voltage spark system). Being engaged in improvement of electric blasting of mines, he built in 1842 a magnetoelectric generator with a manual drive of rotation of a shaft of the armature coil by a tooth gear located in the field of permanent magnets, in which an electromotive force was induced. There was a switching device on the shaft in the form of two half-cylinders, representing the simplest two-

plate collector. It was the first magnetoelectric generator, adopted for the use of «galvanic teams» in the sapper battalions of the Russian army, which used it for remote ignition of minefields by electric current.

In 1847, underwater mines were tested in the area between Kronstadt and Oranienbaum (now the city of Lomonosov in Leningrad Region). With an open electric circuit connecting the galvanic battery with the mines, the friendly ships passed over the mines without danger. With a closed circuit, the ship, passing over a mine, touched it, a charge was ignited and an explosion occurred. During the Crimean (Eastern) War in 1853–1856, according to the proposed system, Kronstadt raid was mined, which did not allow British and French warships to approach the naval base and port, either St. Petersburg.

Communication

Jacobi after the death in 1837 of Pavel L. Schilling, the creator of the electromagnetic telegraph [18], in 1841–1843 was engaged in creation of underground and underwater communication cables, development of the technology of their production and selection of electrical insulating materials. Later they were used in organization of telegraph communications from Europe to America. He supervised the laying of the first telegraph cable lines between the Winter Palace in St. Petersburg and the palace in Tsarskoye Selo (now Pushkin, satellite city of St. Petersburg), he in collaboration with the General Staff and with the General Directorate of Communications for the first time created a methodology for control and operational tests for maintaining telegraph lines in working condition.

Jacobi also invented «contrbattery»** (as he called it) to smuggle telegraphs over poorly insulated wires and developed a portable switchgear telegraph for the army, which was brought into service. He designed about 10 types of telegraph devices, including the first one writing letters and not Morse code in 1839, the first device of synchronous action with direct (without decoding) indication in the receiver of transmitted letters and numbers in 1845, and the first direct-printing telegraph device in 1850.

Electromagnets and electromagnetic relays constituted core elements of his simplest electro-automatic and telemechanical devices, comprising an electromechanical recorder of pulses in writing telegraphs, synchronized rotation devices in the switch and direct-printing telegraphs, relay devices for automatic circuit closing in telegraph devices. The peculiarity of his writing telegraph device was that instead of a multiplier it used an electromagnet with a copper rod, which powered a pencil system using levers. The transmitter was designed as a key, closing and opening the electrical circuit. During attraction and release of the anchor, the rod with a pencil moved up and down, and the pencil traced a wavy line on the porcelain board, which moved in a horizontal direction perpendicular to the pencil along the carriage under the action of a clock mechanism. A broken line corresponded to a specific alphabet.

The transmitting and receiving stations of the direct-printing Jacobi telegraph devices had pointing arrows synchronously rotating under the action of moving electromagnets. At each moment they occupied the same position over the dials with letters. On one axis with an arrow, there was a typical wheel with letters rigidly connected with it. To transmit the desired letter, the telegraph operator used a pin to set the arrow opposite the desired letter. At the same time, at the receiving station, an index arrow

** Polarized platinum battery, that is switched to the circuit in such a manner that after extinction of telegraph signal the battery sends the current into the line oppositely to incoming extra current, so that to neutralize the impact of the latter on the line electromagnet of the receiving station station. – *Ed. note.*

was installed against the same letter, along with a typical wheel. The electromagnets worked and they pressed paper tape to the standard wheel, on which the necessary letters were printed one by one. The principle of synchronous-phase communication developed by him in the electromagnetic telegraph, when the arrows of the transmitting and receiving devices perform uniformly intermittent step motion, moving at the same speed (synchronously) and occupying the same spatial position (in phase), was used by other inventors (Ernst Werner von Siemens, David Edward Hughes, etc.). The German electrical engineering firm «Siemens and Halske» immediately organized mass production with some changes to its direct-printing telegraph devices and introduced them in Russia, America and European countries. This principle is the basis of modern direct printing devices, remote transmission technology and tracking electric drive.

In 1854, the scientist created a telegraph apparatus for communication during long passages between the captain's cabin and the engine room.

Magnetic properties of iron

At that time, there were no data on magnetic properties of iron. In 1838–1844, together with Academician of the Imperial St. Petersburg Academy of Sciences E. K. Lenz, Jacobi studied iron magnetization, attraction of electromagnets, and proposed a method for calculating them in electrical machines (used until Russian physicist A. Stoletov found in 1871 [19] magnetization properties of soft iron). Jacobi and Lenz determined proportionality of magnetization of iron to the electric current and the number of turns (according to modern terminology, the number of ampere-turns). They proved that the magnetic flux generated in the iron rod of an electromagnet does not depend on the diameter of coils and the diameter, cross-section and material of the wire.

Back electromotive force and magnetomotive force

Jacobi discovered the appearance of a back electromotive force in the motor armature winding during its rotation and in 1840 and in 1850 published the articles «On the Principles of Electromagnetic Machines» and «On the Theory of Electromagnetic Machines», which contained the first scientific analysis of the operation of a DC motor. In the theoretical analysis of operation of an electric motor, he proceeded from the laws of conservation of energy and of electromagnetic induction, of Ohm's law, and from the laws established by him and Lenz for electromagnets. He studied the parameters that determined the action of an electric motor and were most important for its characteristics: shaft rotation speed; the magnitude of the acting electromagnetic forces; power; economic effect (according to modern terminology – efficiency factor). He showed in the publications in exact mathematical form that the mechanical power on the motor shaft can only be obtained at the expense of a proportional amount of electrical energy. Also for the first time a formula for the magnetomotive force was derived and the ratio of currents in the braking and operating modes was obtained.

Measurement of magnetic values

Jacobi in the 30s of 19th century (together with Lenz) developed a ballistic method of electrical measurements of magnetic quantities, compared the readings of electromagnetic and electrochemical galvanometers. In 1839 he carried out the first attempt to calibrate a galvanometer. In the years 1840–1850, he created a mercury «voltagometer» (a device for measuring electrical resistance) and several designs of galvanometers. He proposed to measure the current strength according to the amount of silver extracted from silver sulphate solution (the measurement unit based on this approach was adopted in 1893 at the International Electrotechnical Congress in Paris), developed the first wire and liquid resistors, rheochords, resistance stores and other similar devices. The wire copper standard of resistance created by him in 1846 became widespread in Russia and in different countries of Europe. For several years, this standard had been used in electrical laboratories, contributing to develop measures to reproduce the physical quantity of a given size.

Education and training programs

In the 1840s, Jacobi developed programs for created «learning galvanic team» and conducted the first courses of theoretical and practical classes in applied electrical engineering. The «learning galvanic team» under his leadership for 15 years trained the staff of the first galvanizers in the sapper units of the Russian army and was the basis on which the Russian higher military electrical engineering school subsequently grew.

Achievements and merits

In 1847, he was elected an ordinary (full-time) academician of the Imperial Saint Petersburg Academy of Science, and in 1864 he received hereditary nobility.

He participated in the commission of the Ministry of Finance to develop ways to determine the strength of alcoholic beverages. He invented an apparatus for separating and measuring the density of liquids of various specific gravities, which found use as a test instrument in distilleries.

In 1867, Jacobi was awarded the Grand Gold Medal and the prize at the World Fair in Paris, where he represented Russia in an international commission to work out common units of measures, weights and coins. The same year, he was elected a foreign member of the Royal Belgian Academy, a correspondent member to the Society of Sciences in Rotterdam (Netherlands), an honorary member of the Polytechnic Society in Leipzig (Germany), the Turin Royal Academy of Sciences (Italy), and the British Society for Promotion of Useful Arts. From 1865, after the death of Lenz, he was entrusted with management of the office of physics of the Imperial St. Petersburg Academy of Science. In 1872, he participated in Paris as a Russian delegate in the work of the International Commission on the choice of a metric system of units, defending its advantages, which contributed to establishment of a uniform system of weights and measures.

Boris Semyonovich Jacobi died on March 11 (on February 27, Julian date used in Russia at that time) 1874 from a heart attack at the age of 72, and was buried in St. Petersburg at the Smolensk Lutheran cemetery on Vasilyevsky Island.

He invented the first electric motor with direct rotation of the shaft, the collector-brush device of electric machines of direct current, galvanoplasty (electroplating), switch, electromagnetic and direct-printing telegraph devices. He was a member of many scientific institutions and of a jury of contests and exhibitions, conducted an examination of inventions, reviewed articles and participated in the scientific and public life of his time.

In 1889, the Russian Technical Society solemnly celebrated the 50th anniversary of the invention of galvanoplasty, «equated in its significance to the opening of printing», organized the Jubilee exhibition, where demonstrated a magnetoelectric mine explosion machine, telegraph device, electroformed products, documents, handwritten autobiography and other exhibits referred to the activities of the scientist.

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