кова» были основаны во многих странах мира. Автор, уступив право на использование своих изобретений владельцам французской «Генеральной компании электричества с патентами Яблочкова», как руководитель ее технического отдела довольствовался скромной долей от огромных прибылей фирмы, занимаясь исключительно научными исследованиями.

В феврале 1877 года электрическим светом был освещен магазин Лувр в Париже. Здесь 22 свечи заменили 200 газовых рожков. Затем светильники вспыхнули на площади перед зданием театра Шатлэ, а в мае ими облагородили одну из красивейших магистралей столицы Франции – Авеню Опера. Парижане, привыкшие к тусклому свету стеариновых свечей, плохому керосиновому и газовому освещению улиц и площадей, в начале сумерек толпами стекались полюбоваться гирляндами белых матовых шаров, установленных на высоких металлических опорах. Когда они разом вспыхивали ярким и приятным светом, публика приходила в восторг от «русского света». Это название по желанию Яблочкова выгравировали на оправе всех его фонарей.

Были освещены электрическим светом места для зрителей и беговая дорожка огромного парижского крытого ипподрома и Гаврская гавань порта в устье р. Сена. Неудобство гавани заключалось в том, что входить в нее морские суда могли только в момент приливов. Судам долго приходилось ждать, когда светлая часть суток совпадает с временем прилива. Яблочков сделал так, чтобы система электрического освещения включалась синхронно с ночным приливом и отключалась спустя час после его окончания.

(Окончание следует)

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BRIGHT BEAM IN FRONT OF A LOCOMOTIVE (FIRST PART)

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ABSTRACT

Pavel Yablochkov owns one of the most memorable pages in the history of world and domestic electrophysics. In XIX century he became a holder of inventions and patents recognized by the entire civilized world for «Yablochkov candle» and ways to use the effect of «light fragmentation» in the multi-element electric alternating current circuits. Thanks to him, «Russian light» provided a vibrant nightlife to major European cities, gave electric lighting to ships and trains, other public infrastructure facilities. And at the same time the author of the article highlights a dramatic fate of the scientist, early death, unfinished plans and projects. [First part of the article, to be continued].

ENGLISH SUMMARY

Background. *Russian electrical engineer, inventor of electric candle and electric power distribution system Pavel Yablochkov was born in September 1847 at the family estate of his father in Serdobsky district of Saratov province.*

Place and date of his birth in the historical sources are different. At that time there was a cholera epidemic in those districts. Families of landowners were leaving for safer places. Therefore, the child's name at birth was not recorded in the church register of births. Yablochkov family owned several estates in Serdobsky district in the villages Zhadovka and Petropavlovka, in a village Ivanovka and farm Baika. He was born in one of these settlements (now part of Rtishchevsky municipal district of Saratov region). Two dates of birth are indicated: 14 (2-old style) and 26 (14 – old style) of September.

Objective. *The objective of the author is to introduce a biography of a famous Russian electrical engineer Pavel Yablochkov.*

Methods. *The author uses historical method.*

Results.

Civil life of a combat engineer

Since childhood, a boy dealt with designing. When he was 12, he came up with an angle measuring device, which the peasants used for replotting and measurement of crop acres, and also produced a mechanical device propelled by the rotation of wheels of a cart and allowed to measure a distance covered by a cart. It was a prototype of modern speedometers.

He was taught to read and write at home by parents. For teaching special subjects teachers were hired. In 1858, after successful exams Pavel was enrolled in the second grade of Saratov province 1st boy's gymnasium, where children of nobility learn. In early winter of 1862 a pupil of the 5th grade was sent to a private preparatory boarding house because of difficult financial situation caused by the abolition of serfdom and in order to send him later to a military school

In the autumn of 1863, after passing the entrance exam, he was enlisted as a conductor (cadet of a company assigned to prepare combat engineers officers with secondary education) to Nicholas Military Engineering School (now Military Technical University) in St. Petersburg. Two years later, the young man graduated from this school, receiving a rank of second lieutenant -engineer, and became a junior officer of combat engineer battalion of engineer brigade, stationed in Kiev garrison fort. After serving more than a year, on his own initiative in relation to the health he

retired from military service, while receiving a next officer rank of lieutenant.

In civil life it was more difficult to make a living, and in January 1869 Yablochkov returned to his former place of military service. By that time he became interested in electrical engineering, which was a symbol of all new. Electromagnetic telegraph became widespread, developed by a domestic scientist P. L. Shilling and academician of the St. Petersburg Academy of Sciences B. S. Jacoby tested a vessel with an electric DC motor.

A young officer Yablochkov was sent to Officer galvanic classes in Kronstadt, to a single (at that time in Russia) school of military experts in the field of electrical engineering. There during 8 months he improved his theoretical and practical training on galvanic cells as well as on telegraphs and mining. Upon returning from his studies he was appointed a head of a special galvanic team while holding office as a battalion adjutant.

In the early autumn of 1872, Pavel left military service and got a place on Moscow-Kursk railway as a deputy chief of telegraph service and in the workshop he had an opportunity to conduct experiments in electrical engineering, to design and to test his ideas. Here he immediately made the first inventions: blackwriting telegraph and signal thermometer for temperature control in railway cars. In 1873, he was appointed a head of telegraph service.

Yablochkov attended meetings of the Division of Applied Physics, of the Society of Friends of Natural History, Anthropology and Ethnography at Moscow University and joined a team of electrical engineers-inventors and friends of electrical engineering. Scientists shared their experiences in the new at the time field scientific knowledge in electrolysis, electroplating, electric light sources, current regulators, and others.

After learning about the experiments of A. N. Lodygin on lighting with electric light bulbs using heating of a coal conductor, he also began his experiments. He took very thin coals, wrapped with fiber of mountain flax (asbestos) and put them between two conductors. The idea was that that coal did not burn and heated surrounding mountain flax. However he did not succeed in these experiments.

Working further with the first burners of Lodygin system, he found that the resistance of kaolin (white clay), magnesium oxide and many heat-proof bodies to electric current decreases when heated. And the force of the electric current flowing through a kaolin plate and heating it increases, and a red-hot plate begins to glow brightly. Yablochkov subsequently used this phenomenon for the manufacture of incandescent lamps (French privilege on April 17, 1877), which did not require air removal. These lamps illuminated cabins on three ships of Russian Navy in Kronstadt. He did not believe, however, in the possibility of their use and stopped working with them. The idea of incandescent light bulbs, he proposed, was the same as that in lamps of German physicist and chemist V. Nernst that was patented ten years later and had a great success.

Yablochkov believed that the main source of emitted light energy of the arc was a chemical reaction of coal with atmospheric oxygen. Arc lamps seemed more promising for him and he decided to deal with them. Nowadays it is found that by passing an electrical current through the gas, including through the air, its luminescence occurs.

Under seven winds

The phenomenon of an electric arc, later called voltaic, was opened in 1802 by St. Petersburg academician V. V. Petrov. Italian physicist A. Volta had no relevance to his discovery. The arc was a glowing electric discharge in the air between two coals horizontally arranged and closely spaced to each other. When burned, they shortened, the distance between them increased, the electrical discharge weakened and then stopped.

To avoid premature extinction of the arc near each candle a servant was staying, who while burning brought together the ends of coal rods, arranged towards each other. Later a regulator was created that when the current decreased moved one of coals in the horizontal plane and restored a required distance between them. And then quite complex devices emerged. They consisted of an electromagnet, which moved coal, counteracting springs, cargo and gear wheels, resembling clockwork. Complexity of a mechanism led to frequent failures. Furthermore, a mode of electric arc changed during fluctuations of electrical circuit supplying a lamp. With its growth speed of coal burning and distance between them grew rapidly and the arc extinguished. Therefore, a human intervention was required for burning of an electric arc.

In the spring of 1874 a governmental train with the Emperor Alexander II had to follow on Moscow-Kursk railway to Crimea. Administration of the railway in order to ensure traffic safety conceived to highlight a track for this train at night and requested the assistance of Yablochkov as an engineer, interested in electric lighting.

For the first time in the history of rail transport on the train a spotlight was installed with an arc lamp, which had a spring regulator of French physicist Jean Foucault. Arc lamp with Serren weight regulator gave a more plane light, but it did not work with declination and could not stand the shaking. Foucault regulator in the presence of greater reliability was very complex, operated with use of three springs and required continuous attention. During the lamp burning it had to maintain a constant arc length, bringing together the coals as they are burning. Upon the termination of the current movement the coals had to be brought together till contact, the arc could be formed at the time a new lamp switched on.

At night Yablochkov, sitting and standing in cold and strong wind on the forecourt of a locomotive, changed coals, repeatedly corrected by hand twisting the action of «automatic» regulator, since it was impossible to allow the light to go out at least for a short period of time. When a locomotive was changed, he had to drag a spotlight and wires from one locomotive to the other, to strengthen them and to connect the lamp with a bulky battery of Bunsen elements, which were in the baggage car, and make sure the wiring was in good condition.

The experience was a success, a bright light beam was running in front of a train, lighting roadbed, rails and sleepers. It was the first case in the world, when the railway line was illuminated over a large area when changing locomotives and actually functioning passenger train. But because of the inconvenience to the operation of the regulator of a voltaic arc, it became clear that a regulatory mechanism had to be simplified for the widespread use of electric lighting.

Candle minus regulator

To have more opportunities and time for research and inventive activities, Yablochkov in 1874 left the service at the telegraph office and opened in Moscow on modest personal funds a laboratory, and then organized a universal electrical workshop and store of physical instruments. Together with an experienced electrician N. G. Glukhov, landowner from Chernigov province, a retired captain of artillery, he was involved in the improvement of batteries of G. Plante, dynamos (power generators) of Z. T. Gramm and arc lamps.

At the Polytechnical Museum Yablochkov got acquainted with V. N. Chikolev during one conversation about the creation of a reliable regulator of an electric arc, based on a new differential principle. The idea was that the distance between coals was determined by the action of two electromagnets. The first one adjusted the distance, and the second – voltage fluctuations in a circuit, powering the arc. The young owner of a workshop produced for Chikolev, badly in need of an experimental basis, on his drawing one sample of a regulator with electric propulsion mechanism. He managed to create an electromagnet with a winding of copper strip, set on edge with respect to the core. Partners installed electric lighting of a large area with spotlights with arc lamps on the roof, but soon the police forbade them to do so.

In 1875, during one of experiments on the electrolysis of salt brine coals arranged in parallel and vertically immersed in the electrolytic bath accidentally touched when they approached each other. Between them a steadily burning electric arc broke out, illuminating walls of a workshop with a bright light. Yablochkov got an idea of improved arc lamp with vertical configuration of electrodes without regulator of distance between electrodes.

The financial situation of a workshop, meanwhile, worsened and in autumn 1875 Yablochkov, went in bankruptcy and did not get a financial support from relatives, liquidated workshop and store. To avoid falling into debtor's prison, he was forced to flee abroad from his creditors. Gendarmes, pursuing him to Odessa, arrived late and he could safely board the ship with the intent to escape from Russia to the United States to exhibit in Philadelphia his electromagnet. But money was only enough to get to Paris. There he picked the interest of a head of clockmakers, telegraph apparatus and accurate physical devices academician L. Breguet, who hired him and gave him an opportunity to carry out his own experiments, but with the condition to improve dynamo.

Yablochkov immediately took out a French patent № 110479 of November 29, 1875 on an electromagnet with a strip winding made of copper, lead or other metals, whose plane was perpendicular to the core of soft iron. French patent № 111535 of February 17, 1876, he applied to the electromagnet cast iron, which had an «advantage due to its residual magnetism». In the workshop of Breguet in the study of gypsum, lime and clay, he found out that in the voltaic arc at high current, they melt and steamed, releasing a colored flame, the color of which depended on the type of material being tested.

By early spring Yablochkov, after working a lot over the choice of an insulating material and methods of preparation of suitable coals, completed a development of the first model of an electric candle without a regulator and on the 23rd of March he received a French patent № 112024, containing the image of its original form and a brief description. It looked like an ordinary paraffin candle, was extremely simple and consisted of two vertical carbon rods separated by insulating seal of a certain thickness of wax, gypsum, kaolin or other material. Sealing part fastened coals together and kept always the same distance between them, isolated them from each other, preventing the occurrence of electric discharge and allowing voltaic arc to be formed at the upper ends. Each of the rods was cramped in a separate cleat of a candlestick.

Ignition of the electric arc was initially achieved using a thin piece of coal, which served as a fuse and was removed after the emergence of a voltaic arc. Then the same role was played by a fine coal bridge – igniter that, when current was flowing, first blushed, then burned and caused arcing. At the upper ends of electrodes arose a main electric discharge and the arc flame was shining brightly, gradually moving down. But ends of coals always overhung a little above the plate.

Electric candle was easier, more convenient and less expensive to operate than Lodygin carbon lamp, did not have a regulator of the distance between electrodes, mechanisms and springs, did not require any control and care. Soon, the inventor began to use as a fuse a strip of metal, showing weak conductivity, which was spread on the upper face of a body, insulating coals.

The candle burned an hour and a half. After this time, a new candle was inserted in the lamp. A lantern with several candles was also invented. 4–6 units were inserted in a glass bowl. A separate wire was connected with each candle, a return wire was common. By means of a hand commutator, they could light up one after another. Then the inventor came up with ways to automatically turn on new candles lighting through the use of ignition bridges of different electrical resistance, or the selection of an insulating mass.

When burning electric arc in the candle in a constant current, temperature of hot end of coal connected to the positive pole of the power source was much higher than that connected to the negative pole. For both coals to shorten equally Yablochkov adopted diameter of the positive end of the approximately 2-fold greater than the negative. He offered the use of alternating current instead of direct current, conventional at that time.

Many scientists had prejudice against AC. The famous American T. E. Edison, the owner of the most important patents for the use of DC compared AC underground cables with dynamite charges. However, the fact became undisputed: at AC upper ends of both coals of Yablochkov candle had the same temperature and burned with the same speed. For electric candles of such high conditions the Parisian firm of Gramm took to produce single-phase AC generators.

Russian inventor, the first in the world, initiated application of AC in practice, which had since been the basis of electricity in all sectors of industry.

Russian light on Avenue Opera

Techniques to include multiple light sources in the circuit fed by a single source of electrical energy, remained unknown at that time. Each arc lamp was supplied by a separate generator. Yablochkov candles were applied so only for military purposes, in lighthouses, for illumination of some places in the cities and the production of significant construction works. For example, we can recall the lighting in 1846 of three lines with one arc lamp mounted on the tower of the Admiralty in St. Petersburg, and illuminations in 1856 on Levofortovsky Square in Moscow, arranged by A. I. Shpakovsky and K. I. Konstantinov for the coronation of Tsar Alexander II.

To enable a widespread use of electric current for lightning, it was necessary to find a way for «light fragmentation» from a single large generator. Yablochkov solved this problem differently.

In April, 1876 in London, an International Trade Fair of physical devices was opened, on which he held a public demonstration of his invention. At low metal pedestals were four candles wrapped in mountain flax and installed at a large distance from each other. Wires from the electric generator that was in another room were taken to lamps. After energization, the vast hall was brightly lit with slightly bluish electric light. The success exceeded all expectations. London became the site of the first public demonstration of a new light source. In

English, French, German and other international press reports appeared under a very simple title «Russian light», «Northern light».

On the 21st April 1876 Yablochkov after a report on electromagnet with a lateral winding, which he invented in Russia, was elected as a full member of the French Physical Society. After returning from London, his partner was a French engineer L. Deneyruz, who placed his workshops, manufacturing diving equipment, at the inventor's disposal. With his participation on the advice of Breguet a joint-stock company «Society for the Study of electric light on the methods of Yablochkov» was established.

In Yablochkov lighting system current was first distributed between groups of series-connected electric candles to the stator winding of AC generator. However, for each group of candles two wires were necessary from the start to the end of winding. Such an amount of feed wires complicated electrical network. Later Yablochkov offered to include in basic electrical circuit of a generator consistently primary windings of several induction coils and to power circuits with series candles with currents induced in the secondary windings of the same coils. These coils were wound on an open magnetic core.

That is for the first time in the world Yablochkov applied the principle of a transformer with open magnetic system for practical purposes – an independent power supply of its electric candles. November 30, 1976, the date of receipt of the French patent № 115793, is a birthday of a device, later called transformer, through which it became possible to convert alternating voltage and current. Two years later, the scientist took out German patent № 1630 and Russian privilege (together with the privilege of a candle) on the connection diagram of inducing wiring of induction coils in the circuit of current generator and lamps in the circuit of windings, in which the currents are induced. Through the use of induction coils lighting equipment with candles became much cheaper, and operating costs decreased.

In 1882, an employee of professor A. G. Stoletov, laboratory assistant of physics laboratory at Moscow University I. F. Usagin proved that induction coils, used by Yablochkov, were real transformers. They may be useful not only for illumination but also for power supply of a single-phase AC motor and heating of a platinum wire i. e. to convert electric energy of alternating voltage into mechanical and thermal.

Gradually, the transformer had been improved. Closed stacked magnetic circuit of electrotechnical steel, natural oil and forced cooling etc. appeared. In 1889 Russian electrical engineer M. O. Dolivo-Dobrovolsky invented a three-phase transformer and AC finally defeated DC.

Another mode of «light fragmentation», proposed by Yablochkov was to use the series-connected capacitors. Wherein the second pole of the generator, the second coating of the last capacitor and free clamps of candles were grounded. During the experiments it was revealed that in the presence of induction coils in circuits sum of currents from coatings of capacitors falling to the ground, was 2 times greater than the amperage produced by the generator. The electric arc and the length of hot coals also increased several times. He decided that the source of increased light output was natural atmospheric electricity, which was stored in capacitors. Today it is known that the electrical AC circuits in case of parallel connection of inductance and capacitance arises resonance mode of currents and in the unbranched part of the circuit the total current can be several times less than its components in parallel branches. In fact, the inventor made a resonant transformer. Transformer and capacitor connection circuits of burners, developed by him, were the prototype of the modern parallel connection of electrical receivers to the electrical network.

Electrical candles came into the market in 1876 and began to find a ready sale in large volumes. For example, the Breguet firm produced daily more than 8000 electrical candles. The companies for commercial operation of «Yablochkov candle» were established in many countries around the world. Author, conceding a right to use his inventions to the owners of French «General Electric Company with Yablochkov patents' as the head of its technical department was satisfied with a modest share of huge profits of the company, engaged exclusively in research.

In February 1877 store the Louvre in Paris was lit with electric light. 22 candles were replaced with 200 gas jets. Then the lights flashed on the square in front of the theater Shatle, and in May they ennobled one of the most beautiful roads of the capital of France – Avenue Opera. Parisians, accustomed to the dim light of stearinic candles, poor kerosene and gas lighting of streets and squares, in the early twilight came in flocks to admire the garlands of white matte balls mounted on tall metal poles. When they once flashed with bright and pleasant light, the audience became enthusiastic over «Russian light». This name, at the wish of Yablochkov, was engraved on the rim of all his lanterns.

Seats for spectators and a race track of a huge Parisian indoor hippodrome and Le Havre harbor of the port at the mouth of Seine were illuminated by electric light. The disadvantage of the harbor was the fact that seagoing vessels could sail in the harbor only at the time of tide rise. Ships had to wait a long time, when a light day part coincided with the time of high tide. Yablochkov made so that the system of electric lighting switched on synchronously with the night tide and turned off an hour after its completion.

[To be continued]

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