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Leo Graetz bridge rectifier or Charles Pollak bridge rectifier ?

Abstract. Biographies of two famous electrotechnicians: Charles Pollak and Leo Graetz, living at the turn of the 19th and 20th centuries were presented. They both independently participated in the development of the first electrolytic bridge rectifier. The priority of Charles Pollak in the invention of the system of the first bridge rectifier has been proved. Hence, it follows that the bridge rectifier, commonly used in electrical engineering technology should not be called the Graetz rectifier, but should be called Pollak rectifier.

Streszczenie. Przedstawiono biografie dwóch sławnych elektrotechników: Karola Pollaka i Leo Graetza, żyjących na przełomie XIX i XX wieku. Te dwie osoby niezależnie uczestniczyły w opracowaniu pierwszego elektrolitycznego prostownika mostkowego. Wykazano niepodważalne pierwszeństwo Karola Pollaka w wynalezieniu systemu pierwszego prostownika mostkowego. Stąd wynika, że powszechnie stosowany w inżynierii elektrycznej prostownik mostkowy, nie powinien być nazywany prostownikiem Graetza, ale powinien być nazywany prostownikiem Pollaka. (*Prostownik mostkowy Leo Graetza, czy prostownik mostkowy Karola Pollaka ?*).

Keywords: bridge rectifier, Charles Pollak, Leo Graetz.

Słowa kluczowe: prostownik mostkowy, Karol Pollak, Leo Graetz.

Introduction

A rectifier is an electrical system, whose task is to convert alternating voltage into rectified voltage, i.e. into unidirectional voltage with a constant average value. Rectifiers are widely used as electrical devices for charging accumulators and electrochemical batteries, for powering DC drive motors and excitation circuits of electric machines, in DC traction systems, in power supplies for RTV receivers, audio equipment, household appliances, mobile telephony, measurement systems and many other devices.

Rectifiers belong to electrical systems with a long history of use. There were two famous electricians in the world: Leo Graetz and Charles Pollak, who practically at the same time, independently invented and tested the first bridge rectifier systems.

Jerzy Ignacy Skowroński (1901-1986) was a distinguished professor in electrical engineering at Wrocław University of Science and Technology. In 1954 he published in the Polish journal *Problemy*, a very short notice (about half of page) entitled: *Graetz or Pollak* [1]. In this notice, Prof. Skowroński as the first person from the scientific community, emphasized the priority of Charles Pollak in the invention of the system of the first bridge rectifier. He also mentioned about the need to change the name of the bridge rectifier from the used name: Graetz bridge to the new name: Pollak bridge. In order to commemorate Prof. Skowroński, the Association of Polish Electrical Engineers (SEP) announced the year 2021 as the Year of Prof. Jerzy Ignacy Skowroński. One of the purposes of this article is the recognition of the memory of professor Skowroński and the continuation of his ideas.

In this article, the authors on the basis of confirmed historical facts, showed the unquestionable priority of Charles Pollak in the development of the first electrolytic bridge rectifier. In addition, this article should be a reminder of the forgotten huge contribution of the Polish inventor Charles Pollak in the development of the first bridge rectifiers.

Charles Pollak

The description of Karol Pollak's life and his achievements was based on the data contained in the documents and in the literature [2-7].

Franciszek Karol Pollak (photo in Fig.1) was born on November 15, 1859 in the Sanok city in Austrian Galicia. He

was Polish, but after the partitions of Poland, the city of his birth was under the Austrian government. His father, Karol Pollak, was a printer, and a well-known bookseller and a publisher. Franciszek Karol Pollak adopted the use of his father's name, Karol as his first name, which he also usually used in English form, as Charles.

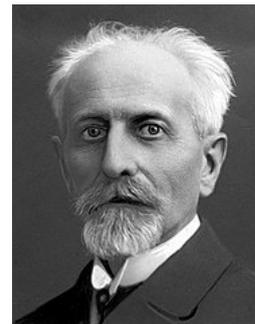


Fig.1. Photo of Charles Pollak [3]

Charles Pollak studied successively in Sanok, in Stryj and in Lviv. He already in his youth showed great skills in electrotechnics. In 1883 he started working in London in the laboratory of British company "The Patent Utilization Co.", dealing with the implementation of various patent solutions. He was quickly appointed as the head of the laboratory in this company. During this time, he constructed and patented several of his first inventions: a microphone, an automatic connector for electric lamps, a printing machine in several colors and others.

In 1885 he started studying electrotechnics at the Royal Technical University in Berlin-Charlottenburg. At the same time, he continued to work on a new series of his inventions. The special achievements of this period include inventions in the field of galvanic cells. Charles Pollak built also a model of a new electric tram. In 1886, at the age of 27, he became the director of an enterprise operating electric trams built according to his ideas. In the meantime, he conducted research in the laboratories of the Sorbonne in Paris.

The most significant and internationally recognized field of research and invention activity of Charles Pollak were research and construction works concerning the development of new types of electrochemical batteries,

mechanical rectifiers and electrolytic rectifiers as well as capacitors with large capacities. He presented a developed electrochemical battery with an original structure with rolled plates to the French Academy of Sciences in Paris. He then became director of the battery factory in Paris. Due to the high interest in battery production, in Frankfurt am Main, Germany, he founded the battery factory (Frankfurter Akkumulatorenwerke & Co.), in which he performed management functions. The similar factory was built by this company in Liessing, Austria. The battery production license held by Charles Pollak was also sold to a factory in Switzerland and in France.

In 1891 in Frankfurt am Main, Charles Pollak participated in the commissioning of an electric tram powered by batteries with quick charging of batteries at the final stations. In 1894, the Pollak company participated in the introduction of buffer batteries to trams and other transport devices.

Charles Pollak is known as the author of many patented technical inventions. He was the author of the patent for a lead-acid battery. In 1892, in Germany, he patented a mechanical rotating rectifier. In 1895, he built the first high-power mechanical rectifier in Zurich. He was the author of several patents concerning the construction of electrolytic rectifiers (British patent - 1896, German patent - 1897 and American patent - 1901). In 1896, he patented a large-capacity electrolytic capacitor.

The inventions of Charles Pollak were presented at many world technical exhibitions and congresses. Among others, at the world exhibition in Paris in 1900, he received a gold medal for the construction of a battery. At the exhibition in Lviv in 1902, he received a diploma of recognition and a silver medal for his inventions and application works.

In 1899, Charles Pollak resigned from direct management of the factory in Germany. He went to France and set up his own research laboratory there. In this laboratory, he conducted research works related to new and already developed inventions. He worked on new issues, often far removed from electrical engineering. At the exhibition in Nice, he received a medal for an airplane model. He patented a new medical procedure and conducted also research in other fields of technology. During World War I, he cooperated with the French military authorities on improving military equipment.

After Poland regained independence (November 1918), Charles Pollak for patriotic reasons returned in 1922 to his homeland, Poland. Despite his older age (63), he founded in 1923 the battery factory in Biała (now part of the city of Bielsko-Biała). He became the first director of this factory, which adopted the name Polish Accumulator Company S.A..

Charles Pollak was the author of numerous inventions in various fields of technology. He obtained as many as 98 patents. For these reasons, he was also called the Polish Edison. In 1924, for his inventive achievements, he was awarded honorary academic degree of Doctor Honoris Causa of Warsaw University of Technology, Poland.

Charles Pollak died on December 17, 1928 in Biała and was buried there.

Leo Graetz

The description of Leo Graetz's life and his achievements was based on the data contained in the documents and in the literature [8-12].

Leo Graetz (photo in Fig.2) was born on September 26, 1856 in Breslau, to a Jewish family. His father, Heinrich Graetz, was a famous professor of history at the University

of Breslau, which until 1911 was called Universitatis Litterrarum Vratislaviensis.

Leo Graetz studied mathematics and physics at the universities of Breslau, Berlin and Strasbourg. In 1879 he obtained a doctorate at the University of Breslau. From 1881 he worked as a researcher at the University of Strasbourg. Immediately after starting work in Strasbourg, he published his habilitation thesis entitled: "On thermal conductivity of gases depending on temperature". In 1882 he moved to the University of Munich, where in 1893 he was appointed associate professor and in 1908 full professor of physics.



Fig.2. Photo of Leo Graetz [10]

Leo Graetz's scientific work was characterized by a wide range of interests. The subjects of his research works included the theory of heat conduction and radiation, the problems of friction and elasticity, the problems of electrical engineering, studies of electromagnetic waves as well as x-ray and cathode radiation.

A very large part in the professional work of Leo Graetz at the university played also his teaching activities. He gave specialist lectures in physics and in electrical engineering. He also conducted popularizing lectures for people representing other fields of science, including medicine.

Leo Graetz has a great scientific output as the author of numerous textbooks and scientific books. The subjects of these books mainly concerned selected areas of physics and electrical engineering. These issues were then particularly intensively developed fields of science and technology. Books by Leo Graetz on electrical engineering aroused great interest among readers. Many books had even several editions (one of the books had as many as 23 editions), many books were also translated into foreign languages.

Leo Graetz retired in 1928, at the age of 72. In the German Lexicon of Electrical Engineers and in other sources [10] it is only stated that Leo Graetz died on November 12, 1941 in Munich. In the Polish historical album [12] it is mentioned, that Leo Graetz, because of his Jewish nationality, was murdered despite his old age in the Dachau concentration camp (Dachau is about 20 km from Munich).

Graetz bridge rectifier or Pollak bridge rectifier

The most commonly used rectifiers are composed of rectifying valves connected in an appropriate bridge system. Commonly used bridge rectifiers are executed as 1-phase or 3-phase systems. The first applied rectifiers were mechanical commutator rectifiers, working with a mechanical principle of operation. They were developed at the end of the 19th century. The basic design and principle of operation of a mechanical rectifier used for charging an electrochemical battery is shown in Fig.3.

In Fig.3, the battery *B* which should be charged with rectified voltage is connected to the middle terminal of the transformer secondary winding and to the terminal of the mechanical switch *P*. When the transformer *T* is supplied with alternating voltage, the terminals *a* and *b* take alternately positive and negative polarity. When terminal *a* is positive, switch *P* is set up, and when terminal *b* is positive, switch *P* is set down. The output voltage from the rectifier is thus rectified and has the form of a two-pulse voltage waveform with invariable polarity. For this aim the position of the switch *P* must be synchronized with the waveform of the supplying alternating voltage.

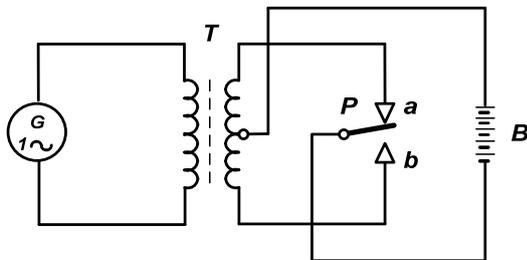


Fig.3. Basic elements and principle of operation of a mechanical rectifier: *G* - supplying alternating voltage source; *T* - transformer with tap in the secondary winding; *P* - mechanical switch; *B* - charged electrochemical battery

This type of mechanical rectifier could be used to power, for example, arc lamps, but unfortunately not to charge the batteries or accumulators. It is caused by the fact, that the mechanical rectifier does not have any valve elements and the rectifying action is achieved only by appropriate switching of the receiver to the supply circuit. Since the rectified voltage is made up of supply alternating voltage segments, the charging process occurs only in the time intervals in which the instantaneous rectified voltage is greater than the electromotive force of the battery. In the remaining time intervals, in which the instantaneous rectified voltage is lower than the electromotive force of the battery, there is a flow of reverse current from the battery to the AC voltage source and there is the battery discharge process.

For these reasons, a more complex mechanical switch was implemented in the mechanical rectifiers used to charge the batteries. The operation of this type of mechanical rectifier was presented by Charles Pollak in his article [5]. The complex mechanical switch caused the battery to be connected to the AC voltage source only in those time intervals in which the instantaneous rectified voltage was greater than the electromotive force of the battery. The mechanical switch used for these purposes was designed in the form of a rotating commutator switch, driven by a low power synchronous motor. The commutator consisted of an appropriate number of conductive metal sections and adjoining extensible rows of brushes, allowing the rectifier conductive intervals to be adjusted.

Charles Pollak built the first high-power mechanical rectifier in Zurich in 1895. In the battery factory in Frankfurt, four this type of mechanical rectifiers with a rotating switch were used. Each rectifier was provided an output voltage of 65V and a current of 400A. Rectifiers were used in the factory around the clock and worked continuously for up to 4 years. Charles Pollak modernized the construction of the mechanical rectifier by replacing the rotating commutator switch with a suitable mechanical vibrating system [5].

In order to eliminate numerous disadvantages of a mechanical rectifiers, Charles Polak developed an electrolytic rectifier in 1895. Unlike a mechanical rectifier,

the electrolytic rectifier was a static rectifier with no rotating parts. In addition, the electrolytic rectifier was composed of elements with a valve operation, i.e. electrically conductive in one direction only, which is also a basic property of semiconductor rectifiers used today.

The basic element of the electrolytic rectifier was a cell filled with an ammonium salt solution in which two metal electrodes were placed: one made of aluminum (Al) and the other made of lead (Pb). Such a cell has good electric current conductivity only for the current flow from the lead electrode to the aluminum electrode. In the case of the reverse flow of electric current, the cell has a blocking effect (has high resistance). A complete electrolytic rectifier circuit can be composed of two cells and a transformer with a tap in the secondary winding, or as a more preferable bridge circuit of four properly connected cells.

In the bridge circuits of the electrolytic rectifiers at a certain value and polarity of the alternating supply voltage, two cells are always operated with forward bias, and the other two cells are reverse biased. When the polarity of the supply voltage is changed, the polarity and the direction of conduction of the cells are reverse changed. As a result, in the rectified circuit of the rectifier, current flows always in only one direction. The bridge rectifier can be supplied from an ordinary transformer, without the need to lead the tap from the secondary winding.

Charles Pollak was the first to develop a bridge rectifier system with an electrolytic effect. The electrolytic rectifier was patent pending on December 19, 1895, and the patent was granted on December 5, 1896 (British Patent No. 24398 [13] and German Patent DRP 96564 [14]). The American patent for electrolytic rectifier was patent pending on March 7, 1899 and the patent was granted on April 30, 1901 (American Patent No. 672 913 [15]).

In the Fig.4 the scheme of bridge circuit of a 1-phase electrolytic rectifier is presented. This scheme is one of the many electrolytic rectifier systems included in the British patent specification obtained by Charles Pollak in 1896 [13].

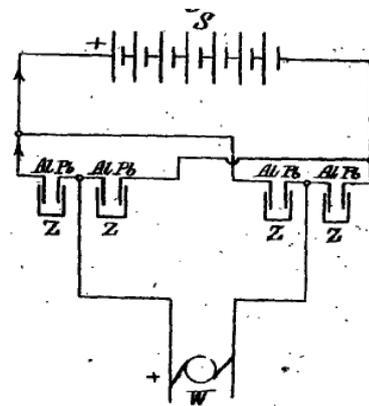


Fig.4. The bridge circuit of a 1-phase electrolytic rectifier included in the British patent specification obtained by Charles Pollak [13]: *W* - alternating voltage source; *Z* - electrolytic cell with Al and Pb electrodes; *S* - accumulator battery

Fig. 5 shows the topology of a 1-phase electrolytic bridge rectifier included in the description of the American patent obtained by Charles Pollak in 1901 [15].

The description of the rectifier systems included in the Pollak patent applications was also published by Charles Pollak in German in the article entitled: "*Ein neues Gleichrichter-Verfahren (A new rectifier method)*", printed in the *Elektrotechnische Zeitschrift (ETZ)* journal, No 25 of June 24, 1897. A note from the editorial office was added in journal to this publication. The editorial office reported in

that note, that Prof. Leo Graetz from Munich University sent the letter to the journal with the message, that for several years he had also been conducting research on electrolytic bridge rectifiers with a similar system and principle of operation. But the professor admitted, that the results of his research had not yet been published and patented.

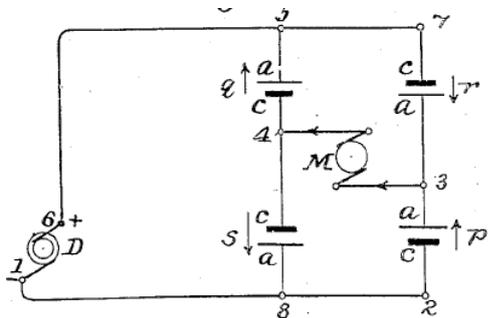


Fig. 5. The bridge circuit of a 1-phase electrolytic rectifier, included in the description of the American patent obtained by Charles Pollak [15]: D - alternating voltage source; M - receiver powered by rectified voltage; p, q, r, s - the cells of the electrolytic rectifier (marked with the symbols used for electrochemical cells)

Directly before the publication of Charles Pollak article, Prof. Leo Graetz on May 1, 1897, at the meeting of the Mathematical and Physical Scientific Society gave a lecture in German on the electrolytic rectifier system he had developed. The delivered lecture was entitled in German: "Electrochemisches Verfahren, um Wechselströme in Gleichströme zu verwandeln (Electrochemical method of changing alternating currents into direct currents)". Immediately after this meeting, this lecture was published in the scientific reports of this society, entitled: *Sitzungsberichte der Mathematisch-Physikalischen Classe der Königlich Bayerischen Akademie der Wissenschaften zu München (Transactions of the Mathematical-Physical Classes of the Royal Bavarian Academy of Sciences in Munich)*, [16]. Fig. 4 shows the topological system of the electrolytic bridge rectifier developed by prof. Leo Graetz, which was the subject of the given lecture and was included in his article [16].

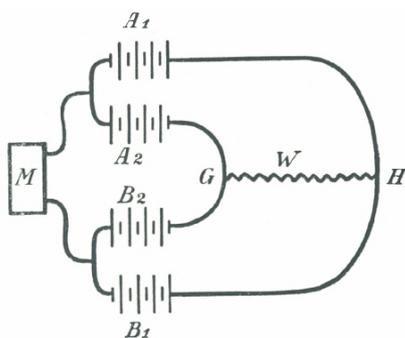


Fig.6. Bridge circuit of a 1-phase electrolytic rectifier developed by prof. Leo Graetz [16]: M - alternating voltage source; W - receiver powered by rectified voltage; A1, A2, B1, B2 - electrolytic rectifier cells

Shortly after that, the article of Prof. Leo Graetz, entitled: "Electrochemisches Verfahren, um Wechselströme in Gleichströme zu verwandeln (Electrochemical method of changing alternating currents into direct currents)" was published in German in journal *Elektrotechnische Zeitschrift (ETZ)*, No 29 of July 22, 1897 [17]. This publication presented a rectifier bridge circuit with a topology that was practically identical to the rectifier topology previously

presented in the patent descriptions of Charles Pollak. The ETZ editors published a note in this journal with a comment that the described rectifier system was developed independently by two researchers: Charles Pollak and Leo Graetz. Prof. L. Graetz added a comment to this note, in which he stated that the rectifier described in his publication had already been tested by him four years ago. However, he did not publish their results as he considered them unsatisfactory.

In addition to the above mentioned article in ETZ, prof. Leo Graetz published at the same time two other articles with the same or slightly changed titles, presenting his bridge rectifier system [18, 19]:

- 1) Graetz, Leo (20 July 1897). "Über ein Elektrochemisches Verfahren, um Wechselströme in Gleichströme zu verwandeln". *Zeitschrift fuer Elektrochemie*, Vol.4, Iss.2 [18].
- 2) Graetz, Leo (1897). "Electrochemisches Verfahren, um Wechselströme in Gleichströme zu verwandeln". *Annalen der Physik und Chemie*. 10, 62 [19].

On the basis of the presented considerations, it can be stated, that the patent descriptions and the publication of Charles Pollak and the above mentioned articles by Leo Graetz refer to the same type of single-phase bridge rectifier system and to the rectifier with the same principle of operation - the electrolytic rectifier. From the formal and legal point of view, the matter of priority and rights to an invention seem obvious. Prof. Leo Graetz published the idea of his solution about 1.5 years after the patent was filed by Charles Pollak and about 0.5 year after Charles Pollak obtained the patent. Hence the explanations given by Prof. L. Graetz are irrelevant. For these reasons, the rectifier bridge circuit should be named as Pollak rectifier bridge, but not Graetz rectifier bridge. But the reality presented in this article is practically unknown to most people involved in electrical engineering.

Summary

In the history of technology similar solutions were sometimes proposed by several inventors. Doliwo-Dobrowolski constructed the first three-phase alternating current generator with a rotating field in 1888, several months before Nikola Tesla. In 1900, Marconi was a few days ahead of Tesla by patenting a radio invention.

Despite the unquestionable recognition of the priority of Charles Pollak as the author of the invention of the bridge rectifier, in the technical and scientific literature, the bridge rectifier system is commonly called the Graetz system. This is the case from the initial years of using bridge rectifiers until the present years.

This situation was badly perceived by Charles Pollak still during his lifetime. In 1925, that is three years before his death, Charles Pollak published an article in Polish journal *Przegląd Elektrotechniczny* [5]. In this article, Charles Pollak reviewed his life inventive activity in the field of mechanical rectifiers and electrolytic rectifiers. In this article, Charles Pollak additionally criticized the publication in the military journal "Saper and Military Engineer", in which the invention of the electrolytic rectifier was not assigned to the real author - Charles Pollak, but to the French author - A. Nodon and the German author - L. Graetz. Although this military journal was not scientifically significant, this fact pointed to a certain distraction from Charles Pollak due to the lack of appreciation of his inventive contribution in the field of rectifiers.

In the known German coursebook by E. Arnold: *Wechselstromtechnik*, published in Berlin in 1910 (vol. I, p. 499), the authorship of the invention of the electrolytic bridge rectifier is attributed to both inventors: Charles

Pollak and Leo Graetz [1]. In some textbooks on electrical engineering, electrical machines and rectifiers published in Poland in the pre-war period Charles Pollak is mentioned as the author of the electrolytic rectifier, but he is not mentioned as the inventor of the mechanical rectifier.

The state presented in the textbooks on electrical engineering and power electronics published at the present time in the world literature and in Polish literature should be assessed very critically. The name of the Polish inventor, Charles Pollak, does not appear in these textbooks, while the name of Leo Graetz is often mentioned in the chapters dealing with rectifier systems.

Nowadays, more and more often the appropriate internet resources are treated as the sources of the knowledge. In this case, it should be stated that some internet sources try to present the real state of knowledge objectively. In the Polish-language version of the Wikipedia internet portal, after entering the wording: "Graetz Bridge", you get a fairly extensive description of the design and operation of this rectifier circuit. The website of this portal also includes the following sentence: "Although the bridge rectifier was invented by the Polish constructor Charles Pollak, the structure of the bridge was named after the German physicist Leo Graetz, born in Wrocław in 1856." A similar sentence is posted on the equivalent page of this portal in English, Russian, Spanish and other versions. Such information is not included in the German version of this portal. The page of German portal only states that Leo Graetz is the source of the name Graetz rectifier.

However, a completely different situation applies to the contents of other publicly available online educational portals, lexicons, guides and other similar websites. You cannot find information about the Polish inventor anywhere here. When presenting descriptions and diagrams of rectifier circuits, the following expression is commonly used: Graetz circuit or Graetz bridge. A similar situation occurs even when using application materials related to various computing and simulation packages of rectifiers.

Bridge rectifiers are manufactured, sold in large numbers and presented in numerous company catalogs, commercial offers and leaflets. Based on the review of these materials, it can be concluded that the bridge rectifiers are commonly offered under the trade name Graetz bridge or Graetz rectifier. Due to the common use of bridge rectifiers for various types of power supply systems, it seems impossible to change this situation.

In conclusion, it should be stated that the common use of the name Graetz bridge is very unfair due to the real priority of the invention of the rectifier bridge held by Charles Pollak. For these reasons, it is advisable to take appropriate actions and information actions in order to change this state. Charles Pollak, due to his involvement in research and production works related to the development of technology, deserves a different treatment. The year 2028 will be the 100th anniversary of Charles Pollak's death. Popularization of the inventive and organizational achievements as well as other merits of Charles Pollak would be a certain payment of our debt to this meritorious person. In our times, the life of Charles Pollak should be an example of a way to gain high qualifications and to implement your innovative solutions in industry.

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