Karlsruhe Institute of Technology

Elektrotechnisches Institut (ETI)

Elektrotechnisches Institut

The invention of the electric motor 1800-1854

A short history of electric motors - Part 1

Univ.-Prof. Dr.-Ing. Martin Doppelbauer

Summary

With the invention of the battery (Allessandro Volta, 1800), the generation of a magnetic field from electric current (Hans Christian Oersted, 1820) and the electromagnet (William Sturgeon, 1825) the foundation for building electric motors was laid. At that time it was still open whether electric motors should be rotating or reciprocating machines, i.e. simulate a plunger rod of a steam engine.

Worldwide, many inventors worked in parallel on this task - it was a "fashion" problem. New phenomena were discovered almost daily. Inventions in the field of electrical science and its applications were in the air.

Often the inventors knew nothing about each other and developed similar solutions independently. National histories are shaped accordingly until present day. The following is an attempt to provide a comprehensive and neutral picture.

The first rotating device driven by electromagnetism was built by the Englishman Peter Barlow in 1822 (Barlow's Wheel).

After many other more or less successful attempts with relatively weak rotating and reciprocating apparatus the German-speaking Prussian Moritz Jacobi created the **first real rotating electric motor** in May 1834 that actually developed a remarkable mechanical output power. His motor set a world record which was improved only four years later in September 1838 by Jacobi himself. His second motor was powerful enough to drive a boat with 14 people across a wide river. It was not until 1839/40 that other developers worldwide managed to build motors of similar and later also of higher performance.

Already in 1833 the German Heinrich Friedrich Emil Lenz published an article about the law of reciprocity of the magneto-electric and electromagnetic phenomena, i.e. the **reversibility of electric generator and motor**. In 1838 he provided a detailed description of his experiments with a Pixii-generator that he operated as a motor.

In 1835 the two Dutchmen Sibrandus Stratingh and Christopher Becker built an electric motor that powered a small model car. This is the first known practical application of an electric motor. In February 1837 the first patent for an electric motor was granted to the US-american Thomas Davenport.

However, all the early developments by Jacobi, Stratingh, Davenport and others eventually did not lead to the electric motors we know today.

The **DC motor** was not created from these engines, but rather from the development of power generators (dynamometers). The foundations were laid by William Ritchie and Hippolyte Pixii in 1832 with the invention of the commutator and, most importantly, by Werner Siemens in 1856 with the Double-T-anchor and by his chief engineer, Friedrich Hefner-Alteneck, in 1872 with the drum armature. DC motors still have a dominant market position today in the low power (below 1 kW) and low voltage (below 60 V) range.

The years 1885 until 1889 saw the invention of the **three-phase electric power system** which is the basis for modern electrical power transmission and advanced electric motors. A single inventor for the three-phase power system can not be named. There are several more or less well known names who were all deeply involved in the inventions (Bradley, Dolivo-Dobrowolsky, Ferraris, Haselwander, Tesla and Wenström).

Today, the three-phase **synchronous motor** is used mostly in highly dynamic applications (for example in robots) and in electric cars. It was developed first by Friedrich August Haselwander in 1887.

The highly successful **three-phase cage induction motor** was built first by Michael Dolivo-Dobrowolsky in 1889. Today, this is the most frequently produced machine in the power range of 1 kW and above.

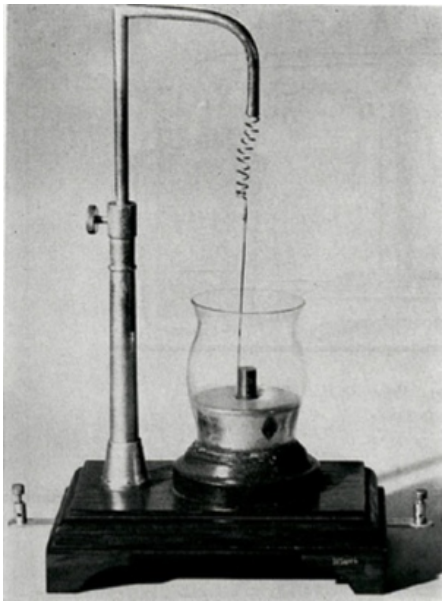
Timetable 1800 - 1834: First experiments with electromagnetical devices

1800 For the first time Allessandro **Volta** (Italian) produces a continuous electrical power (as opposed to a spark or static electricity) from a stack of silver and zinc plates.

1820 Hans Christian **Oersted** (Denish) finds the generation of a magnetic field by electric currents by observation of the deflection of a compass needle. This was the first time a mechanical movement was caused by an electric current.

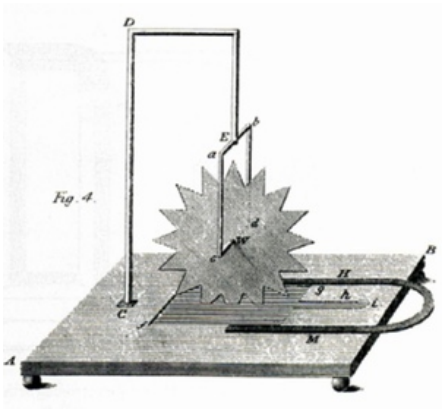
1820 André-Marie **Ampère** (French) invents the cylindric coil (solenoid).

1821 Michael **Faraday** (British) creates two experiments for the demonstration of electromagnetic rotation. A vertically suspended wire moves in a circular orbit around a magnet.



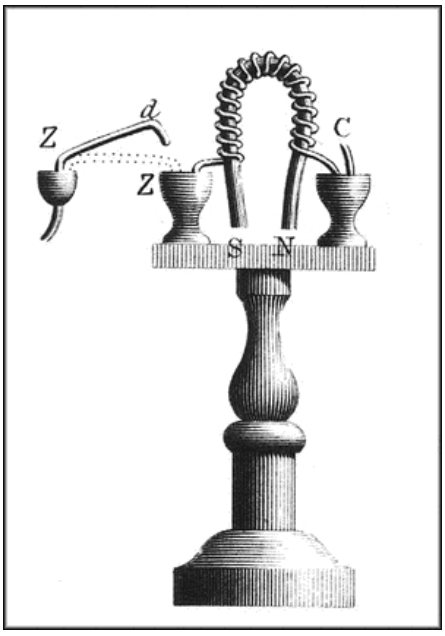
Rotating wire by Faraday, 1821
Photo courtesy of Division of Work & Industry, National Museum of American History, Smithsonian Institution

1822 Peter **Barlow** (British) invents a spinning wheel (Barlow's wheel = unipolar machine).



Barlow's wheel, 1822
Philosophical Magazine, 1822, vol. 59

1825-1826 William **Sturgeon** (British) invents the **electromagnet**, a coil of wires with an iron core to enhance the magnetic field.



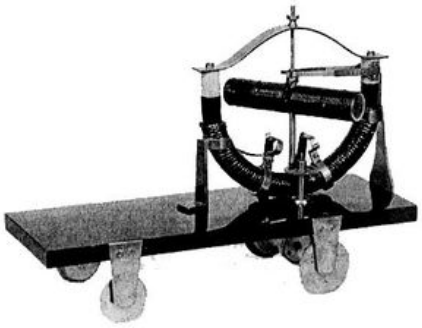
First electromagnet by Sturgeon, 1825
Transactions of the Society for the Encouragement of the Arts, Manufacturers and Commerce, 1824, vol. 43, pl. 3

1827-1828 Istvan (Ányos) **Jedlik** (Hungarian) invents the first rotary machine with electromagnets and a commutator.
However, Jedlik publicly reported his invention only decades later and the actual invention date is uncertain.

Still many Hungarians believe Jedlik has invented the electric motors. A functional model of his apparatus is displayed at the art museum in Budapest.

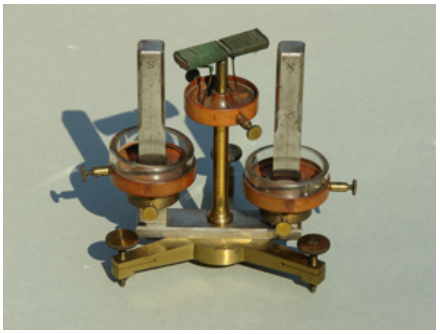
Although this could actually be the first electric motor it has to be realized that this device had no influence on further development of electric machines. Jedlik's invention remained hidden for a long time and was not pursued by the inventor. The field of electrical engineering owes Jedlik nothing.

Rotary device by Jedlik, 1827/28
Photo: Wikipedia



Jedlik's electric car, 1827/28
Photo: Wikipedia

before 1830 Johann Michael Ekling, mechanic in Vienna, builds a motor according to the plans and ideas of Prof. Andreas von Baumgartner (Austrian physicist; since 1823 Professor of Physics and Applied Mathematics in Vienna). This apparatus was aquired in 1830 by the University of Innsbruck for the price of 50 fl c.m. The year of construction is unknown, but must have been before 1830 as the date of purchase is proven.

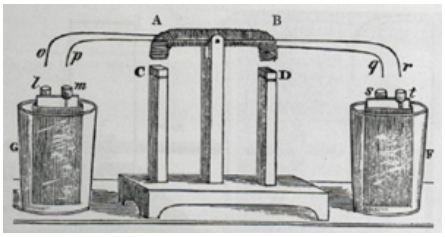


Baumgartner's Engine, built by Ekling, before 1830
Photo courtesy of the University of Innsbruck, Museum of Experimental Physics, Ao. Univ. Prof. Mag. Dr. Armin Denoth.

1831 Michael **Faraday** (British) discovers and investigates electromagnetic induction, i.e. the generation of an electric current due to a varying magnetic field (the reversal of Oersted's discovery). Faraday lays the foundation for the development of the electric generator.

1831 Joseph **Henry** (US-American) finds the induction law independent of Faraday and builds a small magnetic rocker. He describes it as a "philosophical toy".

In an article for the english *Philosophical Magazine,* in 1838 Englishman F. Watkins acknowledges Henry's device in detail and calls it the first electric motor ever known. This view extends to present day mainly in British literature.

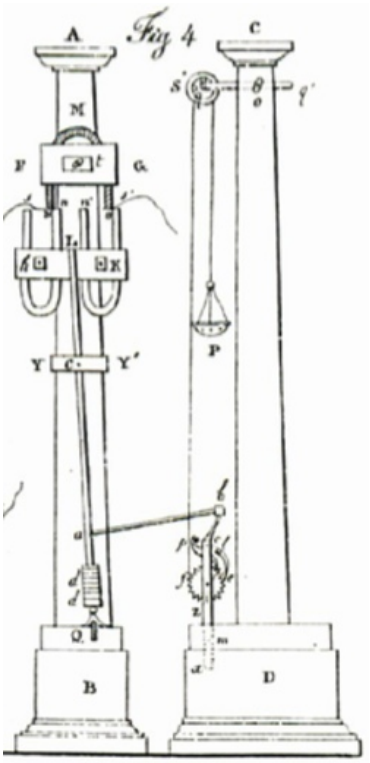


Henry's magnetic rocker, 1831
American Journal of Science, 1831, vol. 20, p. 342

April 1832 Savatore **dal Negro** (Italian) builds a device that can lift 60 grams in one second by 5 centimeters and hence develops nearly 30 mW mechanical power.

He was probably inspired by Henry's magnetic rocker and creates a similar reciprocating machine. However, Dal Negro's device can produce motion by a special gear arrangement.

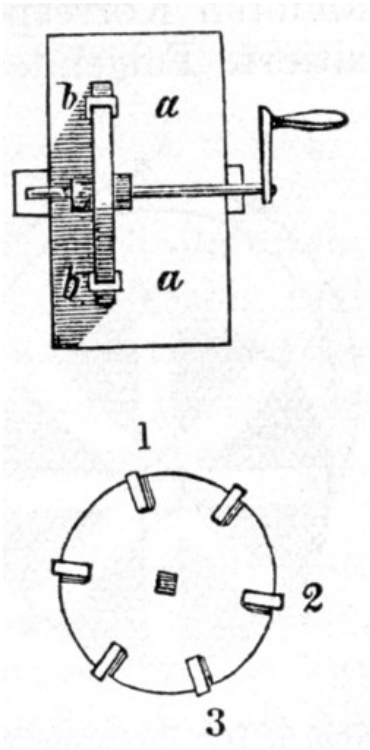
Dal Negro describes his experiments in a letter of April 1832 and later in a scientific paper „*Nuova Macchina élettro-magnetica*" in March 1834.
His devices are stored at the *Museum of the History of Physics* at the University of Padua. Unfortunately, they are not displayed.



Dal Negro's electromagnetic pendulum, 1832
Annali delle Scienze de Regno Lombardo-Veneto, März 1834, pl. 4

July 1832 First public description of a **rotating electric machine**.

The author is an anonymous letter-writer with the initials P.M. He has now been identified with high probability as the Irishman Frederick Mc-Clintock from Dublin.
Michael Faraday, the recipient of the letter on 26 July 1832. publishes it immediately. For the first time a rotating electric machine is described in public.

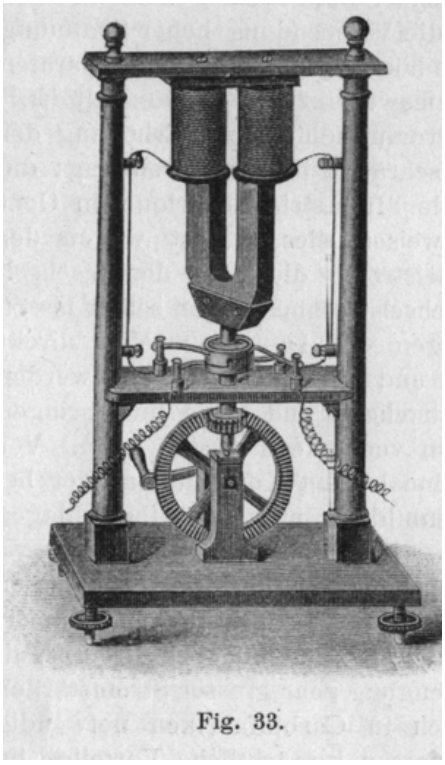


First description of a rotating electrical machine by P.M., 1832
Philosophical Magazine, 1832, p. 161-162

July 1832 Hippolyte **Pixii** (French) builds the first apparatus for generating an alternating current out of a rotation .

The device is presented publicly in September 1832 at a meeting of the *Académie des Sciences*. His description is printed already in the July issue of the *Annales de Chimie*.

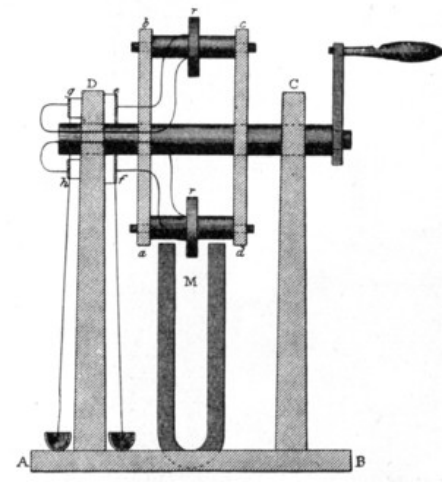
Pixii improved his device in the same year by adding a switching device. He can now produce a pulsating direct current.



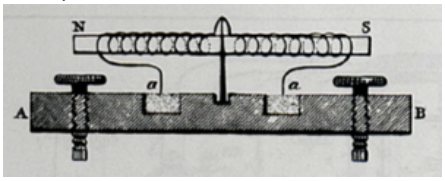
Pixii's first DC generator, 1832/33
F. Niethammer, Ein- und Mehrphasen-Wechsel-strom-Erzeuger, Verlag S. Hirzel, Leipzig 1906

1832 William **Ritchie** (British) reported in March 1833 of a device that he claimed to have built already nine month earlier in the summer of 1832. It is a rotating electromagnetic generator with four rotor coils, a commutator and brushes.
Ritchie is therefore generally regarded as the inventor of the commutator.

At the end of his article Ritchie describes how he was able to rotate an electric magnet by utilization of the magnetic field of the earth. He could raise a weight of several ounces (50-100 grams). The commutation was performed by two wire ends, which ran into two semicircular troughs of mercury.



First DC generator with commutator, 1832/33

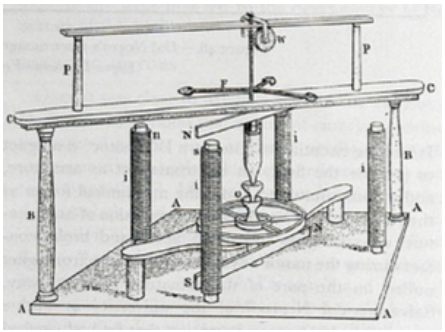


Ritchie's revolving coil, 1833
Philosophical Trans. of the Royal Society of London, 1833, Vol. 132, p.316, pl.7

Jan 1833 A **Dr. Schulthess** gives a lecture at the Society of Engineers in Zurich in 1832, in which he describes his ideas of an electric motor. In January of 1833 he successfully demonstrated a machine before the same Zurich society.
No further details are known.

March 1833 In the autumn of 1832 William **Sturgeon** builds a rotating electric device that he publicly displays in March 1833 in London.

As with Jedlik there are is no definite evidence of the date and details of his construction. Sturgeon reported in 1836 in the first edition of his own magazine about the invention.



Rotation device of Sturgeon, 1832
Sturgeon's Annals of Electricity, 1836/37, vol. 1

Dec. 1833 In the early years of electrical engineering it was strictly distinguished between the magnetic-electro machines, i.e. electric generators, and electro-magnetic machines, i.e. electric motors.
Heinrich Friedrich Emil **Lenz** (German) found the "*law of reciprocity of the magneto-electric and electromagnetic phenomena*", i.e. the reversibility of electric generator and motor.

His scientific text is recited at the end of 1833 at the *St. Petersburg Academy of Sciences* and published in 1834 in Poggendorff's *Annalen der Physik und Chemie*. His ideas are slowly becoming commonplace, especially in 1838 after several reports of successful reversal experiments.

Sometimes it is claimed that the reversal principle was discovered in 1861 by the Italian Pacinotti or even only in 1873 by chance at the Vienna World Exhibition. Both claims are false. Emil Lenz widely reported already in 1838 in *Poggendorff's Annalen der Physik und Chemie* how he used a Pixii generator as a motor.

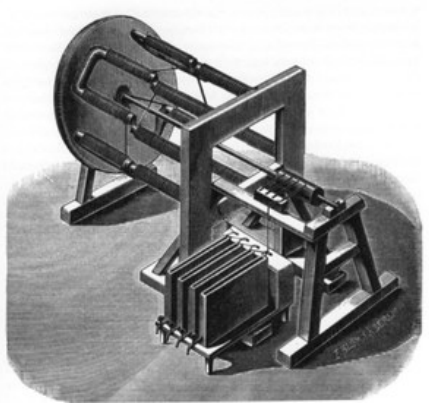
July 1834 Guiseppe Domenico **Botto** (Italian), a physics professor in Turin, publishes in July 1834 in the Geneva magazine *Bibliotheque Universelle* the description of an electric motor, on which he works.
His device corresponds to a metronome (similar to Henry's and Dal Negro's constructions), acting on the pendulum with two electromagnets. Rotary motion is generated via a piston rod.

A replica of the device is now on display in the *Museo Galileo* in Florence.

Rotary machine of Botto, July 1834 (Reconstruction)
Photo courtesy of Museo Galileo, Florence

Timetable 1834 - 1837: The first real electric motors

May 1834 Moritz Hermann **Jacobi** (German-speaking Prussian, naturalized Russian) starts with experiments on a horseshoe-shaped electromagnet in early 1833 in Königsberg (then Prussia, now Russia). In January 1834 he writes in a letter to Poggendorff, editor of the *Annalen der Physik und Chemie* of his successes.
He turns to the construction of an electric motor, which he completes in May 1834. His motor lifts a weight of 10 to 12 pounds with a speed of one foot per second, which is equivalent to about 15 watts of mechanical power.
In November 1834, he sends a report to the *Academy of Sciences* in Paris and publishes a detailed scientific memoir in the spring of 1835. This paper later earns him an honorary doctorate from the Faculty of the University of Königsberg. His text is divided into 23 sections and was expanded in 1837 with a further 15 sections.

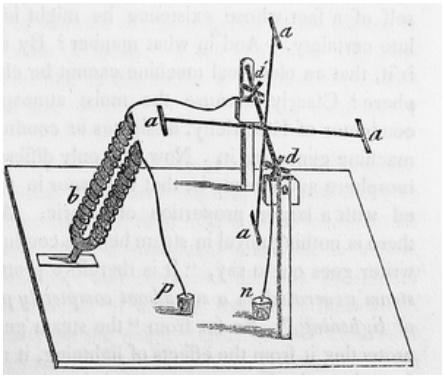

The first real electric motor
Moritz Jacobi, Königsberg, May 1834

Jacobi expressly claimed in the memorandum of 1835 that he was not the sole inventor of the electromagnetic motor. He indicates the priority of the inventions of Botto and Dal Negro.

However, Jacobi is undoubtedly the first to create a usable rotating electric motor.

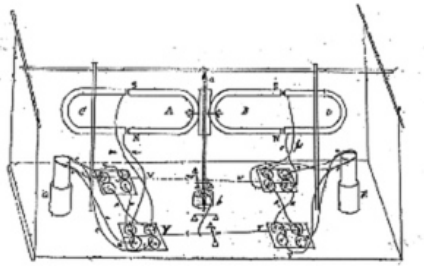
A fully functional replica of his engine is displayed at the Institute of Electric Engineering (ETI) of the Karlsruhe Institute of Technology (KIT) in the Engelbert-Arnold-Strasse 5 (Building 11.10) in Karlsruhe, Germany.

Oct. 1834 The US-American T. **Edmundson** builds an electromagnetic rotary device that resembles a water wheel.



Electromagnetic wheel by Edmundson
American Journal of Science, 1834, vol. 26, p. 205

1834-1835 In December 1833 the blacksmith Thomas **Davenport** (American) purchases a solenoid directly from Joseph Henry and begins experiments together with Orange **Smalley** (American) in a workshop in Forestdale, Vermont.
In July 1834 the two men create their first rotary machine. They improve the device in several steps before they publicly demonstrate it in December 1834 for the first time.

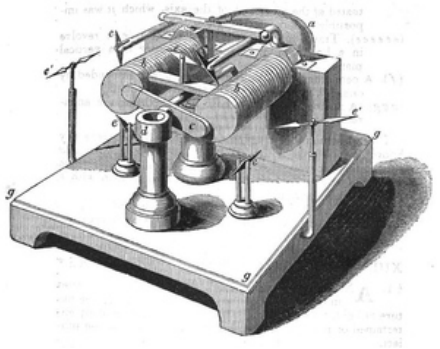

First motor of Davenport from his first patent application in June 1835

In the following year Davenport separates from Smalley.

In the summer of 1835 Davenport travels to Washington, D.C., to demonstrate his machine before the patent office and have it registered. Due to lack of money, however, he has to return home without success.

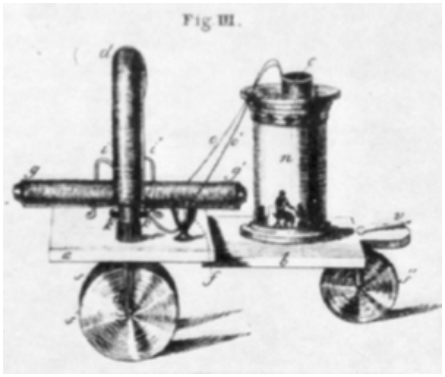
Aug. 1835 Francis **Watkins** (British) creates an electrical "toy" with which he can bring several magnetic needles to rotation. He describes the apparatus in a paper for the *Philosophical Magazine*.
He admits to being inspired by the electro-magnetic machine (generator) by Joseph Saxton, which is on display in a public gallery in London since August 1833.

Watkins can be counted among the first who understood the principle of reversal of motor and generator.



Watkin's toy, 1835
Philosophical Magazine, 1835, vol. 7, p. 112

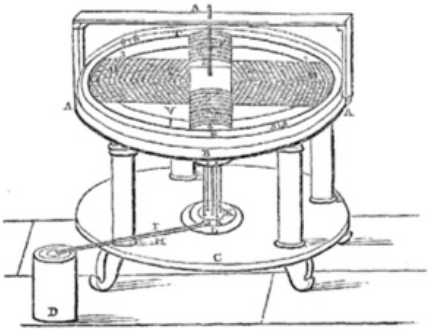
1835 Sibrandus **Stratingh** and Christopher **Becker** (Dutch) build a small (30 x 25 cm), electrically driven three-wheeled vehicle of about 3 kg in weight. It can drive roughly 15 to 20 minutes on a table until the battery is empty. Stratingh and Becker publish a report of their success in the same year. Stratingh knew the work of Jacobi and wanted to build a real electric car in 1840, which he never succeeded.



Electric model car by Stratingh and Becker, 1835

May 1836 Johann Philipp **Wagner** (German) presents an electric motor at the *Stiftungsfest* of the *Sencken-bergischen naturforschenden Gesellschaft*. His apparatus is similar to the device that Stratingh and Becker created. It can run for about 10 mins until the battery is empty.
Wagner holds his construction a secret and so there are reports on the demonstration, but no drawings of the machine. In subsequent years, Wagner developes his engine further and publicly demonstrates improved versions.

1836 **Davenport** has been further improving his devices. In 1836 he finds a new
1837 partner in Ransom **Cook** and moves to Saratoga Springs, New York to further develop his motors. With the help of Cook he builds a model for the patent office.
On January 24, 1837, Davenport files his caveat in Washington and on February 5, 1837, he gets the first U.S. patent for an electric motor: "*Improvement in propelling machinery by magnetism and electromagnetism*".
His model motor is now on display in the Smithsonian Institute in Washington, DC.


Davenport's patented motor, February 1837

Davenport's patented design uses four rotating electromagnets that are switched by a commutator, and ring-shaped fixed permanent magnets made of soft iron.

An improved motor, which he presents in August 1837, has 6 inches in diameter, rotates at about 1,000 revolutions per minute and can lift a 200 pound weight one foot in one minute. This corresponds to a power of 4.5 W.

Davenport continuously improved his designs in the following years.

Together with Edwin **Williams** of New York and his partner Ransom **Cook**, Davenport forms a joint capital stock association on March 3, 1837. However, Williams fails to sell enough of the stocks and the whole undertaking collapses just one year later.

Thomas Davenport – Inventor of the electric motor?

There are several texts of dripping pathos in US-American literature that celebrate Thomas Davenport as inventor of the electric motor. This assertion is based on the undisputed fact that Davenport was the first American who created a useable electric motor and also the first to receive a patent for such a device in the beginning of 1837.

Davenport, however, was far from being the first to build an electric motor. In Europe (especially in England, Italy and Prussia) technology was already much advanced. Already in summer 1834, three years before the patent, Moritz Jacobi presented a motor that was three times more powerful than an improved machine, which Davenport had developed in the months after his patent application. In addition, Davenport's motor was running faster than Jacobi's. So the output torque of Davenport's motor, the decisive factor in the comparison of electric machines, was only about one tenth of Jacobi's three years earlier design.

In 1835, shortly after Jacobi's motor, the two Dutchmen Strating and Becker already presented a first practical application by driving a small electric model car.

In the years following Davenport's patent the advancement of Jacobi hardly diminished. At the same time when Jacobi demonstrated his next machine in the fall of 1838, a motor that was capable of 300 W output power and could drive a boat occupied with 14 people across a wide river, Davenport showed a tiny model train.

Davenport's motor is not remarkable in a historical context. His construction is not a substantial improvement of other contemporary designs.

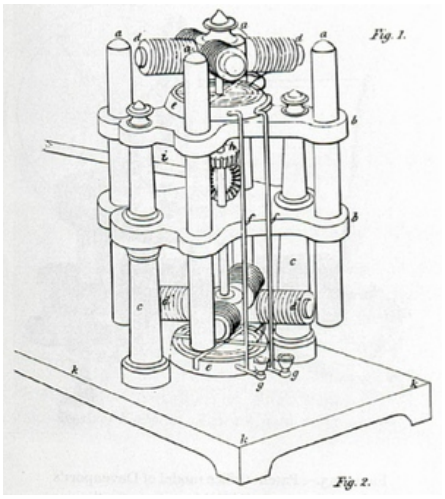
Over the years, Davenport manufactured quite a number of machines. But unlike Werner Siemens, George Westinghouse and Thomas Edison, he was not the founder of an important company. And unlike Nikola Tesla, for example, Thomas Davenport was never able to sell nor license his patent.

Davenport did not receive the patent on the electric motor as such but only on his special design features. In the years from 1837 to 1866 about 100 patents on electric motors were granted to other inventors in England alone. After Davenport redesigned his motor already during 1837 his patent became practically worthless.

Davenport is the honor of being the first of thousands of engineers who received a patent for an electric motor. But he is neither their inventor nor did his designs have had any significant influence on the further development of electric motors.

Timetable 1838 - 1854: Stronger motors, new applications

Febr. 1838 **Watkins** publishes an extensive article in the *Philosophical Magazine* where he presents his motor.



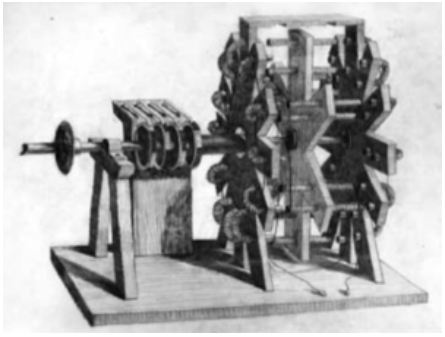
Watkin's motor, February 1838
Philosophical Magazine, 1838, vol. 12, pl. 4

Aug. 1838 In August, 1838, a tiny model train with one of **Davenport's** motors is displayed in London. It moves at 3 mph.

Davenport's model train, 1838
Photo courtesy of the Division of Work & Industry, National Museum of American History, Smithsonian Institution

Sept. 1838 **Jacobi** moves to St. Petersburg in August 1838 at request of the Russian Tsar. He was accepted at the St. Petersburg Academy of Sciences and generously supported by the Tsar in his further work on electric motors. On 13 September 1838, Jacobi demonstrates for the first time on the river Neva an about 8 m long, electrically powered boat with paddle wheels.

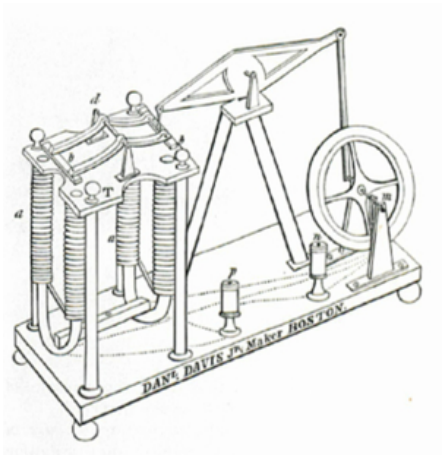
The zinc batteries have 320 pairs of plates and weighed 200 kg. They are placed along the two side walls of the vessel. The motor produces between 1/5 and 1/4 hp power (300 W), the boat travels with 2,5 km / h over a 7.5 km long route. It can carry more than a dozen passengers. Jacobi drives around for days on the river Neva. Contemporary newspaper articles state that after two to three months of operation the zinc consumption was 24 pounds.



Improved motor of Jacobi, 1838

1838 Charles G. **Page** (American) starts a lifelong occupation with electric motors.
Over the next 20 years, Page is researching to find better, more powerful machines. His engines were sold via catalog in the U.S. and reached a high level of public awareness.

In early years, many inventors of electric motors mimic steam engines with an oscillating (reciprocating) piston. Page also builds such a machine (see right), but then turns to rotating devices.

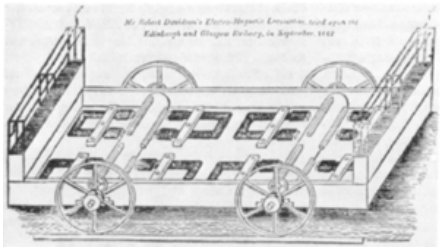


First motor of Page, 1838
American Journal of Science, 1838, vol. 35, p. 264

Aug. 1839 On 8 August **Jacobi** tests an improved electric motor with three-to four-fold the mechanical performance of his second machine of 1838 (about 1 kW). His boat is now reaching 4 km/h. A key factor for his success is the improved zinc-platinum battery according to William Robert Grove, which he has made himself.
In October 1841 Jacobi demonstrates once again a further improved motor, which, however, is only slightly superior to the model from 1839. This is the last electric motor Jacobi ever builds. He now turns to the theory of electric motors and later moves on to other electric phenomena.

1837-1842 Robert **Davidson** (Scottish) also developed electric motors since 1837. He made several drives for a lathe and model vehicles.
In 1839 Davidson manages the construction of the first electrically powered car.

In September 1842, he makes trial runs with a 5-ton, 4.8 m long locomotive on the railway line from Edinburgh to Glasgow. Its engine makes about 1 hp (0.74 kW) and reaches a speed of 4 mph (6.4 km / h).



First electric locomotive by Davidson, 1839
From T. du Moncel, *Electricity as a Motive Power*, London, 1883, fig. 32

In subsequent years, a flood of patents on electromagnetic machines begins - about 100 in England alone between 1837 and 1866.

Among the inventors who deal with electric motors are: James Joule (English, ab 1838), William Taylor (English, ab 1838), Uriah Clarke (ab 1840), Thomas Wright (ab 1840), Wheatstone (English, ab 1841), de Harlem (ab 1841), P. Elias (US-American, ab 1842), G. Froment (French, ab 1844), Moses G. Farmer (US-American, ab 1846), G. Q. Colton (US-American, ab 1847), Hjorth (ab 1849), Thomas Hall (US-American, ab 1850), T. C. Avery (ab 1851), Sören Hjorth (Danish, ab 1851), Du Moncel (French, ab 1851), Marié Davy (French, ab 1855), Pacinotti (Italien, ab 1861) and others.

Initially there is a contest between oscillating (reciprocating) and rotary machines. Later, the oscillating machines disappear completely from view.

A fundamental problem of the early electric motors is that the electric current from the galvanic elements (zinc batteries) is far too expensive to compete with steam engines. R. Hunt reported in 1850 in the *British Philosophical Magazine* that the electrical power even under the best conditions is 25 times more expensive than a steam engine. Only with the ongoing development of the electric generator (dynamo) the situation is beginning to change.

1840 On 18 January, 1840, the first edition of Davenport's new newspaper, *Electro Magnet and Mechanics Intelligencer*, is released. The printing press is driven by two of his own motors. The motors do supposedly about 2 hp, which is about 1.5 kW.

1841-1844 On the initiative of **Wagner,** the German Confederation under the leadership of Prussia, Bavaria and Austria, sets a prize of 100,000 Gulden in 1841 for the construction of an electrical machine whose power is cheaper than that of horses, steam, or human power.
Of course, this price attracts other inventors, who start working on an electric motor in parallel to Wagner's efforts. Among them are Mr Karl Ludwig **Althans** from Bückeburg close to Minden, Emil **Stöhrer** from Leipzig, Emil **Groos** from Karlsruhe and Peter **Bauer** from Nuremberg. In particular, Stöhrer designs a remarkable machine in 1843.

In examining the final Wagnerian machine in May and June 1844 in Frankfurt am Main, the federal Commission determined a power of only 50 watts. The zinc consumption is so high that horse, steam and manpower is considerably cheaper. Because of this failure the price is withheld from Wagner and he falls from grace.

Without a powerful electric generator this competition could not be won, and for such a generator mankind had to wait another 25 years.

1851 **Page** boosts its motors from 8 to 20 HP power.
With two engines, he drives a 10-ton locomotive with a top speed of 30 km/h. He travels the route from Washington to Bladenburg in 19 minutes.

1854 Another, 12-ton locomotive of Page is traveling on the route from Baltimore to Ohio.

... more in part 2.

Karlsruhe Institute of Technology

Elektrotechnisches Institut (ETI)

Elektrotechnisches Institut

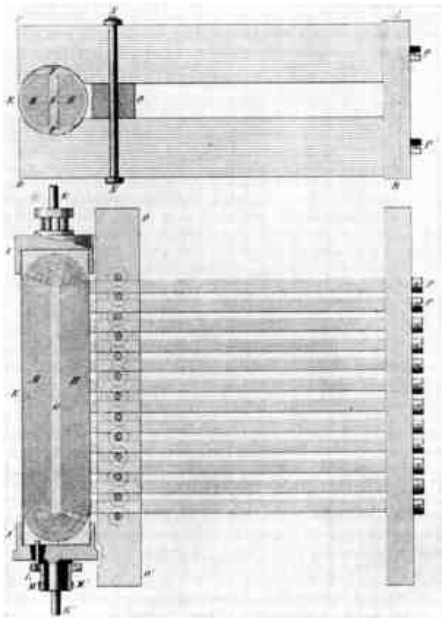
The invention of the electric motor 1856-1893

Timtable 1856 - 1873: From the invention of the dynamo to the dc motor

1856 Werner **Siemens** (German) builds an electric generator with a double-T armature winding. He is the first one to place a winding into slots.

This invention marks a turning point in the design of electrical machines. All previous designs disappear from the market during the following decades. To date, almost all electric motors are built with windings in slots.

In 1856, Siemens produces around 50 such devices for the Bavarian railways. The first machines are designed to deliver pulses for telegraphs and are operated by hand. They do not supply continuous electrical energy.



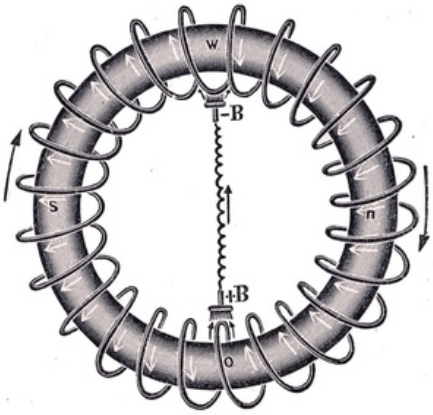
Siemens double-T armature winding
Poggendorffs Annalen der Physik 101 (1857) Taf. II

1861-1864 James Clerk **Maxwell** (British) summarizes all the current knowledge of electromagnetism in 20 fundamental equations. Around 1882, Oliver **Heaviside** (British) uses vector calculus and reduces 12 of the equations further to just 4 equations with 4 variables. These equations are still valid today and fully describe the theory of electrical engineering.

1866-1867 **Siemens** develops the dynamo-electric machine based on the double-T armature. Finally, a powerful electric generator is available and the advent of electricity begins.

1871 The Siemens double-T armature has the disadvantage of producing a pulsating direct current.
Zénobe Théophil **Gramme** (Belgium) solves the problem by the invention of the anchor ring, which produces a smooth DC voltage. In subsequent years, Gramme's machines are in strong competition Siemens' double-T armature machines.

Gramme's construction, however, is no longer used today.

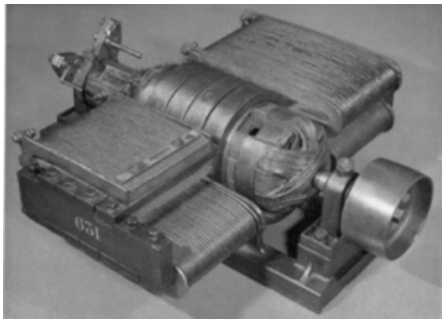


Gramme's anchor ring, 1871
Photo: Wikipedia

1872-1875 Friedrich von **Hefner-Alteneck** (German), a close associate of Werner Siemens, starts development of the anchor drum motor.

He wraps wire around a cylinder-shaped anchor. This improves the double-T anchor machine, which can now also produce a smooth DC voltage.

In 1875, he reduces the problem of eddy currents by using iron wires instead of solid iron for the magnetic core.



Siemens' drum armature, app. 1872 (sliced model)
Photo: Science Museum, London

1873 Auguste **Pellerin** (Franzose) proposes to subdivide the iron core into several separate, mutually insulated steel sheets in order to avoid eddy current losses. He does not, however, pursue his idea any further.

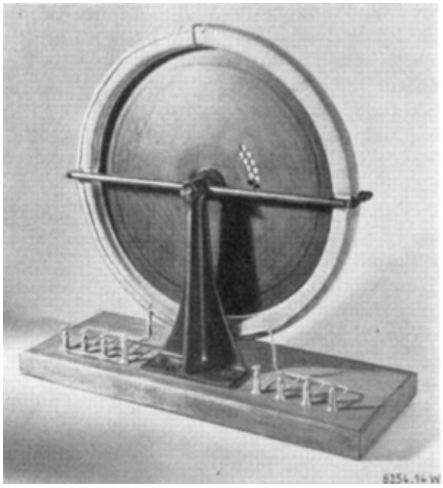
With Ritchie's commutator, the drum armature of Siemens and Hefner Alteneck and the lamination of the magnetic circuit all important design features of modern electric DC motors are known.

The future DC motor does not emerge from the developments of Jedlik, Jacobi, Davenport, Davidson, Page or other early inventors, whose designs are ultimately proven to be inferior, but from Siemens's dynamo machine.

J. Zoellner writes in 1885: "The history of electromagnetic motors ends in its childhood, or rather, goes along with the history of the dynamo."

Timetable 1885 - 1893: The three-phase system and the induction motor

1882-1889 Nikola **Tesla** (Croatian, naturalized US-American) already thinks about a multi-phase voltage system while studying in Graz / Austria in 1882.
He emigrates to America in 1884 and launches a small company and development laboratory in 1886 in New York.



Meanwhile, the Italian professor Ferraris is successful in building a small two-phase induction motor in 1885 (see below).
Tesla knows nothing of Ferraris' induction motor and reinvents it shortly thereafter. He also builds a series of functional models.

Tesla falls out with its investors in 1886 and must now make his living as a laborer for the next two years, while he continues to work on his inventions.

In 1887 Tesla files his first patents for a two-phase AC system with four electric power lines, which consists of a generator, a transmission system and a multi-phase motor.

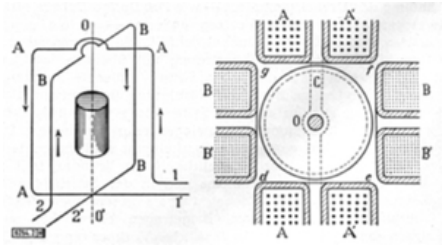
George Westinghouse becomes aware of Tesla in May 1888 due to his remarkable speech in Pittsburgh to the *American Institute of Electrical Engineers.* He buys his more than 40 patents for $ 1 million. In addition, Westinghouse hires Tesla as a consultant for his company.
Tesla still fails to recognize the advantages of three-phase voltage systems. During his work at Westinghouse, he concentrates on two-phase and single-phase induction machines with relatively high frequencies (125 Hz and 133 Hz).

Ultimately, he fails to build a reliable induction motor and leaves Pittsburgh and the Westinghouse Company dissatisfied in 1889. Westinghouse thereafter stops all developments of induction motors.

Only after the German AEG company with Dolivo-Dobrovolsky's machines (see below) proves that reliable three-phase induction motors can be built, Westinghouse restarts its own developments of three-phase motors in 1892.

These efforts are successful already in 1893 - however, without the involvement of Tesla, who had turned to other topics.

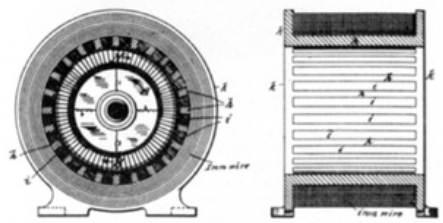
1885 Galileo **Ferraris** (Italian) builds the first induction motor. Like Tesla, he uses two phases.
However, Ferrari believes incorrectly that such motors can never exceed an efficiency of 50%. He therefore loses interest and does not continue to develop his machines.



Schematic drawing of Ferraris' first induction motor
from his patent application, 1885

1887-1889 Charles Schenk **Bradley** (US-American) has been experimenting with multi-phase generators already before the publication of Ferraris' work.

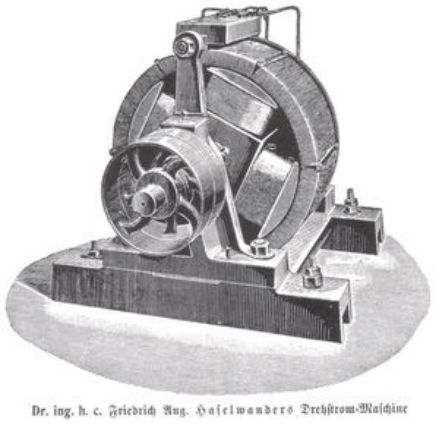
In 1887/88 he is granted several US-patents on this subject. At first on two-phase and later also on three-phase systems. But Bradley never puts his inventions into practical use.



Bradley's induction motor
from his patent application, 1887

1887-1888 Friedrich August **Haselwander** (German) from Offenburg/Baden is the first one to come up with the idea to use a three-phase alternating voltage and current system in July 1887.

He builds the first three-phase synchronous generator with salient poles. However, the German Post (postal authority) prohibits the operation of his machine for fear of disturbances of telegraph lines.
Haselwander's patent applications fail as well.

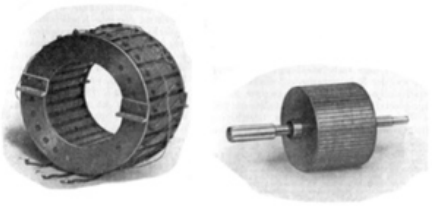


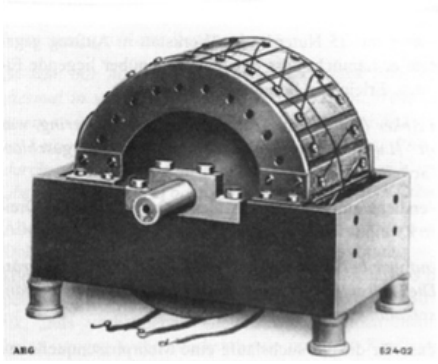
Haselwander's synchronous motor, 1887

1889-1891 Michael **Dolivo-Dobrowolsky** (Russian, naturalized Swiss), chief electrician at the AEG company in Berlin, builds on the basic ideas of Tesla and Ferraris and improves them considerably.

He designs the three-phase cage induction motor, which is still widely used today. In the beginning of 1889, his first motor is running properly.

Later, Dolivo-Dobrovolsky also invents the three-phase slip ring induction motor with starting resistors.

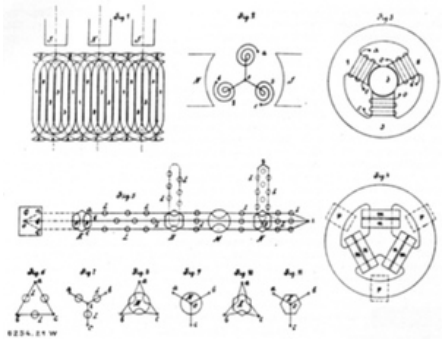



Dolivo-Dobrowolsky's first three-phase cage-induction motor, 1889
Illustration from ETZ, 1917 [9]

1889-1893 In a British patent of April 1889 Jonas **Wenström** (Swedish) describes all components of a three-phase electrical power system.

In 1890 he builds a three-phase generator. Three years later, in 1893, the first 13 km long AC power transmission system is installed in Sweden.

Wenström probably knew nothing about the other participants although they were ahead of him by one or two years.


Sketch from Wenström's patent application, 1890

Energy Transmission

Dobrovolsky is the first one to realize that a three-phase system connected in star or delta requires just three power lines and thus is less expensive than even a two-phase system (which uses four lines).
In **August 1889** he receives a patent on the invention of the three-legged three-phase transformer. This is the beginning of the world wide success of the three-phase alternating current system.

Under the leadership of **Dolivo-Dobrowolsky** and together with the **Maschinenfabrik Oerlikon** and its chief engineer **Charles E.L. Brown**, the **AEG** builds the first three-phase electric power transmission line in 1891 over 175 km from Lauffen (river Neckar) to Frankfurt am Main, which later reached a remarkable efficiency of 96%. The line could deliver up to 220 kW output power and was operated at voltages up to 25 kV.

Five years later in **late 1896**, the first U.S. american electric power line is inaugurated. Built by **Tesla** and **Westinghouse** it leads from the Niagara Falls to Buffalo, NY over a distance of 22 miles (35 km). This line is also a three-phase system, which Tesla has learned to appreciate in the meantime. However, three individual single-phase transformers were used at both ends of the line as the advantageous three-legged transformer construction had been patented by Dobrovolsky. The Niagara Falls line can deliver an output power up to 750 kW at voltages up to 11 kV.

Summary

Franz **Hillebrand** investigates the priority question on behalf of the Scientific Committee of the VDE in 1959 in a thorough study of the subject [10]. He remarks:

"... The solution of the problem was almost in the air, and so it is not surprising that similar paths of thought formed in many minds and almost simultaneously very similar solutions were created ...

One had the solution, at least in principle, already in his hands, but postponed their publication by three precious years because he fails to recognize its meaning due to an error of thought (**Ferrari**);

the other one was thoroughly familiar with the matter, gradually developed the technical solution in a usable form, but only in patent specifications and he did not seem to think of an implementation in reality (**Bradley**).

Another one got almost by chance the correct solution, instantly recognizes it thanks to his technical talent, instantly turns it into a small scale model in the right way in an amazingly short time, but has neither the gift nor the economic backing to bring his ideas to the breakthrough (**Haselwander**).

Another one fights for the solution in restless intellectual work, dreaming of fantastic views opened by his flights of thought, from the bondage of the forces of Niagara Falls and other things more, but does not possess the ability to quickly find a technically usable form, or inspire employees for his ideas (**Tesla**).

One clearly recognizes the problem, creates technically sound, well thought out solutions for the whole application area, but his solutions appear one to two years too late in the race (**Wenström**).

Next comes a man who knows the situation in the field of energy supply well, a sovereign master of the matter, who is used to overcome difficulties in the development of electric machines, who connects courage with decisiveness and has the great good fortune to be working with far-sighted economists (**Dolivo-Dobrowolsky**).

... How hard is it to distribute the merits properly on this background! ...

Tesla was the first to work intensively on electric power transmission through a multi-phase alternating current system, he was the first to find the basics for such a transfer and was the first to present the principles of a multi-phase induction motor.

Bradley filed the first patent on a two-phase AC power transmission system with synchronous machines and four electric wires. He also created the first patent for a three-phase induction motor with a completely shorted-circuited rotor winding (squirrel-cage induction).

Haselwander was the first to design a three-phase transmission system with three-phase synchronous machines and three transmission lines. He built the first such facility, and gave it first into practical use.

Dolivo-Dobrowolsky built the first simple, practically useful three-phase induction motor with squirrel cage rotor. In broad scientific lectures and essays, he explained nature and characteristics of the three-phase current system and three-phase motors ... and two years after the construction of his first 1/10 hp induction motor he put a 100-horsepower three-phase motor into normal operation ... Dolivo-Dobrowolsky must therefore be seen as the pioneer for the introduction of the three-phase current system. "

Literature

[1] G. Neidhöfer, *Michael von Dolivo-Dobrowolsky und der Drehstrom*, Geschichte der Elektrotechnik Band 19, VDE Verlag Berlin, 2004

[2] K. Jäger (Hrsg.), *Alles bewegt sich*, Geschichte der Elektrotechnik Band 16, VDE Verlag Berlin, 1998

[3] H. Lindner, *Elektromagnetismus als Triebkraft im zweiten Drittel des 19. Jahrhunderts*, Dissertation TU Berlin, 1986

[4] O. Mahr, *Die Entstehung der Dynamomaschine*, Geschichtliche Einzeldarstellungen aus der Elektrotechnik, VDE, Verlag Julius Springer, 1941

[5] B. Bowers, *Die Frühgeschichte des Elektromotors*, Philips Technische Rundschau, 35. Jahrgang, 1975/76, Nr. 4, S. 85-104

[6] A. Imhof, *Die ersten Elektromotoren*, Bulletin des SEV Elektrotechnik, 70(1979)23, Seite 1241-1246

[7] T. Davenport, *Improvement in propelling machinery by magnetism and electro-magnetism*, United Stated Patent Office Patent No. 132, February 25, 1837

[8] J. Zöllner, *Die elektromagnetischen Apparate*, Buch der Erfindungen, Gewerbe und Industrien, Band 2, S. 360 – 380, Verlag Otto Spamer, Berlin/Leipzig, 1885

[9] M. Dolivo-Dobrovolsky, *Aus der Geschichte des Drehstroms*, ETZ Elektrotechnische Zeitschrift, Bd. 38 (1917), Heft 26, S. 341-344, Heft 27, S. 354-357, Heft 28, S- 366-369 und Heft 29, S. 376-377

[10] F. Hillebrand, *Zur Geschichte des Drehstroms*, ETZ-A Elektrotechnische Zeitschrift, Ausgabe A Bd. 80 (1959) Heft 13, Seite 409-421 und Heft 14, Seite 453-461

[11] M.H. Jacobi, *Mémoire sur l'Application de l'Électro-Magnétisme au Mouvement des Machines*, Potsdam, Spring 1835

[12] T.D. Visser, *Smalley-Davenport Shop Forestdale*, Vermont, http://www.uvm.edu/~histpres/SD/hist.html, 1995

[13] W.J. King, *The development of electrical technology in the 19th century. Part 1: The electrochemical cell and the electromagnet*, Bulletin of the United States National Museum, 228(1962), S. 231 – 271

[14] J. Abele, G. Mener, *Technikgeschichte – Der Tesla Motor*, Deutsches Museum, 1995

[15] B. Silliman, *Notice of the Electro-Magnetic Machine of Mr. Thomas Davenport, of Brandon, near Rutland, Vermont*, American Journal of Science and Arts, Vol. 32, July 1837, Appendix, p. 1-8

[16] P. Hempel, *Deutschsprachige Physiker im alten St. Petersburg: Georg Parrot, Emil Lenz und Moritz Jacobi im Kontext von Wissenschaft und Politik*, Oldenbourg Wissenschaftsverlag, 1999

[17] W.R. Davenport, J. Hartness, *Biography of Thomas Davenport, the Brandon Blacksmith: Inventor of the Electric Motor*, Kessinger Publishing, 2010 (Faksimile Reprint)

[18] The Mechanics' Magazine, Museum, Register, Journal and Gazette, London; Ausgabe 1837, S. 159, 160, 404, 405; Ausgabe 1838, S. 115, 322, 323, 426-428, 441, 442; Ausgabe 1840, S. 407-408; Ausgabe 1852, S. 22-25

[19] Journal of the Franklin Institute, Vol. 24, Issue 5, Nov. 1837, S. 340-343

[20] F. Watkins, *On Magneto-electric Induction*, Philosophical Magazine and Journal of Science, London and Edinburgh, Vol. 7, August 1835, S. 107-113

[21] F. Watkins, *On Electro-magnetic Motive Machines*, Philosophical Magazine and Journal of Science, London and Edinburgh, Vol. 12, Februar 1838, S. 190-196

[22] C.G. Page, *Magneto-Electric and Electro-Magnetic Apparatus and Experiments*, American Journal of Science and Arts, Vol. 35, January 1839, p. 252-268

[23] W. Siemens, *Über eine neue Konstruktion magneto-elektrischer Maschine*n, Poggendorffs Annalen der Physik und Chemie, Ausgabe 101, 1857, S. 271-274

[24] F.L. Pope, *The Inventors of the electric motor*, The Electrical Engineer, Vol. XI, 1891, No. 140, S. 1-5 und No. 141, S. 33-39

[25] M.H. Jacobi, *Notiz über Elektromagnete*, Poggendorffs Annalen der Physik und Chemie, Ausgabe 31, 1834, S. 367-368

[26] J.C. Poggendorff, *Jacobi's Commutator*, Poggendorffs Annalen der Physik und Chemie, Ausgabe 36, 1835 , S. 366-369

[27] M.H. Jacobi, *Ueber die Principien der elektro-magnetischen Maschinen*, Poggendorffs Annalen der Physik und Chemie, Ausgabe 51, 1840, S. 358-372

[28] C.Th. Moncel, F. Geraldy, *Electricity as a motive power*, E.&F.N.Spon, London, 16, Charing Cross., 1883

[29] M.H. Jacobi, *On the application of electro-magnetism to the moving of machines,* The Annals of Electricity, Magnetism & Chemistry, Vol. 1, July 1837, S. 408 ff. and Vol. 1, October 1837, S. 419 ff.

[30] W. Sturgeon, *His electro-magnetic engine*, The Annals of Electricity, Magnetism & Chemistry, Vol. 1, October 1836, S. 76 ff.

[31] E. Lenz, *Ueber die Bestimmung der Richtung der durch elektrodynamische Vertheilung erregten galvanischen Ströme*, Poggendorffs Annalen der Physik und Chemie, Ausgabe 31, 1834, S. 483-494

[32] E. Lenz, *Ueber die Beziehung zwischen elektromagnetischen und magneto-elektrischen Strömen*, Poggendorffs Annalen der Physik und Chemie, Ausgabe 44, 1838, S.347-349