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Electrostatics and Electrodynamics at Pest University in the mid-19th Century

Abstract

The voltaic pile opened a new chapter in the history of electricity. Electrodynamics, which deals with flowing charges, became a basis for the practical utilization of electricity. In addition to classical electrostatics, the research of electrodynamics became increasingly extensive. Ányos Jedlik, professor of physics was a prominent personality at Pest University, in the period after Volta. In 1829 he experimented with Ampére's conductor frame and, by using a commutator, fabricated a device capable of continuous rotation. He made high-power galvanic cells, and then his attention turned to induction-based generators. In 1861 he constructed a unipolar generator and came to the idea of self-excitation (the dynamo-electrical principle). He also continued dealing with electrostatics. By means of a cascade-connection capacitor battery, he multiplied the high voltage of the typical induction device of that age, which was the spark inductor, and thus created a connection between electrodynamics and electrostatics (1863). His scholarly activities span a period from the theoretical research in Volta's age to the emergence of the electrical industry.

1. Electricity before Volta

On the occasion of the bicentenary of the invention of the voltaic pile, we must also remember the 200th anniversary of the birth of a new technology, electrical engineering.

Looking back to that age now, 200 years later, all we see is a straight unbroken development in which the voltaic pile opened a new chapter in electricity: electrodynamics, which then served as a basis for the practical utilization of electricity, in other words, electrical engineering. In this simplified picture the science of the old age is represented by electrostatics, whilst the 19th century is represented by electrodynamics. The old rationalistic approach in physics, based on mechanics, was replaced by natural philosophy which sought relations between phenomena relating to different sciences. This search for relationships was now not focused on the movement of material but on the transformation of energy. The voltaic cell, the current of which can be transformed into chemical and mechanical energy or heat, had a key role. All this seems logical and clear now but the situation was not that simple in reality.

Electricity in the 18th century was not restricted to electrostatics, that is, the science of stationary charges. There were moving charges, in other words, current was flowing in the electrostatic experiments of those days. Friction machines are also current generators, although their current is only to the order of microamperes ($10^{-6}A$). However, the discharge of Leyden jars may generate a current impulse as high as $100A$, even if for only a few microseconds. This means that in principle, it was not impossible to notice the effects of the current. Such observations did take place but the science of the 18th century was unable to recognize their importance. It was observed that the discharge current of the Leyden jar was capable of melting a metal wire; moreover, on the basis of his melting experiments, Pristley observed the different conductivity of metals. Troostwijk from the Netherlands managed to decompose water by means of the current from a friction machine. In 1799, Pearson from England was capable of producing approx. 0.1 cm^3 oxyhydrogen gas, although to achieve this, he had to drive a friction machine as long as 3 hours. Franklin noticed that upon electric discharge, a non-magnetic steel needle became magnetic. In 1786 Marum observed a similar phenomenon but thought that the discharge only had a mechanical effect and that becoming magnetic was due to earth magnetism. In other words, the chemical, thermal and magnetic effects of electricity were in fact observed but science in the age before Volta could do nothing with them.

2. Voltaic Pile and Electrodynamics

Volta's pile, and later his jar-battery, generated a current of a few Ampères, that is to say, almost a million times higher than the friction machine. Evidently, it was now easier to examine the effects of the current; but development was promoted by other factors, too. Natural philosophy changed the sequence between observations and theory: the relationship between electricity and other phenomena was assumed and searched in anticipation. However, well-intentioned attempts frequently led astray. The Galvanic cell was assumed to have a magnetic effect from the beginning, yet another two decades passed by until Oersted's discovery. As an inheritance from electrostatics, electricity was characterized by voltage or maybe charge but the term "current" was not generally used. This is how it could happen that many people tried – or, in their opinion, even managed – to observe a magnetic effect with a Volta battery but without a closed circuit.

In 1802, Romagnosi from Italy gave account of an experiment in which a compass, when touched by one of the outlet wires of a voltaic pile, deviated from the north-south direction. The reason for this attempt is as evident as the fact that he was wrong. In 1808, Prechtl from Austria tried to use a voltaic pile, suspended on a silk string, as a compass; naturally, without success. At about 1803, Ritter from Germany, an enthusiastic follower of natural philosophy, used two connected metal wires (silver and zinc) as a compass in order to demonstrate a connection between galvanic electricity and magnetism. He claimed that the positive metal pointed at the north and the negative one at the south. His finding was later proved to be incorrect by experiments. (Surprisingly, in this experiment Ritter set out of the theory of the galvanic cell's contact electricity although he had a major role in the creation of electrochemical theory connected with natural philosophy and was the discoverer of electrochemical polarization. Nevertheless, it is not impossible that a current and a magnetic field could occur in a wet environment).[1]

In 1803, Oersted in cooperation with Ritter made efforts to demonstrate electromagnetism but without success. He was led by a natural philosophical assumption but the false interpretation of this idea delayed the result. Namely, he assumed that the phenomena form a unit and thus magnetism would only appear together with the other effects of the current, that is, heat and light generation. Therefore, he led current through a thin platinum wire to make it glow. However, the thin wire had a high resistance and thus considerably restricted the current. Therefore, the magnetic effect was extremely weak. He only managed to perceive this phenomenon 17 years later, in 1820.

In view of all this, no wonder that Arago's report about Oersted's discovery was received with doubts at the French Academy of Science. However, within a few days Ampère confirmed the questioned result by his own measurements. In a letter he wrote the following about the reason for this doubt:

> ... I think the reason is quite simple: ... Coulomb's hypothesis of the magnetic effect ... simply excluded the possibility of any interaction between electricity and the so-called magnetic filaments; aversion was so intense that when Monsigneur Arago spoke about the new phenomena at the Academy, his observations ... were refused. Everybody was convinced that this was impossible ... People tend to have an aversion to changing their ideas to which they have become accustomed to.[2]

Now, the magnetic effect of the current was acknowledged but there were still lots of questions to be answered. It was the unexpected structure of the magnetic field of the electric conductor that caused the greatest surprise. This cylindrically symmetric field has neither defined north and south poles nor an attractive force but exerts a rotating force on the compass. This created confusion in interpreting the phenomenon. Before Faraday's field theory, and even decades after, the majority of people attached a special importance to the magnetic poles. The reason for the unfavorable construction of the early electric machines is that attention was focused on the creation of well-defined poles instead of a closed magnetic circuit. More than fifty years later, in 1885, the closed iron-core transformer constructed by three Hungarian engineers, Zipernowsky, Déri and Bláthy won the competition against the open iron-core secondary generator of the French Goulard; this was exactly because of the fact that these Hungarian engineers deviated from the almost

[1] FRAUNBERGER (1985).
[2] SIMONYI (1990).

obligatory practice of creating poles. The comparative measurements carried out by Galileo Ferraris demonstrated that the specific power of a transformer without poles was 3.4 times higher than that of a secondary generator.[3]

Theories to explain the rotating effect were born one after another. Instead of the word “current”, Oersted initially used the term “conflictus electricus” according to which “two opposite electricities coming from the two poles of the Volta battery come upon each other”, causing a “helicoidal” movement upon their impact. This idea survived for long. At the beginning of electrical lighting, the man in the street thought that it was the impact between positive and negative electricity that caused the carbon filament to glow.[4] However, Prechtl and Schmidt sought poles in the wire. According to their theory, which was called transversal magnetism, magnetism longitudinally parts over the wire and in each wire section, on its two opposite points, a north and a south pole is created.[5] Ampère’s circular current theory and Faraday’s field theory could explain the direction of force without any poles, but experiments were needed to establish the force law of currents. Ampère dealt with conductor frames (plane coils), and Faraday with unipolar structures, that is, the rotating effect occurring between a closed circuit and a magnetic pole. Experiments were repeated at various research sites, especially in physical laboratories of schools. Electrodynamics appeared in university education; at least at those universities where the professor of physics was susceptible to new scientific achievements.

3. Research of Electricity in Hungary

The Hungarian research center was the Department of Physics, Pest University. Electrostatics was a traditional subject at the University. Its first textbook expressly dealing with electricity (*De Vi Electrica*) was published in 1746. Pál Makó’s book about lightning – published in Latin in Italy in 1780 and in Hungarian in Hungary in 1781 – describes Volta’s experiment concerning the conduction of electrical charges. In addition to electrostatics, Adamus Tomtsányi’s physics textbook (*Institutiones Physicae*) deals with galvanic electricity and the Volta battery, and its second issue published in 1823 introduces Oersted’s experiment. Naturally, the book also describes Volta’s electrometer and electrophorus (*Electrometrum Voltaianum*, *Electrophorus Perpetuus*).

The introduction of electrodynamics research and education in Hungary is attached to the name of Ányos Jedlik, a Benedictine professor of physics. He was of the same age as the galvanic cell; he was born in 1800. He lived almost 96 years, his scholarly activities embraced the period from early electromagnetism to the

[3] JESZENSZKY (1996).
[4] OERSTED (1820).
[5] HELLER (1902).

extensive use of electrical engineering. He became engaged in teaching and research in 1825; from 1840 to 1878 he was professor of physics at the Pest University.[6]

A note written by Jedlik in 1829 contains 292 physical experiments; of these, 13 deal with electromagnetism. Faraday's unipolar device with continuous rotation is also included among them. He extended the experiments relating to continuous rotation to the force between conductor frames. In 1822 Ampére claimed that the force applied by two closed circuits on each other could not create a continuous rotation.[7] In his experiments Jedlik pointed out that attraction between the frames could be changed into repulsion by altering the current direction, and thus it was possible to create continuous rotation with two closed circuits by properly changing the direction of the current. In section 290 he put this conclusion into words as follows:

> Una drata electro-magnetica circa aliam pariter electro-magneticam motum rotatorium continuum concipere potest,

that is to say, "an electromagnetic wire can create continuous rotating movement around a similarly electromagnetic wire". The experimental device contained a fixed and an iron-core rotating coil, with mercury commutator. This device was the ancestor of the DC motors with a commutator. Its later, further developed version drove various machines and a model railcar.

The current of the voltaic pile was insufficient for the powering of motors. Jedlik improved the operation of galvanic cells by several technological innovations. For instance, he used an impregnated paper wall instead of a ceramic diaphragm in a high-power two-fluid Bunsen cell and thus considerably reduced internal resistance. His battery with 100 cells generated power of a *kW* order. However, it was not the galvanic cell but the induction-based generators that led to progress.

In developing generators, Jedlik returned to Faraday's unipolar construction without a commutator. In order to increase voltage, he used several discs connected in series. His experimental machine made in 1861 had a special feature of technological importance; namely, the principle of self-excitation, in other words, the dynamo principle first appeared in the operating instructions Jedlik wrote for this machine. This machine was only used as a demonstration device, and Jedlik did not publish the new construction.[8,9]

4. The Capacitor Battery of Jedlik

Electrodynamics took roots at Pest University but this does not mean that electrostatics was pushed into the background. The typical device of electrostatics, the capacitor battery, remained to be the device for high-voltage and high-energy

[6] JÄGER ed. (1996).
[7] ALBRECHT (1885).
[8] VEREBÉLY (1931).
[9] SINGER and HALL (1958).

discharges. In 1863 Jedlik introduced his voltage multiplying capacitor battery in which the capacitors were charged in parallel and discharged in series connection. The device, which generated enormous sparkles, was awarded golden medal at the 1873 Vienna World Exhibition.[10] The appliance was made of an electrostatic and an electrodynamic device. The electrostatic device was a battery including 8 capacitors and a mechanical parallel-series switching device, whilst the electrodynamic one was one of the first induction devices, a Ruhmkorff spark inductor, which supplied high voltage for the charging of the capacitors. The inductor was fed by galvanic cells, which means that the appliance transformed a low-voltage galvanic current into a high-voltage static charge. The maximum spark length of Ruhmkorff's inductor was 20 cm, whilst the voltage multiplying capacitor plant gave a 2-feet (63 cm) long spark after a parallel-series switching over.

Jedlik made the connection on the analogy of the series-connected cells of the voltaic pile. In the long run, it was the basic device of electrodynamics, the voltaic pile, which paved the way for the improvement of the traditional device of electrostatics, that is, the capacitor battery.

The question may now arise where the conception of the voltaic pile, that is to say, the idea of connecting individual galvanic cells into series comes from. Although Franklin made experiments with capacitors connected in series, they were both charged and discharged in series connection. These experiments were not aimed at increasing voltage but their purpose was to examine the resultant capacity of Leyden jars. It would seem reasonable to seek the roots of voltage-increasing series connection in electrostatics but no trace of this connection can be found in the technical literature of the 18th century. This is what professor Teichmann pointed out in a paper he gave on the occasion of the Volta bicentenary.[11] It can now be deduced that the series connection of batteries was Volta's unprecedented genuine construction. It is easy to understand how he came to this solution. In the age of electrostatics there was no need for increasing voltage. Big friction machines were capable of generating a voltage of several hundreds of kV. The Leyden jars were used in order to collect a bigger charge, with the aim of increasing capacity. Since the size of these jars was restricted for technological reasons, a battery consisting of several jars was made, with units connected in parallel. On the other hand, the voltage of the silver-zinc galvanic cell, about $1.5V$, could hardly be observed, so the application of a voltage increasing series connection was a necessary idea.

With the parallel-series switching over of the Leyden jars, Jedlik made a significant achievement in electrostatics. This is also shown by the correspondence between Jedlik and Poggendorff. Although Poggendorff debated the novelty of the parallel-series switching device, he acknowledged that it had not yet been used for capacitors. In 1863 the significance of voltage increase by a capacitor was not yet quite evident but had a big role in high-voltage laboratories later on. Jedlik's

[10] 1873. "Science Exhibits at the Vienna Exhibition" - No.V. *Engineering* Oct. 31, pp. 365-6.
[11] TEICHMANN (1998).

capacitor battery is the ancestor of the surge generators used in our days. In 1876, three years after the Vienna World Fair, a device operating on that principle was constructed by Ernst Mach from 16 Leyden jars. In 1877, Gaston Plante's battery, comprising 80 capacitors, increased the voltage of a 800-cell battery to above 100 kV when connected in series. This device was considered to be the future competitor of spark inductors. An electrostatic device fed from a chemical power source became a competitor of the typical device of electrodynamics. These devices became symbols of the elimination of the limit which separated electrostatic and galvanic electricity or, in other words, the creation of an electricity that combined electrostatics and electrodynamics. This combined electricity became a theoretical basis for electrical engineering that took shape in the last third of the 19th century.

1999 was not the first time that the three pioneer devices of professor Jedlik, namely, the motor made from Ampére frames, the unipolar generator and the high-voltage capacitor battery were mentioned in Como. These devices were displayed at an exhibition held in Volta's home town in 1927 to remember the 100th year of his death.[12]

[12] ZELOVICH (1929).

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