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Johan Jacob Nervander and the quantification of electric current

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This article focuses on the developments in electromagnetism during the early 19th century. The discovery of electromagnetism by Hans Christian Ørsted in 1820 was a game-changing event which opened perspectives into deep understanding of physics and fundamental technical applications. In this paper, the principles to measure and quantify the electric current are given particular attention. Several scientists, like Schweigger, Poggendorff, Nobili, and Pouillet, contributed to the development of an instrument towards this purpose, the galvanometer. In this article, we put special emphasis on the researches by Johan Jacob Nervander, whose "tangent bussol", presented to L'Institute de France in Spring 1834, and later published in Annales de Chimie et de Physique, was a significant milestone in the instrumention of electrical engineering.

***Index Terms*—history of electromagnetics, electric current, tangent galvanometer, tangent bussol, Ørsted, Pouillet, Schweigger, Nervander**

Fig. 1. Hans Christian Ørsted [1] honored by the airline company Norwegian (photo: A. Sihvola).

I. Introduction: Ørsted and electromagnetism

Human understanding and exploitation of electrical and magnetic phenomena have a long history. For centuries these forces were considered to independent and separate. However, after the invention of the voltaic pile, a battery, by Alessandro Volta in 1800, a continuous source of electricity was available. This device offered the possibility to study the effects of electric current: production of heat, radiation of light, and chemical electrolysis. But indisputably the most profound development was the discovery of electromagnetism: the creation of magnetic force by electric current.

This happened two hundred years ago. In 1820, Hans Christian Ørsted (Fig. 1) demonstrated and documented the connection between electricity and magnetism for the first time. His short letter *Experimenta circa effectum conflictus electrici in acum magneticam*, dated 21 July 1820, spread out fast through the scientific circles of the world and caused a revolution in the understanding of the unified character of natural forces. Ørsted lived, worked, and performed his experiments in Copenhagen. And there, in Denmark, the bicentennial has duly been celebrated in 2020. For example, the recent publication of the book *Hans Christian Ørsted—the Unity of Spirit and Nature* [2], [3] illustrates several aspects of the man and his work.

What where the after-effects of the 1820 discovery? Ørsted's letter reached soon the scientific community in Paris, where François Arago demonstrated the electro-magnetic connection to the French academic circles in September 1820. And as the history goes, André-Marie Ampère (1775–1836) absorbed immediately Ørsted's discovery and started to build on it. During the weeks after Arago's seminar he worked intensively, and established the quantitative laws of electrodynamics. These were later (1827) codified into his exposition on the mathematical foundations of electromagnetism [4], which has been called by L. Pearce Williams—not unfairly—as the "Principia of Electrodynamics" [5]. It is, however, essential to note the different emphases of the character of magnetism by the two scientists: while Ampère reduced magnetic effects into macroscopic and microscopic electric currents, Ørsted considered that magnetism should have an ontological status in its own right [6].

Also other French scientists contributed to the understanding of the magnetic laws. To electrical engineering students, the law named after Jean Baptiste Biot (1774–1862) and Felix Savart (1791–1841) is a fundamental one, analogous to the Coulomb law in electrostatics. And again, this dates early, from the year 1820, with the connection to Pierre-Simon Laplace (1749–1827) who attached the field's inverse-square dependence on distance in the differental law to the inverse-distance dependence for the field due to a straight long current wire [7].

Also in Great Britain, the discovery of electromagnetism was immediately appreciated. Sir Humphry Davy and Michael Faraday reproduced the experiments, and Davy, as the President of the Royal Society, secured the prestigious Copley Medal already for the same year 1820 to Ørsted [8]. In France, however, it took considerably longer before he was formally honored: the French Académie des Sciences elected Ørsted as correspondent in 1823, and finally in 1842, he became Foreign Associated Member [9].

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Further advances in electromagnetics took place soon. In 1831, Faraday was able to demonstrate the generation of electricity from magnetism, and it was Faraday's Experimental Researches [10], [11] that inspired J.C. Maxwell to formulate his famous equations in 1860's. On the continent, another direction in the search of a general framework of electromagnetism can be traced from Ørsted and Ampère towards Wilhelm Eduard Weber and his efforts to unification of electric and magnetic effects in the mid-19th century [12].

But apart from the scientific understanding of electromagnetics, there were several domains in which Ørsted's discovery would have enormous impact, like telegraphic communications, electrical machines, and measurement instrumentation to quantify the electric current, all obvious in retrospect. In the following, let us focus on this last application which began to develop immediately after Ørsted's communications in July 1820. Although many people contributed to the progress in the development of devices for electric current measurements, the emphasis is mainly on the Finnish scientist Johan Jacob Nervander and his tangent galvanometer, the instrument also called "tangent bussol".

II. Schweigger and the multiplier

As everyone who teaches electromagnetics knows, demonstrating the Ørsted effect can be done much more effectively than using a straight current-carrying wire, like Ørsted has most probably done in his early experiments, see Fig. 2. Instead of a wire held close to the compass, let the current flow through a coil, a wire wound in a circle. A DC current loop is known to work as a magnetic dipole, and it makes a very efficient source of magnetism, in particular when its effect is multiplied by winding it into a coil of several rounds. The magnitude of the magnetic field decreases inversely with the distance from the straight wire of current, while that of a coil, being equivalent of a static dipole, has an inverse-cube dependence at large distances. Therefore, in the vicinity of the coil, the field can be made large, in particular when the number of loops in the coil is increased.

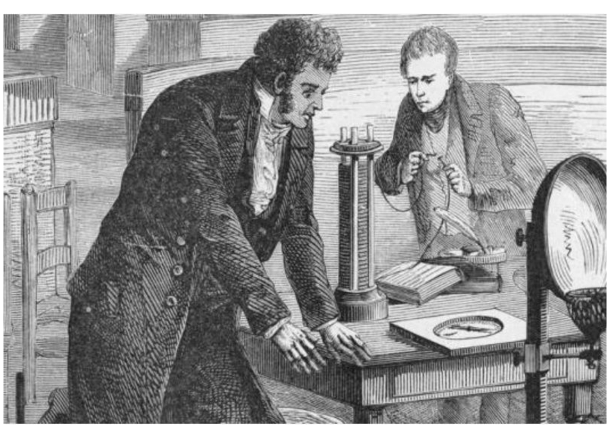

Fig. 2. The famous engraving of Ørsted's discovery depicts the situation of the observation in a very qualitative manner. The magnetic field from the wire at the distance in this constellation must have been rather weak. (Part of picture from [13, p. 61])

This idea of a "multiplier" as a source of electromagnetism dates from times shortly after Ørsted's publication. It was known under the name "Schweigger-Multiplikator" (Schweigger multiplier) to honor Johann S.C. Schweigger (1779–1857), professor of chemistry in the University of Halle in Saxony, present-day Germany [13]. The multiplier was used as a means to measure electric current. Simultaneously with Schweigger, similar multiplier arrangements were designed and built by Johann Christian Poggendorff (1796–1877).

The intensity of studies around the fascinating electromagnetic effect and race to uncover new properties around this law of nature lead also to disputes of priority. The honor for the discovery of the very phenomenon was claimed by also other people, sometimes even in a very blunt manner as Fig. 3 shows.

True enough, the possible connection between electricity and magnetism had been considered before. Ørsted was affected by German idealism and natural philosophy through persons like Immanuel Kant, Johann Wilhelm Ritter, and Friedrich Wilhelm Joseph von Schelling. Indeed, one can find obscure speculations in Schelling's writings about the interaction between electricity and magnetism and conclusion that all magnetic phenomena can be put to correspond to electric ones but not vice versa [15, p. 298].

The ethos in Ørsted's search can also be appreciated in this philosophical vein. Looking for the electromagnetic effect was not a random trial-and-error exercise for him: a mental preconception is needed in order to be aware of the direction from where to search and *"submit questions to Nature [...] this is only possible for someone who already knows how to ask such questions"* [16], [17]. A true observation cannot happen by chance.

III. Towards galvanometer

Using multipliers to estimate the magnitude of the electric current started from the efforts of Schweigger and Poggendorff. The instruments were, however, not yet able to provide quantitatively accurate estimates of the amplitude of the electric current. That would have been too much to expect. It is important to note that the concepts of circuit theory were not well established at the time: the researches by Georg Simon Ohm (1789–1854) were first published only in late 1820's. His textbook *Die galvanische Kette mathematisch bearbeitet* appeared in 1827, but not without hostile reception. It took a long time before Ohm's work was accepted by the scientific community. But finally, it was honored: in 1841, the Royal Society in London awarded the Copley Medal to Ohm "for his researches into the laws of electric currents".

Leopoldo Nobili (1784–1835) developed the astatic galvanometer in 1825 in which the current to be measured affects on a fixed magnetic needle pair where the two needles are antiparallel (see, for example [18]). Hence the earth's magnetic field does not have an effect on the system. However, one of the needles is inside a box which is surrounded by the coil in which the current flows, whence the current exerts a net effect on the needle pair. Less-known than the works by Nobili, Schweigger, and Poggendorff are the efforts during

Dr. J. S. C. Schweigger

ehemals ord. Professor der Physik an der Universität Halle a. S.

ist der Entdecker

des

Electromagnetismus

während

Dr. Hans Christian Oersted

ehemals Professor der Physik an der Universität Kopenhagen

irrthümlich

dafür angesehen wird.

Berlin 1874.

E. Schweigger'sche Hof-Buchhandlung

(früher Mylius Verlag.)

Fig. 3. J.S.C. Schweigger has also been claimed to be the discoverer of electromagnetism, here in a manner which is rather disrespectful towards Ørsted. The book cover says "Dr. J.S.C. Schweigger, earlier professor ordinarius of physics in the university of Halle (Saale) *is the discoverer* of electromagnetism while Dr. Hans Christian Oersted, earlier professor of physics in the university of Copenhagen, is *mistakenly* considered to be the one". Picture taken from [14].

the same time (presented in Spring 1821) by the chemistry professor at Cambridge University, James Cumming [19], see the galvanometer illustrations in [20].

For telegraphic purposes, the sensitivity of the detection of current was improved by attaching a mirror into the magnetic sensor. This is turned by the magnetic force, thus making it possible to observe small changes by the reflection of a light beam from the mirror. Such "mirror galvanometers" were used by professors Carl Friedrich Gauss (1777-1855) and Wilhelm Eduard Weber (1804–1891) in their telegraphic experiments in the Observatory of Göttingen in the 1830's. The mirror galvanometer was later (1858) patented by William Thomson (1824–1907, ennobled as Lord Kelvin in 1892).

Another name that appears in the literature about the development of the galvanometer is Claude Pouillet (1790–1868). The article by Pouillet [21], much cited in the literature, discusses the measurement of the electric current by its magnetic effect. In the article, Pouillet defines two instruments: the tangent-bussol and the sine-bussol ("boussole des tangentes" and "boussole des sinus") which he uses for this purpose. (The French term "boussole" is often translated as "compass".) It is however conspicious that in [21] Pouillet does not refer to earlier works on the subject, except to Mr. Beqcuerel, and that only in connection of the principle of the particular Voltaic piles used (*piles clissonnées* [21, p. 267]).

But the history of galvanometers is not complete without additional remarks. The aim in the present article is to focus attention on the fact that the tangent galvanometer ("tangent-bussol") had been designed and used earlier. In the following, let us return to the 1820's and concentrate on the Finnish scientist and poet J.J. Nervander who had an important contribution to the development of the instrumention to accurately measure the electric current.

IV. Johan Jacob Nervander

Johan Jacob Nervander (1805–1848, Fig. 4) was born in Nystad (Uusikaupunki), Western coast of Finland. He excelled in school and university and graduated in 1827 from the Royal Academy in Åbo (Turku), the oldest university in Finland. This was founded already by the Queen Christina of Sweden in 1640. In the peace treaty of Fredrikshamn (Hamina) that concluded the Finnish war (1809), Finland had been ceded from Sweden to become an autonomous grand duchy of the Russian Empire. The great fire of Turku in 1827 helped the Emperor to move the university to Helsinki. Nervander, who was extremely gifted in humanities and sciences, followed with his Alma Mater to the new capital. Among his interests one was the new effect of electric current on the magnetic needle. On this topic he, in 1829, defended his docent thesis *In doctrinam electro-magnetismi momenta* [22] at the university in Helsinki [23], [24].

After the docent position, Nervander gained a grant with which he would launch on a years-long to travel to Europe's leading centers of physical science. He visited Stockholm, Copenhagen, Göttingen, Paris, Florence, and St. Petersburg during the trip in 1832–1836. During this journey, Nervander met also with Ørsted, among other scientists. Nervander worked on his galvanometer during these years and presented the instrument to the French Academy in the spring of 1834. A report on the work *(Mémoire sur un Galvanomètre à châssis cylindrique par lequel on obtient immédiatement et sans calcul la mesure de l'intensité du courant électrique qui produit la deviation de l'aiguille aimantée)* was published in the Academy's Annals the same year 1834 (for a reprint and commentary of this work, see [23]).

After returning to Finland, Nervander entered academic politics and was able, using connections to the imperial capital St. Petersburg, to secure funding to establish an observatory for extremely precise geomagnetic measurement [25], [26], [27]. Unfortunately smallpox cut his life short only in an age of 43 years. However, the documented magnetic measurements are very comprehensive and cover several decades through the 19th century [28].

V. The tangent bussol by Nervander

The design of a galvanometer to quantify the electric current was occupying Nervander's mind already during his early study times in the university in Turku. Unluckily, with the fire of the city, the library and the machine shops of the university were destroyed, and hence the scientific starting circumstances

Fig. 4. Johan Jacob Nervander (1805–1848). Litography by Frans Oskar Liewendahl based on the painting by Carl Petter Mazér (1837). In the Antell and Wadström collections, Museovirasto (Finnish Heritage Agency). Attribution 4.0 International CC BY 4.0.

of Nervander were modest. Nevertheless, his docent thesis [22] lead him already very far towards understanding the concepts of current and even elementary circuit theory, and the possibilities to evaluate the magnitude of the electric current. Hence during his later extensive travels through Europe's scientific centers he succeeded with the final designs and fabrication of his tangent galvanometer.

The label "tangent galvanometer" (or "tangent bussol") is a proper name for the instrument. In its simplicity, the working principle is that a magnetic needle, floating freely by a light thread and aligned with the horizontal geomagnetic south-to-north direction, will be deflected by the magnetic field caused by an electric DC current in its surroundings. As Fig. 5 shows, the relation between the (horizontal component of the) local Earth's magnetic field (flux density) $\mathbf{B}_{\text{Earth}}$ and the magnetic field caused by the electric current $\mathbf{B}_{\text{current}}$ is

$$\tan\alpha = \frac{\mathbf{B}_{\text{current}}}{\mathbf{B}_{\text{Earth}}} \tag{1}$$

where α is the deflection angle of the compass needle. As the magnetic field caused by the electric current is proportional to the magnitude of the current, so is also the tangent of the angle. Of course this requires that the arrangement of the measuring constellation is such that the two magnetic field components in Fig. 5 are perpendicular to each other.

Nervander has documented very well his galvanometer [23], [29]. A silk string is carrying a long magnetic needle which hangs freely inside a box surrounded by a multiplier coil, as shown in Fig. 6. The string is inside a glass tube to prevent external disturbations affecting the movement of the needle. The coil (in fact a double coil, a twisted wire to double the effect of the current) has been wound around the wooden box, making several rounds. The box can be turned about its vertical axis. Hence the magnetic field due to the current in the coil can be oriented in any direction. To detect the deflection angles, there is a scale and a pointer above the box. The only part of the system which is magnetic is the hanging needle; all other materials are non-magnetic (copper, silver, cherry wood, and glass).

What was so revolutionary in the design by Nervander? The galvanometer was certainly original in many of its details, but

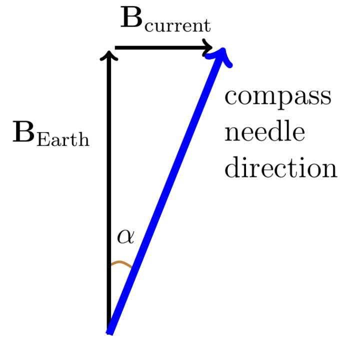

Fig. 5. The tangent of the compass needle deflection angle α is proportional to the magnetic field amplitude of the DC-current-caused magnetic field $\mathbf{B}_{\text{current}}$.

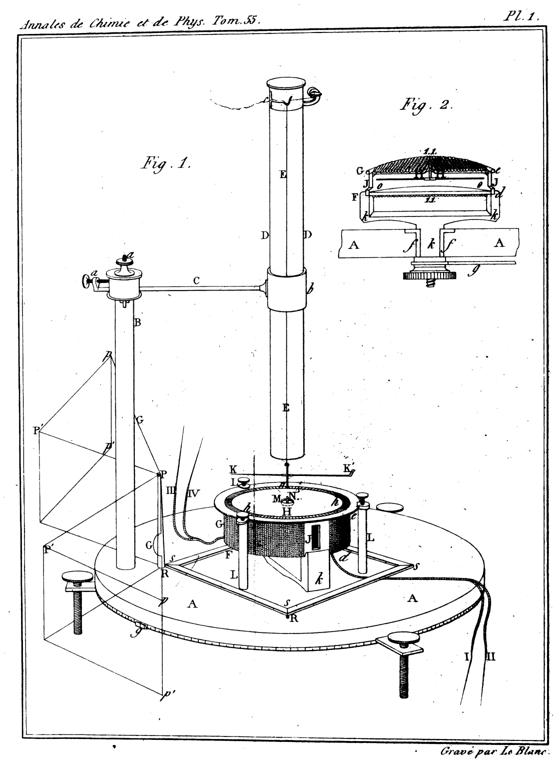

Fig. 6. Nervander's original tangent galvanometer from his report of 1834 [23].

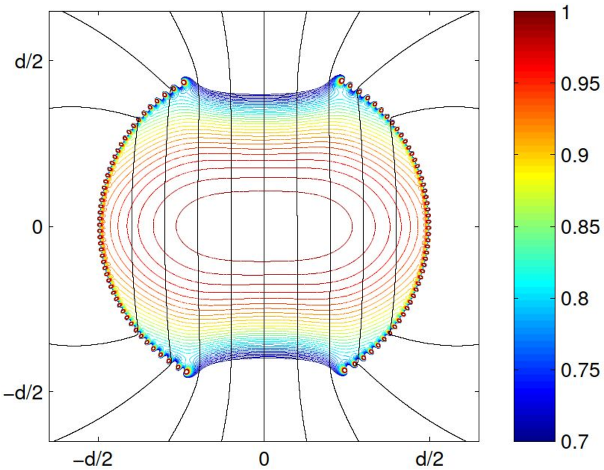

Fig. 7. Contours of equimagnitude of the magnetic field in the horizontal plane of the galvanometer cavity of Nervander's design. The field amplitude is normalized by the field in the center of the box. Computations by J. Venermo [30].

a particular advantage was its extreme sensitivity. Nervander wound his double coil very densely around the box in which the sensor needle was located. The box (with height of 23 mm and diamater of 70 mm) was for the most of its surface covered by the wires, thus creating an effective uniform surface current. Unlike in other multiplier designs of the time in which the field due to the current is strong in the center of the coil but decreases strongly elsewhere, the field distribution is very homogeneous within Nervander's box. This allows the use of a longer needle and greatly increases the sensitivity and accuracy of the instrument.

Fig. 7 shows the results of a present-day numerical computation [30] of the field distribution in the box with exactly the dimensions and parameters in Nervander's original galvanometer. It is quite astonishing that Nervander, without any computational tools to enumerate the magnetic field, was able to achieve such a high degree of homogeneity throughout the internal dimensions of the box, thus making use of the extended volume in sensing the field.

The voltage sources that were available for Nervander were typical of the time: he used Voltaic piles, and the galvanic connections to his circuits were mercury cups in which the ends of the coil were immersed. He was aware of the fact that when he would double the current by connecting both of the wound coil wires to the source, the sources would be more loaded, with the risk of the effect being not linear. To this problem he had a smart solution: instead of forcing the current through only one wire in the double coil, he had a third wire (of the same length as the two measurement wires) which did not touch the box. Then the comparison between single and double currents could be safely performed by first connecting a single wire with this idle wire, and in the double-current case by using both wires of the twisted wire, thus retaining the same load upon the Voltaic piles.

The description by Nervander of his tangent bussol was so detailed that it allows a faithful reconstruction of the instrument. Such a project was performed by Mr. Jukka Venermo as his Master of Science (Tech.) thesis in Helsinki University of Technology [30]. In addition to the magnetic field analysis of the system, the reconstructed instrument was also tested experimentally and shown to perform as Nervander had reported in [23]. Fig. 8 shows the resulting galvanometer on display.

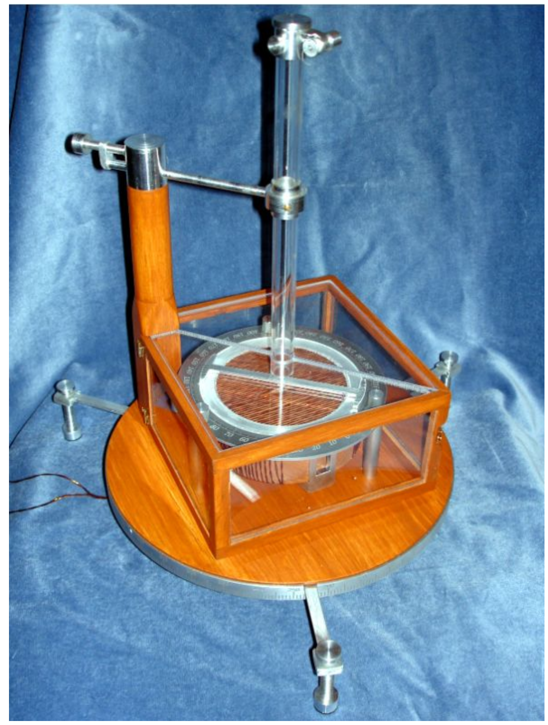

Fig. 8. The modern reconstruction of Nervander's tangent galvanometer [30]. This instrument is on display in the lobby of the Maarintie 8 building at the Aalto University campus in Espoo, Finland. (Photo: J. Venermo).

VI. Conclusion

The early 19th century was one of the golden times in the intellectual and technical developments of electricity and magnetism. The discovery of the magnetic effect by electric current two hundred years ago opened avenues, in addition to several useful applications of electricity, also for the possibility to quantify the ”electric conflict” (to use Ørsted's terminology for the direct electric current). Scientists and technicians around Europe, like Schweigger, Poggendorff, Cumming, Nobili, Gauss, Weber, Pouillet, and Nervander worked tirelessly in searching for new design principles for measuring electric current. The evolution of galvanometers towards increasing accuracy produced instrumentation for electrical scientists in the coming decades of the 19th century in their mission to uncover the still-hidden laws of electromagnetics.

Acknowledgment

I thank Professor Emeritus Ismo Lindell for many helpful discussions and relevant historical references.

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