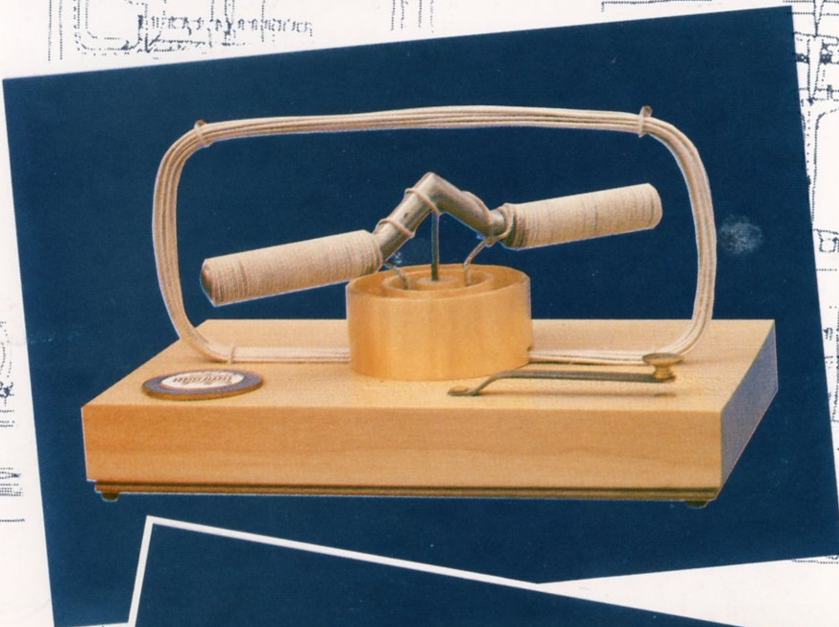
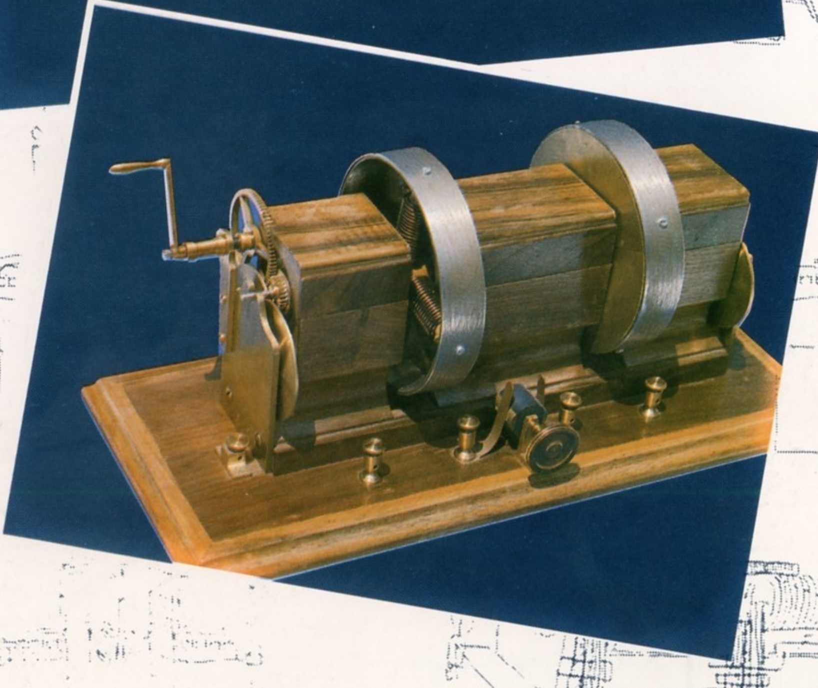
Ányos Jedlik

a Hungarian pioneer of electricity





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Ányos Jedlik
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of electricity

by Professor László de Verebélÿ

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Preface

The Ányos Jedlik Society, established on 22nd April 1993 at Budapest considers his honourable duty to re-edit the nowadays not easily accessible books, scientific papers, manuscripts written about its denominator. The Society hopes to provide thereby adequate information—both home and abroad—partly on the activity of the first great Hungarian electrical engineer, partly on the scientist himself: the Benedictine monk, the university professor and the patriot.

It is therefore my pleasant duty to put before you a paper of professor Verebélÿ, written in 1928. I feel this preface is lacking completeness, if the paper's author, professor Verebélÿ himself is not introduced shortly as well.

Professor Verebélÿ was born in 1883. His present paper appeared 1928 in the periodical of the Hungarian Electrotechnical Society, to establish Ányos Jedlik in the ranks of physicists and pioneers of electrotechnics for the past century.

When the paper was published in 1928, Professor Verebélÿ was in charge of the chair for electrical power plants and railways at the Budapest Technical University.

The author of this preface, who was once a pupil of professor Verebélÿ himself cannot escape his opinion that the personal characteristics of these two men were in many cases very similar, sometimes in total agreement. That applies to the conceptual independence, the intellectual curiosity, the perseverance, the love of their country and the almost total lack of the quest of fame.

This parallelism can be further extended. Both had almost paternal feeling and appreciation toward their pupils. Long is the list of Hungarian men of erudition, who under the watchful guidance of Jedlik became physicists, respectively distinguished engineers in the laboratory and plants of the electrical industry.

It is finally my firm conviction that both these men are entitled to a positive reappraisal of their role in the Hungarian history of science. That is, why our Society turns to the much quoted Verebélÿ paper on Jedlik, publishing it again after 70 years.

November 1998, Budapest

Árpád Király
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Introduction

Famous masters and modest workers are building up the ever increasing magnificent edifice of our knowledge of natural science. The genius of the former, generally crowned by the acknowledgement of their contemporaries, constructs at single strokes whole aisles of this edifice and their wide mental horizont fixes the trend of development for many decades, even for centuries in advance. The in details absorbed silent work of the latter, usually almost unknown even to their closest surroundings, compiles one by one the stones, the importance of which—from the point of view—of the whole edificeremains sometimes unrevealed even to themselves and of which often the devoted investigation of posterity only makes clear that these stones are the organic parts of a mighty pillar from which in the course of time issued a range of epoch-making inventions.

In this latter group of erudite researchers ranks that honourable eremite of the l9th century's Hungarian scientific life whose work we wish to illustrate and to appreciate in this paper, bowing before him the flag of our homage.

The excellent natural philosopher of our days, Ramón y Cajal, designates five properties which the cultivators of science must absolutely possess to make their work successful. These properties are: spiritual independency, intellectual curiosity, perseverance in work, patriotism and desire of fame.

In the interesting individuality of Ányos *Jedlik* we find all these properties with the exception of the last one which he lacked not only by his innate modesty but also by the spirit of his monastic state which penetrated his whole being. "The timid seclusion—says Baron Loránd *Eötvös* in his memorial speech—was his one great fault that prevented him from widening his scientific horizon by intercommunication with others and, vice-versa, which hindered him from animating others by his own science (...) Jedlik went lonely on the way he traced for himself and yet he trod more than once upon the path of the great inventions that make the glory of the past century. He searched much and found much, but as he did not publish his work, his compatriots took no notice of it, his inventions remained unknown abroad, and therefore his name scarcely appears in the scientific literature on the list of the XIXth century inventors."

It was considered to be the Hungarian Electrotechnical Society's duty to make up for this at the memorial meeting held on the 3rd May 1928, for which we got out from the time-honoured vaults of the seminary of the ancient Abbey in Pannonhalma and from the scientific collection of the I. Physical Institute of the University of Sciences in Budapest, where they have been reposing so long, Jedlik's small machines in order to give palpable proof of the creative mind of their master and to witness the pious reverence with which the Hungarian electricians wish to pay homage to the memory of the first Hungarian pioneer of electricity.

Non omnis moriar.

Ányos *Jedlik* was born at the dawn of the great century of renaissance of the natural sciences, on the 11th January 1800 at Szimő (County Komárom, Hungary), from simple and poor farmers. He began his secondary school training at Nagyszombat, continued the same in the grammarschool of Pozsony and after having finished these studies, he entered, in the 17th year of his life, upon his parents desire and also following his own individual inclination, the St. Benedictine order. He received his monastic disciplines and his higher scientific education in the famous seminary of the Pannonhalma Abbey, where in 1822 the doctor's degree of philosophy was conferred upon him and where he was ordained priest in 1825. Immediately thereafter he began his long career as teacher. He taught physics first at Pannonhalma and then at Győr. In 1830 he went to the Academy of Pozsony. In 1840 he was appointed a professor at the University of Pest where he occupied the professorial chair of physics for 38 years, and wherefrom, after 53 years zealous activity, he retired in the seventy-ninth year of his life, in full mental freshness, to enjoy the well deserved rest.

Jedlik preserved his love of work and his desire of knowledge until his very last days. Even in his reclusion in Győr he continued his zealous work and when the slowly vanishing capacities of his oldering body began to trouble him in his investigations, he used to say desperately pointing at the books recently received: "If they would only send me also time with each one!"

His view of life is concisely characterized by the simple words he addressed on the 15th December 1895, a few days before his death, to a friend of his in Győr, saying: "My dear brother, my life was long, but work did never fatigue me; what would become of us if God'would deprive us of our ability to work?"

Jedlik's spirit was that of a typical researcher. His beloved home was the quiet laboratory, his greatest pleasure were the experiments, and all his delight was to make appear and to govern the mysterious forces of Nature by some small apparatus invented by himself and to unravel the magnificent laws revealing themselves. In his eyes physics were a source of delight completely filling out life. Once, when in his late old age a younger friar-fellow asked him: for which reason he had chosen just physics for the object of his studies and why not theology, which latter surely deals with the most sublime things, he answered: "In any branch of science I could have learned sufficient and nice things, but in physics I not only learned but at the same time I enjoyed and delighted myself." At another occasion: "My dear young brother, I learned to know God much better from physics than you from theology."

His work was—similarly to that of *Faraday*—more of practical than of theoretical nature. For the latter he was lacking the necessary higher mathematical training. For this lack he was, however, compensated by the innate researching instinct of a genuine physicist, which led him also to untrodden paths and which enabled him to create original and even important things on more than one territory of the field of science cultivated by him.

Although his greatest work, for which the Hungarian Academy of Sciences elected him, in 1858, directly a regular member and for which he received the Academy's great prize, was "The physics of the heavy bodies" (1850), yet his interest was mainly devoted to optics and especially to electrophysics, which was in its most promising infancy at the beginning of the last century. Among his studies in optics his work "On the phenomena of the light rays and particularly on the inflection of the light rays" (1845), further his essay "On the modification of the Fresnel and Pouillet apparatus for light interference" (1865), finally his extremely fine optical grates which were well known even abroad, are worth mentioning. His manifold work in electrophysics might be characterised by his academic inaugural address: "Determination of the whole work of electric batteries" (1859), further by his essays entitled "Concatenation of Leyden jars specially assembled" (1863), "On tubular electric condensers" (1867) and "On the concatenation of electric condensers" (1879). These latter two essays referred to an interesting apparatus of his invention that became well known abroad and which the international jury of the Vienna International Exhibition (1873) rewarded with the Medal of Progress.

Much more important, however than all these, are: the "electromagnetic rotor" and the "unipolar electric inductor", which apparatus throw a much stronger light on Jedlik's inventing, genius. Unfortunately these apparatus remained unknown to his contemporaries and the due estimation of same, from the point of view of the development of science, is incumbent therefore upon the historian of posterity.

The electromagnetic rotor

Our generation, living in the era of triumphant electrotechnics, must look back more than a hundred years in the history of physics, in order to arrive at those feverish investigations, started within the walls consecrated to the "pure science" of the laboratories, which investigations inspired scientists to endeavour to penetrate into that miraculous new world of the "imponderabilia", the doors of which were disclosed by the accidental observation made by the anatomist of Bologna, Luigi *Galvani,* on frog legs on the 30th August 1789, and respectively, by the results of the experiments Alessandro *Volta* made with his electric pile, discovered at the end of 1799 and presented on the 26th June 1800 before the Royal Society in London.

The most prominent amongst these inventions and of cardinal importance was the discovery of the Danish physicist Hans Christian *Oersted,* professor at the University of Copenhague, published in his essay dated June 21st 1820, which—revealing, the effect of galvanic current on the magnetic needle—enlightened the long since foreboded correlation between electricity and magnetism.

The inflamed torch of the new branch of science was next carried further by the sagacious professor of the Collège de France, André Marie *Ampère* who, on the 18th September 1820, not more than one week after Oersted's discovery was made known in Paris by Arago, appeared with a new discovery of great importance, before the Institut de France, proving the effect that galvanic currents exert upon each other, and laying down by this discovery the foundations of electrodynamics.

A few weeks later, on the 10th November 1820, the manysided Dominique François Jean *Arago* reported on his observation, viz.: that current-conductors have magnetic properties, attract iron-filings, and that the soft iron or the steel-needle placed inside a coil called by Ampère "solenoid", becomes, under the effect of the current, a temporary or, respectively, a constant magnet.

The rank of inventors having laid down the foundations of electrotechnics is closed by Michael *Faraday,* who became from bookbinder one of the most eminent experimenter of all times and who, while being director at the laboratory of the London Royal Institution, discovered according to his diary on the 29th August 1821, that the current influences not only the magnetic needle and another circuit independent from it, but also that the closing or opening of any circuit induces electric current in any other closed circuit in its proximity, thus also in itself—this current being, however of transient nature only. This is the phenomenon of the mutual or respectively of the self-induction, from which in Faraday's brain—always inclining to realities—issued the basic element of the most fertile hypothesis of electrotechnics: that of the electromagnetic lines of force.

At this epoch, in which physics were full of great discoveries and new ideas closely following each other, young *Jedlik* starts his career, when in autumn 1825, immediately after having been ordained priest, he is nominated—among others—a teacher of natural science in the college of his order. It may easily be understood that this young friar, absorbed by the love of his science and inclined to research, turns all the interest of his susceptive mind to the new branch of science which suggested such enormous possibilities: to electromagnetism. After having made himself acquainted, from foreign reviews, with the fundamental phenomena and with the apparatus designed for demonstrating the same, he also begins to experiment and when studying the effect of current on a magnet, he places, following his own original idea, a strong electromagnet into the *Schweigger* multiplier instead of a feeble magnetic needle. It is certainly the great declination so obtained that suggested to him the possibility of making use of the repulsive force for the realisation of constant rotation.

(J. S. Ch. *Schweigger,* Professor of physics and chemistry at the University of Erlangen and later at the University of Halle, used a multi-turn wire coil wound on a square wooden frame, in order to increase the effect of current on the magnetic needle. He presented this apparatus called *multiplier* before the Society of Natural Sciences of Halle in September 1820 shortly after Oersted's fundamental discovery.)

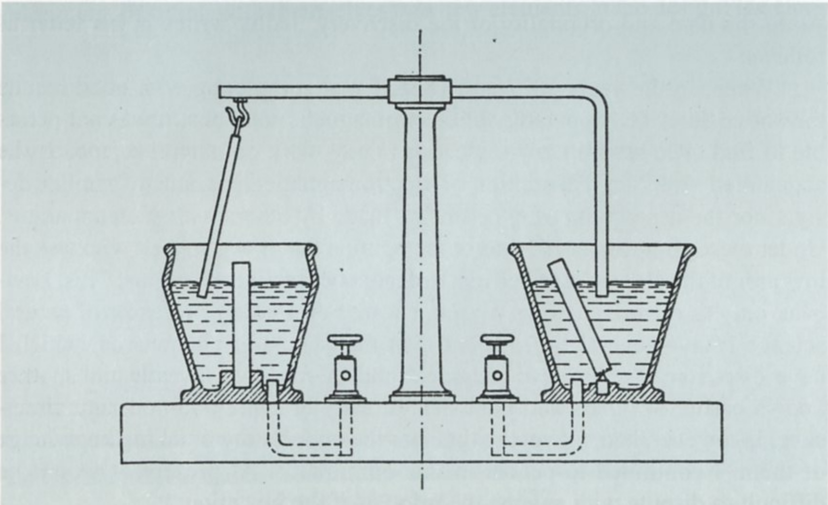

Fig.1. Rotating device of Faraday, from 1821.

The nature of the discovery is characterised by the following words extracted from a letter Jedlik addressed to A. Heller, Secretary of the Hungarian Academy of Sciences, on the 18th February 1886, the draft of which is now in the collection of manuscripts of the Pannonhalma Abbey, where he says: "... since, from the position where it stands parallel to the plane of windings of the multiplier, the electromagnet would, under the magnetic effect of the multiplier, come to a stillstand again at the point where its direction is at right angle to the plane of the windings of the multiplier, therefore, in order to prevent its stopping at those places and, moreover, to cause the electromagnet to continue its rotating motion without interruption; the design of the multiplier has to be modified in such a way, that the current passing through the winding of the electromagnet becomes reversed at the points where the direction of the electromagnet forms a rightangle to the plane of the windings of the multiplier".

It is characteristic to the fertility of Jedlik's mind that on this principle he at once elaborated three kinds of rotating apparatus (which he illustrates in his above mentioned letter by rough sketches), viz.:

in the first apparatus the multiplier coil stands still and the electromagnet rotates in it;

in the second the electromagnet stands still and the multiplier coil rotates around it; finally

in the third apparatus the multiplier is replaced by an electromagnet so that one electromagnet rotates above the other fixed electromagnet.

As to the date and originality of the discovery, Jedlik writes in his letter as follows:

"When, in the years 1827 and 1828, I was completing with good results the above described apparatus for electromagnetic rotations, it was not possible to find or to read, in any review or in any work on natural science I was acquainted with, any description of electromagnetic apparatus of similar design, nor the description of experiments made by others with such apparatus. Under these circumstances I was of the opinion that it was myself who was the inventor of the above described electromagnetic rotating apparatus. This, however, only as regards my own person, because as a young professor of natural science I have several times found that many natural phenomena, which I have discovered by my own judgment and by my own investigations, were known earlier to others and published already in some book on natural science, I, however, had not yet the time nor the opportunity of taking knowledge of them. I continued to persist in this opinion.(...) At present, it would be difficult to dispute with anyone the priority of the invention."

We cannot share this quiet resignation of the retired scientist who worked only to satisfy his own intellectual desire. What his modest person, exempt from all vanity, refused to try though thoroughly conscious of his right, we shall do it now. We shall celebrate—as a homage to his spirit and to the glory of the Hungarian genius—after just hundred years, that joyful moment—which he used to remember still at his very old age—in which he first saw his small apparatus begin to rotate under the effect of the mysterious invisible electromagnetic forces.

*

The first who succeeded in bringing into rotatory motion a current carrying conductor round a magnetic pole, was *Faraday* who reported this in a paper dated 11th September 1821. Faraday then constructed several ingenious small apparatus to demonstrate the reciprocal effect, in which apparatus there rotated either an appropriately shaped current carrying conductor round one pole of a rod-shaped steel magnet (see Fig.1.), or one end of a supported magnetic steel rod round a current carrying conductor. On the same reciprocal effect is based "Barlow's wheel", still nowadays well known in the physical laboratories, invented by Peter *Barlow,* Professor at the Woolwich Military Academy, in 1822 (see Fig.2.). This apparatus consists, as well known, of a toothed copper disc placed between the two poles of a horseshoe steel magnet and plunging with its lower part into a pot filled with mercury. The disc begins to rotate when current flows in radial direction between its axis and the mercury.

It is at this point that Jedlik's electromagnetic rotors join the chain of development, bringing with themselves two new elements in the design: the elec-

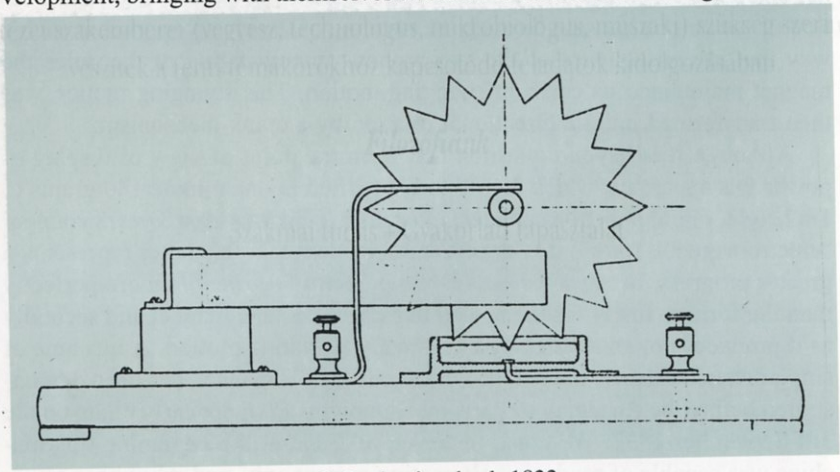

Fig.2. Barlow's wheel, 1822.

tromagnet replacing the steel magnet and the mercury-commutator. Although the date of the invention of these apparatus is not proved exactly by documents, it is certain that this had taken place before Jedlik was called to the professor's chair in Pozsony, consequently at the epoch between 1826 and 1830, from which years the memory of the old scientist designated—as we have seen it from his above cited letter—the years 1827 and 1828 as more exact limits.

Nowhere in the history of physics can we find any notice that the above mentioned two innovations—which we must claim as having been important ones in that early epoch of electrotechnics—have been applied by anyone before Jedlik. Therefore, we can consider it as fully proved that the inventor of the first rotating apparatus working on the basis of pure electromagnetic reciprocal effect was in fact Jedlik, who, with his customary modesty, states this fact in the following words: "I owe the same (i. e. the electromagnetic rotors) to my own endeavourings on the basis of Oersted's, Ampère's, Schweigger's and other's discoveries."

Generally, the technical literature designates Salvatore *Dal Negro,* Professor of physics and mechanics at the University of Padova, as the inventor of the first electromagnetic motor. Dal Negro's machine, a similar one to which was constructed almost at the same time by Joseph *Henry* Professor in America, dates from 1831 and it is the first specimen of the group of the so-called *swinging motors,* inasmuch as the driving force was supplied by a steel magnet swinging to and for between the two poles of an electromagnet, the steel magnet changing—by means of a simple commutator—at each swing, the direction of the current passing through the winding of the electromagnet in such a way that in consequence of the synchronous interchanging of the poles the magnet maintained its constant swinging motion. This swinging motion was then transformed into unidirectional rotation by a crank mechanism.

Although it is beyond question that from the point of view of display of power this apparatus, which is said to have lifted in one minute 180 grams to 1m height, might rather be called *a motor* than Jedlik's at least 3 years younger "electromagnetic rotor", it is nevertheless evident that this latter represents a greater progress, because it resolves the problem *in principle* more perfectly than the former, firstly for the reason that it has no steel magnet and secondly as it produces not an alternating but directly a rotating motion. A machine of similar characteristics, but still provided with a steel magnet, has been demonstrated before the Academy of Paris by Hippolytus *Pixii* not earlier than on the 3rd September 1832. We must, however, add that at the beginning this machine was capable of producing alternating current only, and it has been transformed into a direct current generator, or motor respectively, in the next year only when, upon Ampère's suggestion, it has been equipped with a Clarke commutator. It consisted of a steel horseshoe magnet revolving round a vertical axis, above which, opposite to its poles, two coils were placed connected in series and wound on a soft iron core. If, by means of a handle, the magnet was rotated rapidly alternating current was induced in the coils, this current being rectified by the commutator. Vice-versa, if the coils were excited from a separate source of current, the magnet began to rotate, whilst the polarity of the coils was changed synchronously by the commutator fixed on the shaft. The Scotch William *Ritchie* inverted in 1833 the elements of Pixii's machine ap-

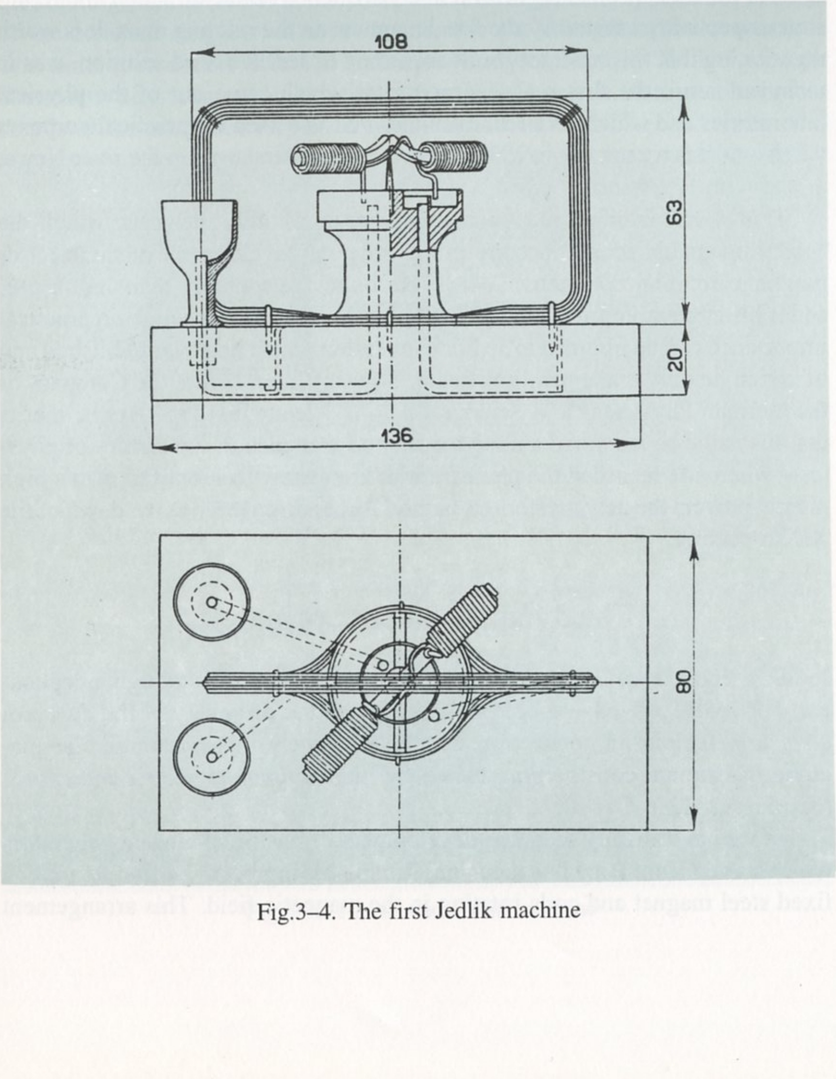

Fig.3–4. The first Jedlik machine

plying a fixed steel magnet and rotating coils, making thus further progress in the direction of the later development of the electric machines.

It is only about six years after Jedlik's discovery that we meet again the essence of his invention, i. e. the merely electromagnetic rotation, in the motor demonstrated in 1834 before the Academy of Paris by Moritz Hermann *Jacobi* the physicist of German origin. This machine consisted of two times twelve horseshoe electromagnets radially disposed and fixed on two star-shaped wooden plates, between which there was placed as rotor a wooden star with 6 arms holding 6 pairs of rod-shaped electromagnets. A four-disc commutator fixed on the shaft changed the direction of the exciting current at due moment so as to produce a constant rotation in consequence of the attraction and repulsion respectively exerted by the fixed magnets on the rotating ones. It is worth mentioning that this machine, built according to Jedlik's third solution, was in technical sense the first real electric motor which came out of the physical laboratories and which, as a real machine, was also used for practical purposes when—as it is reported—in 1838 it drove in St. Petersburg, up the river Newa, a boat with 12 persons.

This short historical retrospection clears up entirely the place which the "electromagnetic rotors" occupy in the order of development of the electromagnetic rotating apparatus, and proves quite indisputably than Jedlik precedes his contemporaries in this domain by several years. Though no practical importance can be imputed to Jedlik's invention which he never published and of which he only made mention, nearly 30 years later, before the Congress of the German Physicians and Scientists held in Vienna in 1856—yet he merits that his name be inscribed among the first on that page of the history of physics—where are recorded the pioneers who knew how to submit to man's high mental powers the new mysterious natural forces discovered at the dawn of the XIXth century.

The dynamo-electric principle

Jedlik's second great invention, which in its consequences—though independently of Jedlik proved—to be epoch-making, is the discovery of the *dynamo-electric principle,* in connection with an extremely ingenious unipolar machine of original construction, called by him *"unipolar electric inductor"*. (See Fig.12–13.)

As we have already seen, the development of the direct-current generators really started from Ritchie's machine, Ritchie having been the first to apply a fixed steel magnet and coils rotating in the magnetic field. This arrangement was also ruling in the magnetoelectric machines of *Saxton* (1833), *Clarke* (1834), *Wheatstone* (1841), *Stohrer* (1844) and of others, these solutions differing from each other merely in the relative arrangement of the constituent parts and, later on, in the number of the magnets applied.

It was for the first time in 1845, that the idea of replacing the constant magnets by stronger electromagnets came to *Wheatstone* and *Cooke* who have in that year patented a machine equipped with electromagnets excited from a separate source of current. Jacob *Brett* was the first who suggested to use the current of the machine for excitation in his patent dated from 1848, according to which the current induced by the constant steel magnets in the winding of the rotating part, after being rectified, is led through coils applied on the legs of the constant magnets, in order to increase the strength of these magnets. The same idea occurred in 1851, independently of Brett, to William Joseph *Sinsteden,* physician and physicist in Berlin, who made also in some other details of the machines very successful amendments.

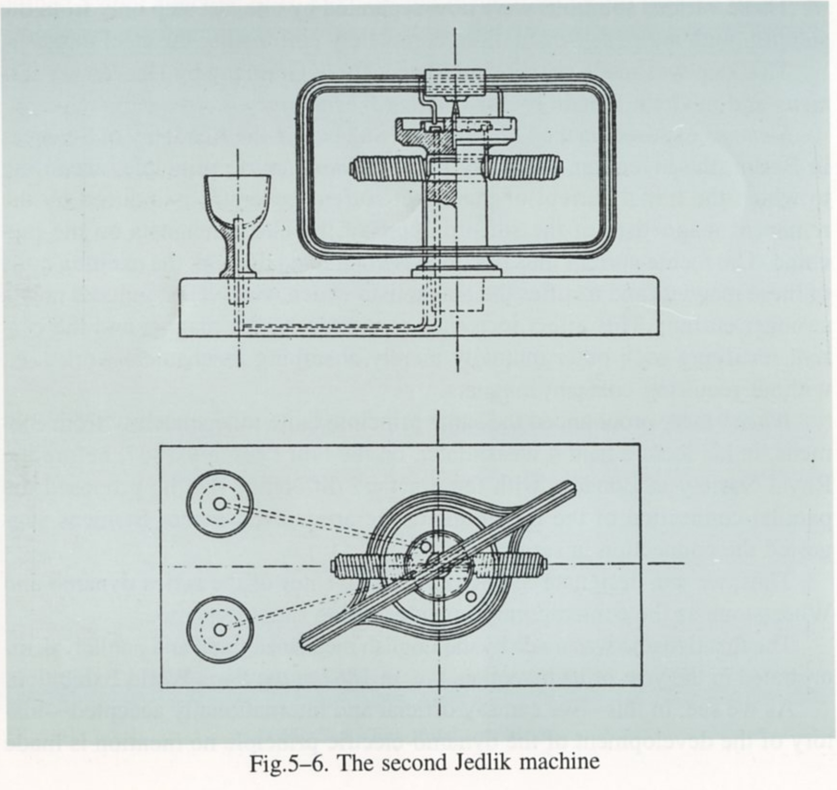

Fig.5–6. The second Jedlik machine

From that time it became general custom, to use in various alternatives, constant steel magnets as primary exciters and electromagnets excited by the current of the machine, as secondary or strengthening exciters.

The Dane Soren *Hjorth* constructs in 1855 a machine having, in addition to the steel magnets, strong electromagnets; these latter were excited by the current of the machine, initially induced by the steel magnets.

Wilde, from Manchester, demonstrates on the 13th April 1866 before the Royal Society in London a double machine set, in which the main current-supplying machine is equipped exclusively with electromagnets these being excited by the current of a small Siemens d. c. generator of the well known double T inductor type. On the same principle Wilde has also built a triple machine set, i. e. in which the current of the steel-magnet Siemens inductor excited the electromagnets of a second machine, and the current of the latter the electromagnets of a third machine, these being consequently so strong that a 15 H. P. steam engine was required for driving the whole set.

These various solutions were now separated by one last step only from the solution with entire self-excitation, completely eliminating the steel magnets.

This step was made nearly simultaneously in Germany by Dr. Werner *Siemens* and in Great Britain by Sir Charles *Wheatstone.*

Siemens exposed on the 17th January 1867 before the Academy of Sciences in Berlin, the invention, called by him *dynamo-electric* principle, according to which the initial current of the direct-current generator is induced by the remanent magnetism of the soft-iron core of the electromagnets on the machine. The feeble current thus obtained is conducted through the exciting coils of these magnets and fortifies the magnetism which, vice-versa, induces now a stronger current. This effect increases continuously, the magnet and the current fortifying each other mutually merely absorbing mechanical work i. e., without requiring constant magnets.

Wheatstone, pronounced the same principle quite independently from Siemens, in his lecture held 4 weeks later, on the 14th February 1867, before the Royal Society in London, with the practical difference that he proposed the parallel-connection of the field coils to the armature, whereas Siemens suggested the connection in series.

Thus, we can designate Siemens as the inventor of the series dynamo and Wheatstone as the contemporary inventor of the shunt dynamo.

The first dynamo was made by the English mechanist Ladd and publicly demonstrated in the year of its invention, i. e. in 1867 at the Paris World Exhibition.

As we see, in this—we can say official and internationally accepted—history of the development of the dynamo-electric principle no mention is made of Jedlik, though he had discovered and applied this principle in his ingenious small machine several years before Siemens and Wheatstone. By good fortune, the machine exists and together with the relative original contemporary documents it incontestably proves Jedlik's priority.

Let us see what the faded notes report. The I. Physical Institute of the University of Sciences in Budapest possesses an *'Inventarium'* dated 1859, and started by Jedlik, he then being professor and director of the institute. On page 127 of this Inventarium we read /translated/:

"XVII. Main Section: Electrical Instruments. E. Sub-Section: Electrodynamic Apparatus."

Item 24.:

"Unipolar Inductor in the multiplier of which, made of thick copper wire and having not more than 12 turns, an uninterrupted electric current is induced if we bring its horizontal cylinder thus shaped ... into rotation with the aid of the toothed wheel attached to it, after having made it an electromagnet by using

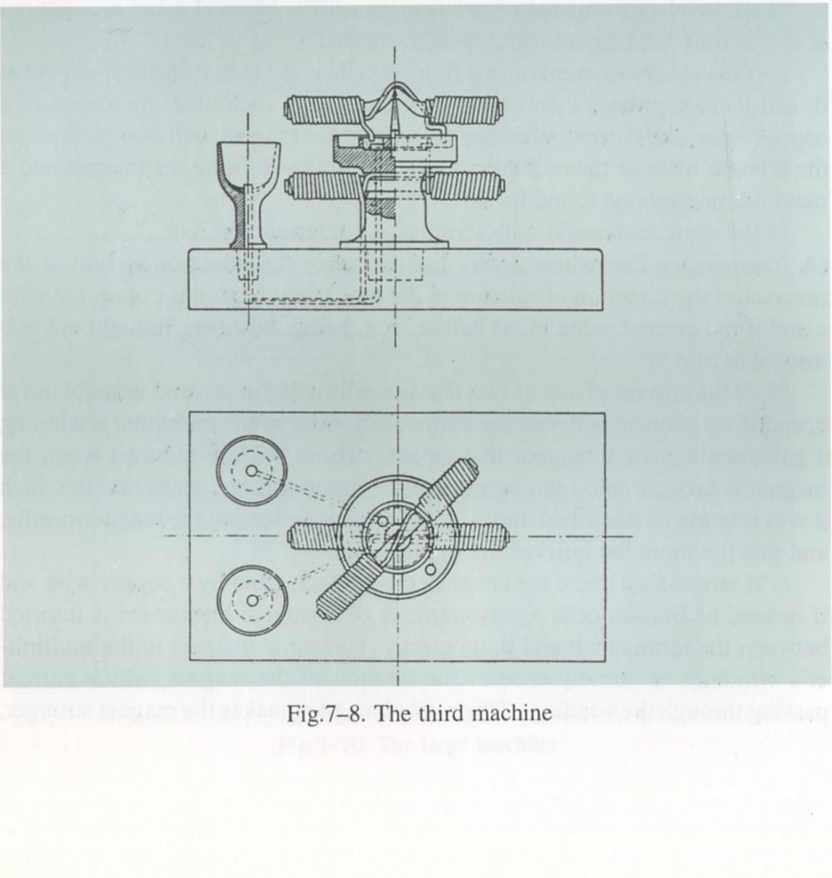

Fig.7–8. The third machine

the current of one or more Bunsen cells. If the current of two or more Bunsen cells is duly led through its multiplier too, the mentioned cylinder begins to rotate rapidly by itself, it being possible to reverse the direction of rotation by the commutator fixed on the baseplate of the apparatus. To facilitate the use of the apparatus its short description and directions for use are to be found on a sheet attached to the baseplate."

"Invented by Ányos Jedlik, made in Nuss mechanist's shop in Pesth.

Procured in 1861.

Price 114 Fl. 94 kr."

The description attached to the apparatus is also Jedlik's manuscript. On one side of the faded sheet (see Fig. 14.) the diagram of connections of the machine is shown. Above this we see a few lines written with pencil, this being a fragment of the first draft of the directions for use. The detailed directions for use are given on the other side of the sheet where, with reference to the corresponding letters of the diagram, we can read the following text /translated/:

"1. If the electric current of two Bunsen cells is led in at a and brought out at c, it is only the magnet which will be excited.

2. If the electric current of two Bunsen cells is led in at a and brought out at d, and if the terminals c and b are connected with each other by means of a copper wire, the current, after having excited the magnet, will also go through the 6 and 6 turns of the multiplier's winding, and will bring the magnet into a rapid rotating motion round its axle.

In the same manner, if with terminal c not terminal b, but..."

(A fragmentary line where Jedlik had probably the intention to hint at the reversal of the direction of rotation in the case if not b but d is connected with c and if the current is led in, as before, at a, being, however, brought out at b instead of at d.)

"3. If the current of one or two Bunsen cells is led in at a and brought out at c, and if we connect between the terminals b and d of the multiplier's winding a galvanometer or a tangent instrument, current will be induced when the magnet is brought into rotating motion, in opposite direction to that in which it was rotating as described under 2, this current deflecting the magnet-needle, and this the more the quicker the rotation.

4. If terminals a and c are connected with each other by a copper wire and if instead of Bunsen cells a galvanometer or a tangent instrument is inserted between the terminals b and d, an electric current is induced in the multiplier's windings in consequence of the rotation of the magnet, which current passing through the winding of the rotated magnet, makes the magnet stronger,

this latter inducing again a still stronger current, and so on."
(At this point a mistake slipped in Jedlik's manuscript inasmuch as he put the letters a and b one for another. Namely, the connection of terminals a and c with each other would short-circuit the winding of the magnet and the current induced in the multiplier's winding could not flow through it. The correct text would be: "If the terminals b and c are connected with each other by a copper wire and if instead of Bunsen cells a galvanometer or a tangent instrument is inserted between a and d... etc.")

Point 2. of this description refers to the machine running as a series motor and point 3. to its operation as a separately excited generator. Finally, point 4. quite clearly pronounces and applies the "dynamoelectric principle", explaining the manner of operation of the self excited direct-current generator, the field winding and the armature (multiplier) of which being connected in series and the initial current being; induced by the remanent magnetism of the magnets, without any external source of current.

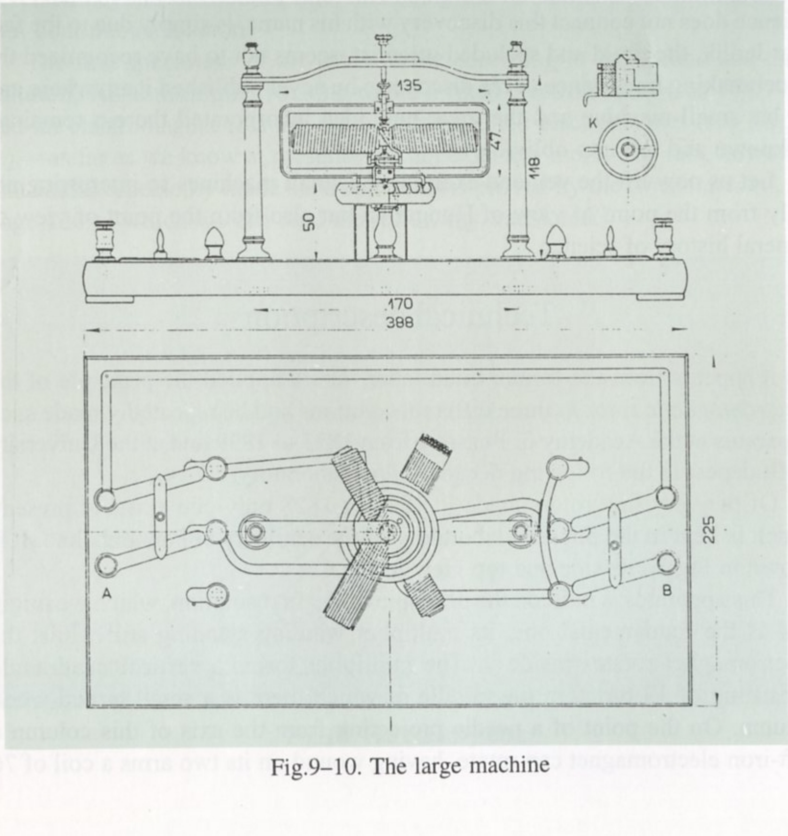

Fig.9–10. The large machine

As to the date of the discovery, Baron Lorand *Eötvös* and Jenő *Klupathy*, both Jedlik's successors in the professor's chair, who were personally acquainted with the old scientist, noted that according to Jedlik's own recollection and to the recollection of the mechanist Nuss the unipolar inductor was already completed in some year between 50 and 60 of the last century and that it had only been inventoried in later years, when it had already appeased the thirst for knowledge of Jedlik's researching spirit and after having been in practical operation for a long time driving the dividing-machine that Jedlik used in making his very fine optical grates.

When deciding the priority, we may, however, without doubting their correctness—conscientiously pass over these statements of subjective nature, which in the perspective of times might have become uncertain.

The year 1861, noted in the inventory authentically and undeniably proves that, Jedlik discovered and even applied the dynamometric principle at least 6 years before Siemens and Wheatstone. That, in spite of this, the history of science does not connect this discovery with his name, is simply due to the fact that Jedlik, the timid and secluded scientist, seems not to have recognized the epochmaking importance of his discovery; he never published it anywhere and so his small machine and the great new idea incorporated therein remained unknown and fell into oblivion.

Let us now lift the veil and examine the small machines so interesting not only from the point of view of Hungarian but also from the point of view of general history of science.

Technical description

As it appears from the former cited letter, Jedlik applied the principle of the *electromagnetic rotor to* three different solutions and he repeatedly made such apparatus at the Academy of Pozsony from 1831 to 1839 and at the University of Budapest in the following decade for his laboratory.

Of the very first rotors made in 1827 or 1828 only one exists at present, which is kept in the physical laboratory of the seminary at Pannonhalma. It is shown in Fig.3., its side and top view in Fig.4.

This apparatus is built on the principle of the first solution, which we might call as the fundamental one, its multiplier winding standing still whilst the electromagnet rotates inside it. The multiplier forms a vertical quadrangle consisting of 13 turns, in the middle of which there is a small turned wood column. On the point of a needle projecting from the axis of this column a soft-iron electromagnet can rotate, having wound on its two arms a coil of 76 turns in total. Current is led to the rotating part in such a way that the two bare ends of the exciting coil immerse into two small round grooves turned into the head of the column and filled with mercury. One of these grooves is connected with the end of the multiplier-winding and the other with one of the two mercury-filled cups arranged for leading in the current. The other mercury-filled cup is connected with the beginning of the multiplier-winding. The circular grooves are divided each into two halves, by means of small and low pegs placed at right angles to the plane of the multiplier, interrupting thus the mercury rings at two opposite points. In consequence of this interruption the two halves of the rings, which halves—as mentioned above—are connected with the two terminals of the source of current, act as regards the rotating part as a two-segmented commutator and assure that the direction of the current will—after a momentary interruption be reversed relatively to the exciting coil as soon as the rotating part has passed the position at right angle to the plane of the multiplier. Consequently, the polarity of the rotating electromagnet is also reversed beyond the neutral line, this being the fundamental condition to obtain continuous rotation.

The first specimens of the rotors made according to the second and third solution, viz. a multiplier rotating round a fixed electromagnet (see Fig.5–6.) and an electromagnet rotating round another fixed electromagnet (see Fig.7–8.),—as far as we know at present—do not exist any more. The fact, however, that Jedlik repeatedly made such apparatus is proved by the '*Inventarium*', on page 126 of which we can read the following /translated/:

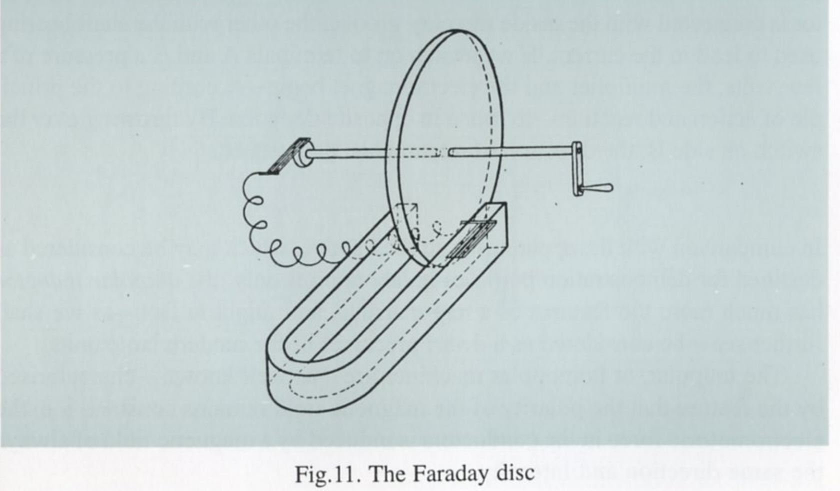

Fig.11. The Faraday disc

"No. 18. Apparatus in which, whilst an electromagnet is rotating round its own axis, a multiplicator rotates round the electromagnet in opposite direction. (Invented by Jedlik.)

Made by Jackwitz. 1857. Price 30 Fl."

No. 20. "Electrodynamic apparatus in which two electromagnets come into rotating motion one upon another, or an electromagnetic multiplier comes into rotation in a direction opposite to that of the electromagnet placed in its opening, if the conductors are traversed by the current supplied by a Bunsen cell. The obtained rotation can immediately be reversed by means of one or the other commutator. (Invented by Jedlik.)

Made by József Wágner. 1859. Price 30 F. 40 Kr."

One of above two descriptions refers to the apparatus shown in Figs.9. and 10., which is kept in the laboratory of the I. Physical Institute of the University of Sciences in Budapest. As we see, the whole design and construction of the apparatus is much more perfect than that of the first rotor. This is natural, as there is an interval of 30 years between the creation of these two apparatus, during which time not only Jedlik's knowledge and experiences but also the means at his disposal made great progress.

The multiplier consists of 19 turns wound on a square brass frame. The exciting coil of the electromagnet placed in its interior has 2x55 turns. Current is led to the multiplier through the mercury groove on the top of the middle wooden column and to the electromagnet through the two-segmented commutator fixed on the shaft, upon which two elastic metallic tongs, connected to the two ends of the exciting coil, sweep like brushes. One segment of the commutator is connected with the inside mercury groove, the other with the shaft bearing used to lead in the current. If we switch on to terminals A and B a pressure of a few volts, the multiplier and the electromagnet begin—according to the principle of action and reaction—to rotate in opposite direction. By throwing over the switch on side B, the direction of rotation can be reversed.

*

In comparison with the apparatus described above, which may be considered as destined for demonstration purposes in laboratories only; the *unipolar inductor* has much more the features of a real machine, and might in fact—as we shall further see—be considered as a dwarf precursor of the modern large units.

The unipolar, or homopolar machines are—as well known—characterised by the feature that the polarity of the magnetic field remains constant, i. e. the electromotoric force in the conductors is induced by a magnetic field of always the same direction and intensity.

Faraday's magnetoelectric rotating apparatus were in fact all unipolar, because the conductor always rotated in the field of a permanent magnet, i. e. in a unidirectional and constant field. A most characteristical example of this is the well known Faraday's disc shown on Fig.11., which is the simplest ancestor of a unipolar generator. This apparatus consists of a copper disc rotating between the legs of a horseshoe magnet, in which disc the constant magnetic field induces a radial electromotive force. Between the shaft and the rim of the disc thus exists a potential difference which, when applied to any closed circuit, sends through the latter a continuous current of constant direction.

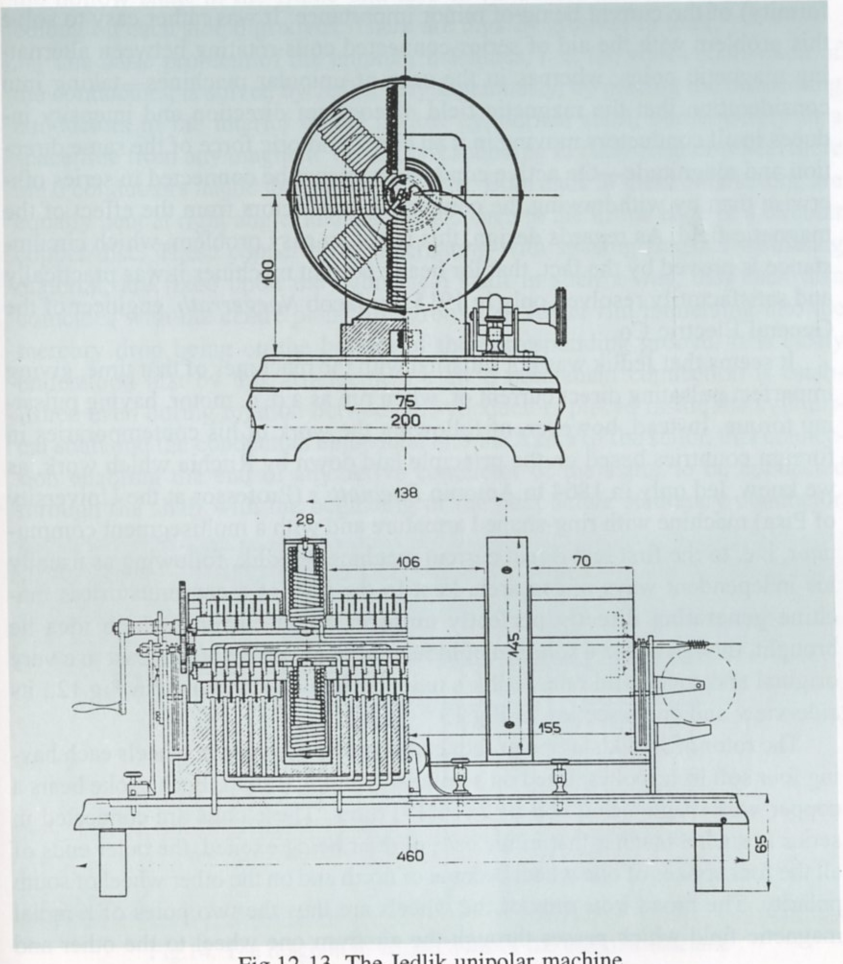

Fig.12-13. The Jedlik unipolar machine

As we have seen in our historical retrospection, the development of the d. c. machines, that started in the fourth decade of the XIXth century, did not take its way towards the unipolar solution. The larger machines of that time were really alternating current machines (f. i. Nollet's and van Malderen's machine, 1849), and when direct current was wanted, the inventors contented themselves with a commutator having two segments per pair of poles, which rectified the alternating current into heavily pulsating direct current. This finds its explanation in the fact that the main practical purpose was to generate a relatively high voltage fit for lighting by electric arc lamps, the quality (uniformity) of the current being of minor importance. It was rather easy to solve this problem with the aid of series-connected coils rotating between alternating magnetic poles, whereas in the case of unipolar machines—taking into consideration that the magnetic field of constant direction and intensity induces in all conductors moving in it an electromotoric force of the same direction and magnitude—the active conductors cannot be connected in series otherwise than by withdrawing the connecting conductors from the effect of the magnetic field. As regards design, this is not an easy problem, which circumstance is proved by the fact, that for heavy current machines it was practically and satisfactorily resolved only in 1915, by Jacob *Noegerrath,* engineer of the General Electric Co.

It seems that Jedlik was not satisfied with the machines of that time, giving imperfect pulsating direct current or, when run as a d. c. motor, having pulsating torque. Instead, however, of following the work of his contemporaries in foreign countries based on the principle laid down by Ritchie which work, as we know, led only in 1864 to Antonio *Pacinotti's* (Professor at the University of Pisa) machine with ring-shaped armature and with a multisegment commutator, i. e. to the first real direct current machine—Jedlik, following as usually his independent ways of research, kept to the idea of a commutatorless machine generating directly perfectly uniform direct current, which idea he brought, though not to a solution of industrial importance, but at least to a very original and successful one. Jedlik's unipolar inductor is shown in Fig.12., its side-view and cross-section in Fig.13.

The rotor of Jedlik's unipolar inductor consists of two iron wheels each having four soft iron spokes, fixed on a hollow cylindrical shaft. Each spoke bears a copper wire magnetising coil of 2x16(17) turns. These coils are connected in series in such a manner that in the case of their being excited, the outer ends of all the four spokes of one wheel become of north and on the other wheel of south polarity. The broad iron rims of the wheels are thus the two poles of a radial magnetic field which passes through the air from one wheel to the other and closes at the inner ends of the spokes through the wall of the hollow shaft, the middle part of which is, with due regard to this, made of an iron tube.

The conductors in which this radial rotating field induces electromotoric force are placed side by side in a groove cut in the bottom of the wooden frame. To each magnet-wheel there belong six insulated copper wire conductors of 3mm diameter. The two ends of these conductors are bent up at right angle and are led through the frame, each into a mercury-filled groove. These small grooves are formed by thin wooden transversal partitions, which are fitted into the cylindrical space surrounding
the hollow shaft in the frame and also in its cover. To each magnet-wheel belong on each side 6 grooves. There are thus 24 grooves in total.

The basic problem of the unipolar machines, i. e. the series connection of the conductors, is solved by Jedlik very ingeniously, by placing the connecting conductors in the interior of the hollow cylindrical shaft, consequently in a space free from any magnetic field. Corresponding to each magnet-wheel there are 6 conductors inside the cylindrical shaft. Both ends of these conductors, are equally bent at right angle, and are welded each to the inside edge of a circular copper disc. These copper discs, alternating with spacing rings of insulating material, are fixed upon the cylindrical shaft in such a way, that each disc coincides with the centre plane of a groove, its lower rim immersing into the mercury drop being on the bottom of the corresponding groove. It is easily understood that by this arrangement a good permanent connection is established even during rotation between the conductors placed inside the cylindrical shaft and the conductors embedded into the frame of the stator, this connection enabling the end of any active conductor of the stator to be connected through the shaft with the beginning of the next active stationary conductor,

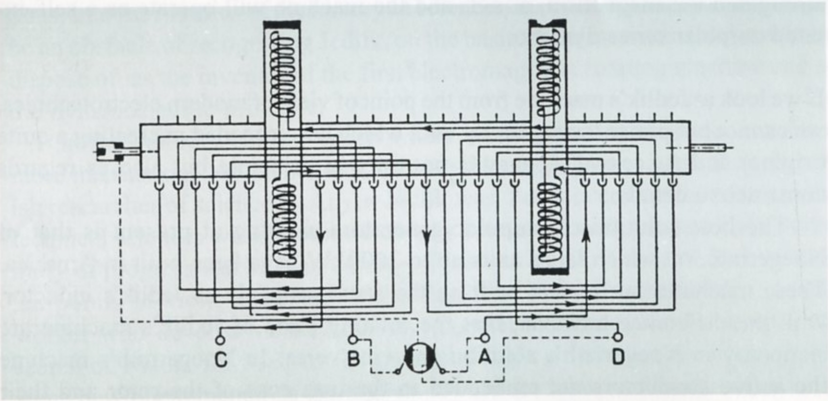

Fig.14. The diagram of connections of the unipolar machine

i. e. to connect in series the six active conductors belonging to the corresponding magnet-wheel. In the same manner are connected in series the two windings, of six turns each, and also the two free ends of the magnetising coils to the terminals A and C, placed on the baseplate of the apparatus, as shown in Fig.14.

Terminals B and D lead to the windings of the stator or respectively to a Ruhmkorff commutator, by means of which the direction of the current in the windings of the stator can be reversed.

It is worth mentioning that the tiny journals of the rotating part turn on both sides in a small saddle formed by the rim of two large revolving brass discs slightly displaced in relation to one another. This arrangement, which can be considered as the primitive ancestor of the present ball bearings, insures very low friction.

The rotor can be driven by a handle and a wheel gear. The cylindric interruptor fixed on one end of the shaft and the screw-wheel mechanism being on the other end are no essential parts of the machine, the latter having certainly been used for driving the dividing machine of the optical grates and served for other experiments.

If, with the existing connections shown in dashlines on Fig.14., we connect a 4–6 V source of current to the terminals B and C, the machine begins to rotate as a unipolar series motor, the direction of which rotation can be reversed by throwing over the commutator.

If, however, we short-circuit terminals C and B through a sensitive current-indicator of very small internal resistance, and then bring the rotor into rapid rotation by means of the handle, the remanent magnetism of the magnet-wheels induces a feeble current in the closed circuit, which current, flowing through the exciting coils of the magnet-wheels in the right direction, will strengthen the magnetism, a. s. f. and the machine will operate as a self-excited unipolar series dynamo.

*

If we look at Jedlik's machine from the point of view of modern electrotechnics, we cannot but praise the ingenuity with which he succeeded in creating a quite original and successful apparatus not only in principle but also as regards constructive details.

The best solution of unipolar generators existing at present is that of Noegerrath, on which large units up to 2000kW have been built in America. These machines are in fact built on the same principle as Jedlik's inductor, with the difference however, that the rotating parts of Jedlik's machine are stationary in Noegerrath's solution and vice-versa. In Noegerrath's machine the active conductors are embedded in the iron core of the rotor and their connection in series is effected by conductors placed in the slots of the iron core of the stator, i. e. by means of conductors lying inactively in the stationary magnetic field. The stationary and revolving conductors are interconnected by means of collector rings and brushes, which correspond to the copper discs and mercury contacts on Jedlik's machine.

The only serious imperfection of Jedlik's machine is that it utilises the radial field of the magnetwheels at one point of the periphery only, whilst the greater part of the magnetic field spreads uselessly through the air. Should Jedlik not have placed the active conductors in a sole groove of the wooden base, but had he distributed the same on the whole periphery, using an iron body to insure a closed magnetic circuit, he certainly would have created a machine which would by far have exceeded the character of a laboratory apparatus, and would most likely have become of a great industrial importance.

In the sublime domain of his science Jedlik was, however, a fervently researching scientist and not an artisan nor an industrialist looking for the ways of practical application. He possessed the divine spark of a genius, which flashed up more than once within the quiet walls of his laboratory, but it did not kindle a torch to light up the way of mankind's progress. The credit for this is due to Pacinotti, to Gramme and especially to Siemens and Wheatstone who were, it is true, not so far removed from real life, and who were also not confined to work at the university of an oppressed poor country, as Jedlik was in Hungary.

The full acknowledgement of their merit can however not in the least lessen the importance of Jedlik's pioneer work. It is most regrettable that his great modesty and seclusion deterred him from appearing before the public in due time with the results of his investigations. To-day, however, when we are able to fit his work with the perspective of a century, respectively of twa generations, into the mosaics of the history of science, this circumstance can no longer be an obstacle of recognising Jedlik, on the basis of the incontestable proofs we dispose of, as the inventor of the first electromagnetic rotating machine and of the dynamoelectric principle.

On the contrary! In our epoch where often superficial success is valued more than serious but silent work, it is our duty to do justice to such an unselfish researcher of science as Ányos Jedlik was. For it is certain that even in the technical sciences which are most closely connected with practical life, continuity of progress can be insured only, if instead of the victory of bare utilitarian points of view, the doors of the Pantheon open also before the modest worker who devotes himself entirely to quiet studies and considers the research of Nature for itself as the greatest delight of life and the discovery of some new phenomenon as the highest reward for laborious work.