Invention of the electromagnetic generator

Wise Eye OverUnity * Serge Rakarskiy

The first electric motors, created at the beginning of the 19th century and powered by the only known source - a galvanic battery, could not be used on an industrial scale. The low economic efficiency of such an electrochemical source, which prevents the replacement of steam engines with electric ones, forced inventors to look for other, electromechanical methods of generating electricity.

The first electromechanical generator was proposed by Faraday in 1832 immediately after his discovery of the law of electromagnetic induction.

The main experiments preceding the discovery of electromagnetic induction took place between August 29 and November 4, 1831, the main ones being two:

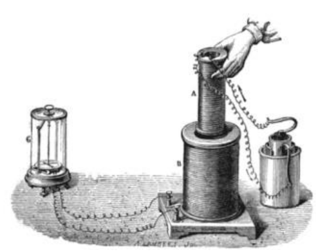
- ***When the magnetic core moved inside the wire coil, an electric current arose in the latter.***
- ***Turning on or off the current in the wire coil led to the appearance of a current in the secondary coil, whose turns alternate with those of the first.***

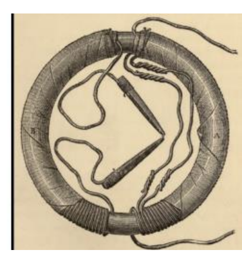
On October 17, 1831, Faraday came to the conclusion: “an electric wave arises only when a magnet moves, and not due to the properties inherent in it at rest.” He conducted a decisive experiment:

I took a cylindrical magnetic bar (3/4" in diameter and 8 1/4" long) and inserted one end into a coil of copper wire (220 feet long) connected to a galvanometer. Then I quickly pushed the magnet inside the spiral to its entire length, and the galvanometer needle experienced a push. Then I just as quickly pulled the magnet out of the spiral, and the arrow swung again, but in the opposite direction. These swings of the needle were repeated every time the magnet was pushed or pushed out.

Even earlier, on August 29, 1831, Faraday conducted a similar experiment with an electromagnet:

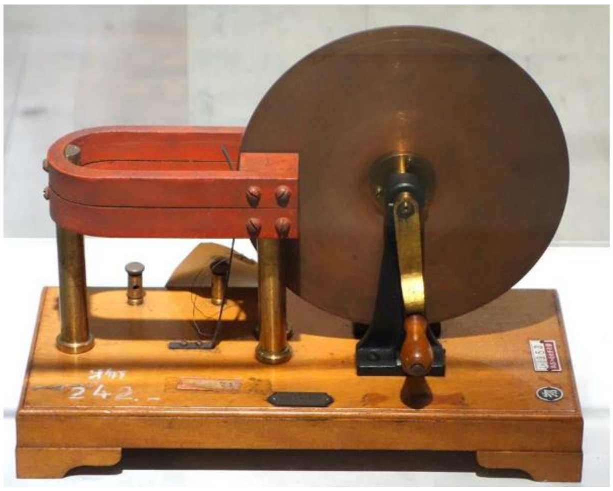
Two hundred and three feet of copper wire in one piece were wound around a large wooden drum; another two hundred and three feet of the same wire was laid in a spiral between the turns of the first winding, the metallic contact being everywhere eliminated by means of a cord. One of these spirals was connected to a galvanometer, and the other to a well-charged battery of one hundred pairs of plates, four inches square, with double copper plates. When the contact was closed there was a sudden but very weak effect on the galvanometer, and a similar weak effect took place when the contact with the battery was opened.

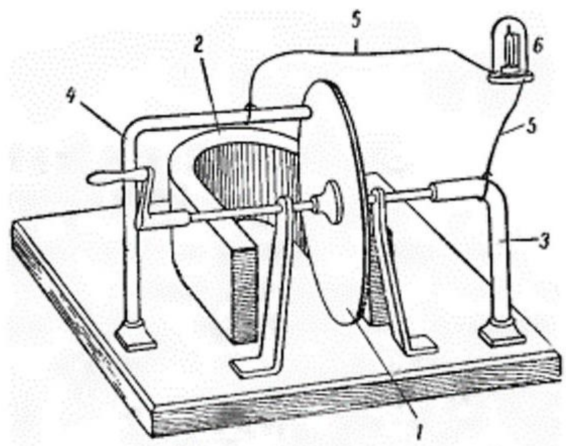




In fact, Faraday, in these experiments, recorded for different phenomena: 1) induction of EMF when introducing a constant field of a magnet/electromagnet into the internal cavity of a solenoid connected to a galvanometer and 2) mutual induction, when two windings are wound on a ring core, one receives a current pulse from the battery and on the second galvanometer records a surge of current, while in this action there was actually an impulse of mutual induction and self-induction.

On October 28, 1831, Faraday assembled the first full-fledged direct current generator (*a "Faraday disk" which contains: a stator in the form of a horseshoe magnet - 2 and a copper disk (rotor) - 1, equipped with movable contacts on the axis and rim.*): when rotating the copper disk nearby With a magnet, an electric potential arises on the disk, which is removed by the adjacent wire. Faraday showed how to convert mechanical rotational energy into electrical energy. The impetus for this invention was the experiment of ***Arago*** (1824): *a spinning magnet attracted a copper disk located below into its rotation, although copper is unable to be magnetized and demagnetized* . If you rotate a copper disk near a magnet suspended in such a way that it can rotate in a plane parallel to the plane of the disk, then as the disk rotates, the magnet follows its movement. *Arago* discussed this effect with Ampere, Poisson and other famous physicists, but they were unable to explain it.





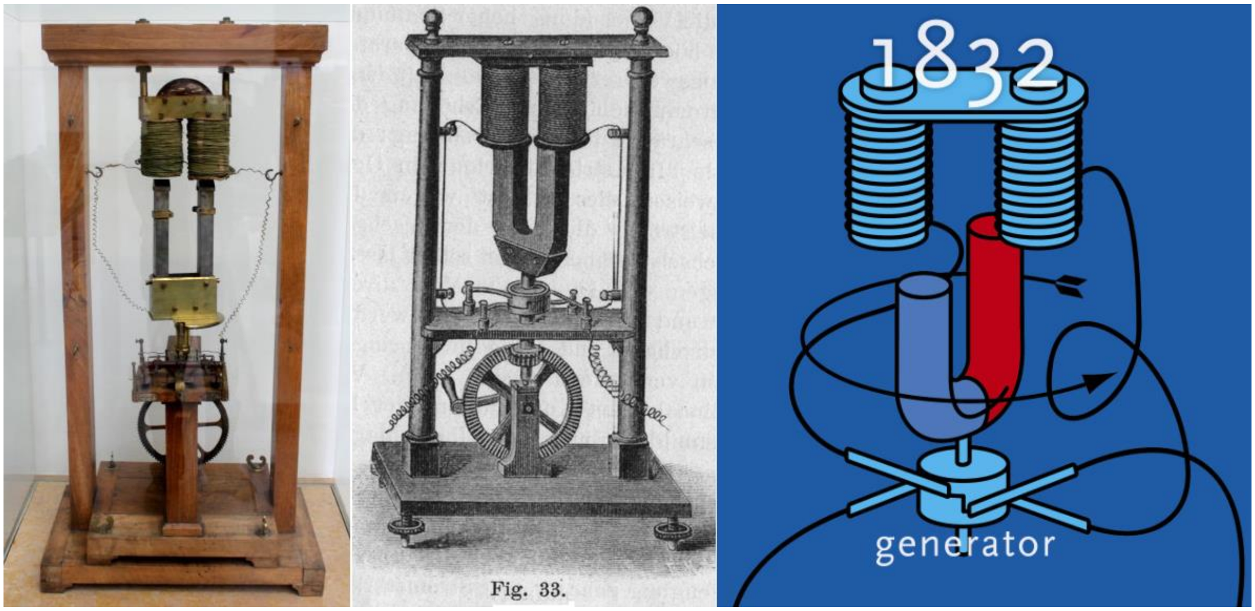
Faraday's magnetoelectric unipolar generator, known as the "Faraday disk", the final stage of his research on electromagnetism: 1 - copper disk;, 2 - horseshoe-shaped permanent magnet, 3 - axial current collector, 4 - peripheral current collector, 5 - wires, 6 - galvanometer.

When a disk rotates in a magnetic field, an EMF of constant sign (spin) is induced in it, causing induced currents (*provided that a section of the disk is included in a closed circuit*), flowing radially according to the right-hand rule, i.e., between the axis and the rim. According to Lenz's rule, induced currents create a magnetic flux that opposes the flux of the magnet, i.e., directed along the axis of rotation of the disk. This is the only known unipolar DC generator that is still used to generate large currents.

The remaining DC generators are essentially AC generators with a rectifier (commutator) at the output.

Hippolyte Pixii , a French physicist and inventor, created many scientific instruments during his short life of 27 years, including the dilatometric thermometer and the vacuum pump. In 1832, he built an early form of electrical alternating current generator based on the principle of electromagnetic induction discovered by Michael Faraday. Pixia's device was a rotating magnet driven by a crank, with the north and south poles running along an iron-core coil. A current pulse was generated each time a pole passed over the coil. He also discovered that the direction of the current changed when the north pole passed over the coil after the south pole. Later, at the suggestion of André-Marie Ampère, different results were obtained when a commutator was introduced that produced a pulsating direct current. At that time, direct current was preferred over alternating current. Therefore, Pixie, on the advice of Ampere, equipped him with a brush commutator. The Pixie generator was used by E. H. Lenz to prove the principle of reversibility of an electric machine, discovered by him in 1833. However, for a long time, engines and generators developed separately.

Although Pixius did not fully understand electromagnetic induction, his device led to the creation of more complex devices. A reproduction of the Pixii electric generator can be admired in the Ampere Museum, near Lyon.

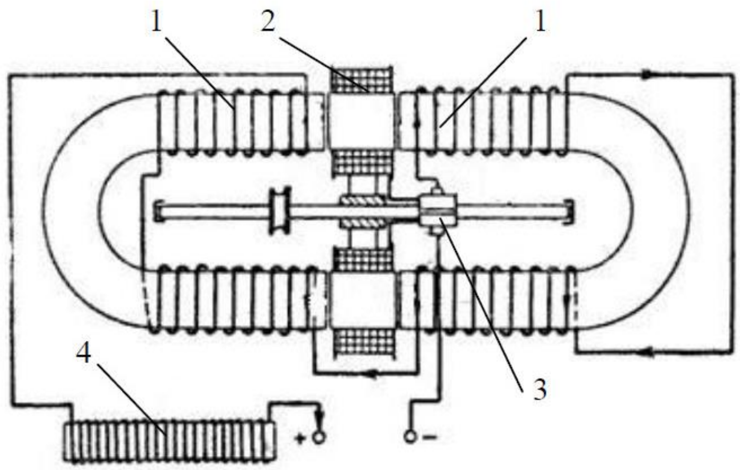


If you compare the drawings and photograph of the Pixia generator, you will notice that in a real generator the coils are wound on a horseshoe-shaped metal core with the same cross-section of the coil core. In the artists' drawings, the cores are individually attached to the body of the core rods by a metal jumper (yoke). In this case, the cross-section of the metal jumper is smaller than the cross-section of the rod.

At that time, permanent magnets were very weak and short-lived. There was also no possibility of regulating the output voltage. To solve this problem, physicists and engineers were looking for the possibility of using an electromagnet. Through a series of many engineering solutions by various physicists and engineers, the optimal design was found by Jacobi (1842) and Frederick Holmes (1856) implemented a primary design using a static magnet and movable coils with commutation through a brush with a commutator. The moss magnet was replaced by an electromagnet powered by a galvanic battery, which in no way made the installation attractive in high-power industrial installations.

A radical solution to the problem appeared after the discovery of the self-excitation effect of generators, which Siemens called the dynamoelectric principle or DYNAMO. The idea of self-excitation is that the initial excitation flow when starting a machine is created by the residual magnetization of the magnetic circuit, where the generator voltage is removed from the armature winding, and the machine is excited either by an excitation winding connected in series with the load $R_{н}$, or by an excitation winding connected in parallel to the armature through an adjusting resistor (so-called excitation through a shunt). Next, the excitation flux increases due to positive feedback from the generated current.

In practice, the idea of self-excitation was realized only ten years later at the same time by several inventors. In a patent application in December 1866, an English telegraph company engineer and Faraday's student, Samuel Alfred Varley, proposed a generator circuit similar to the Jacobi generator, in which, however, the excitation winding replaced permanent magnets. The generator circuit is shown in Fig. 6, where: 1 – excitation electromagnets, 2 – armature, 3 – commutator, 4 – additional adjustment resistor. Before starting, the excitation cores were magnetized with direct current.



A month later, in January 1867, a report by the famous German inventor and industrialist Werner Siemens was presented at the Berlin Academy of Sciences with a detailed description of a self-excited generator, which he called a dynamo. Before starting, the generator was turned on as a motor to magnetize the excitation. Subsequently, Siemens established wide industrial production of such generators in Germany.

In February of the same 1867, the famous English physicist Charles Wheatstone patented and demonstrated a generator with excitation through a shunt. The owner of a musical instrument workshop who took over the business from his father, later a professor at King's College in London, Wheatstone is also known for his inventions of the resistance measurement method (Wheatstone bridge), the single-phase synchronous electric motor, the concertina musical instrument, the stereoscope, the chronoscope (electrical stopwatch) and the improved view of the Schilling telegraph.

A discussion arose in the press about the priority of this technical solution, which was also claimed by Wilde and Hiort. It should be noted that there are three types of priority: scientific, patent and industrial. Scientific priority belongs to the scientist who first published or publicly demonstrated any device, effect or theory. Industrial priority belongs to the person or company that first established the production of a product and its widespread introduction. For example, when opening a radio, scientific priority belongs to Popov, and patent and industrial priority belongs to Marconi. Regarding the self-excited generator, patent priority should be recognized for Varley, scientific priority for Jedlick and Siemens, and industrial priority for Siemens. Wheatstone has priority in a particular, albeit very important, technical solution - excitation through a shunt.

In 1827, Hungarian physicist Anjos Istvan Jedlik began experimenting with electromagnetic rotating devices, which he called electromagnetic self-rotating rotors. In the prototype of his unipolar electric motor (completed between 1853 and 1856), both the stationary and rotating parts were electromagnetic. He formulated the concept of a dynamo at least 6 years before Siemens and Wheatstone, but did not patent the invention because he thought he was not the first to do so. The essence of his idea was to use, instead of permanent magnets, two oppositely located electromagnets, which created a magnetic field around the rotor. Jedlik's invention was decades ahead of his time. (*see* *Magneto*)

The dynamo was an important invention due to the widespread use of direct current. With the invention of the AC motor and the development of its design into industrial applications, the era of alternating current began. The history of the AC motor began at the end of the 19th century, when the first AC electric motors were invented. These included asynchronous motors, synchronous motors and universal commutator motors. An induction motor operates based on a rotating magnetic field created by the stator and an induced current in the squirrel-cage winding of the rotor. A synchronous motor has a rotor with permanent magnets or electromagnets that are synchronized with the magnetic field of the stator. A universal commutator motor is a series-excited DC commutator machine that can operate on both direct and alternating current. For asynchronous and synchronous motors, alternating current generators were required, respectively.

The idea of a multi-coil device rotating with a magnetic rotor belongs to the inventor who sent a letter to Faraday, signed with the Latin initials PM. *The probable name of the inventor is Frederick Mc-Clintock - today the real name remains unknown.* Faraday immediately published this letter in a scientific journal. However, this device generated alternating current, whereas at the beginning of the 19th century only direct current was used. The main thing was that a completely complete multi-coil model of a generator with a rotating multi-pole rotor, similar to a multi-cell galvanic battery, was proposed. The concept of this model is still used today for alternating current generators.

Description in a letter to Michael Faraday by an unknown author P.M. design of a complete multi-coil synchronous generator with a complete permanent magnet rotor, published by [The Royal Magazine, July 7, 1832]().

[161]

XXXIV. *Account of an Experiment in which Chemical Decomposition has been effected by the induced Magneto-electric Current. By* P. M.; *preceded by a Letter from* MICHAEL FARADAY, *Esq. D.C.L. F.R.S. &c.*

To the Editors of the Philosophical Magazine and Journal.

Gentlemen,

ON returning to town yesterday, I found the inclosed letter: it is anonymous, and I have no means of referring to its author. But as it describes an experiment, in which chemical decomposition is for the first time obtained by the induced magneto-electric current, I send it to you for publication, if you think it worthy.

I cannot, from the description, decide whether the effect is really chemical: it may or it may not be so. A careful distinction must at present be drawn between real chemical decomposition and the mere effects of a succession of electric sparks. I hope the author will describe the results in a more precise manner, and corroborate them by other chemical actions.

I presume the writer can have no objection to the publication of his letter; and for my own part, I would rather avoid being in exclusive possession of anonymous philosophical information, lest any mistakes should hereafter arise as to dates. But if you publish the letter, favour me by thanking the author for it. I am, Gentlemen, yours, &c.

Royal Institution, July 27th, 1832. M. FARADAY.

To Michael Faraday, Esq.

Sir,

FROM having read in the Proceedings of the [Royal] Institution your interesting papers on magnetism*, I was tempted to try an experiment, which succeeded beyond my expectations, and which, if tried on a larger scale, I am in hopes would prove very interesting.

I thought that, in place of making use of one powerful magnet, there would be considerably more effect (like in the Voltaic pile) by having a number of smaller magnets, connected with one wire or helix; and also, instead of getting the spark at making or breaking contact, it would be still better to make the instantaneous reversal of the poles the cause. I have contrived to do this in a very simple way; and with a

* See Phil. Mag. and Annals, N.S. vol. xi. p. 300, 465.—EDIT.

Third Series. Vol. 1. No. 2. *August* 1832. Y

162 *Experiment in Chemical Decomposition.*

small battery of magnets I have actually decomposed water. You will therefore excuse me for making this communication to you in this manner.

A wheel and axle is connected to a frame, and turned by the handle; a number of magnets (there must not be an odd number) is inserted round this wheel, and firmly secured in their berths, the wheel having spaces cut out to receive them, as shown in fig. 2.; two of the magnets are shown in their place at fig. 1, *b b*; in the same figure are the lifters, which are secured firmly to a board fast to the frame, as will be shown immediately. In placing the magnets in the wheel, which you perceive are the horse-shoe ones, every second magnet is placed differently. If the magnet at No. 1 has the north pole next the edge of the wheel, and the south next the axis, No. 2 has the south at the circumference, and the north at the axis, and so alternately; the ends of the magnets project a little beyond the surface of the wheel. There are as many lifters as magnets, placed firm in a board, exactly to correspond with the wheel, but made firm to the frame, and in such a manner as to permit the wheel to turn readily, so that the magnets will pass close to them. When any one magnet is in contact with a lifter, all the others are the same. In passing the wire round these lifters, care must be taken to make the turns of the helix be reversed in every second lifter, so that the currents of electricity will be all in one direction, although the poles of the magnets are reversed; by connecting the two ends of the wire to guarded points, and inserting them in a small tube containing water, on turning the wheel the decomposition will take place rapidly.

Fig. 1.

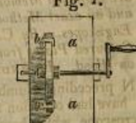
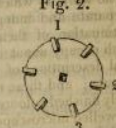


Fig. 2.



I put a small projector on the wheel at every magnet, which, on touching a spring, separated the two wires every time; and at the moment the pole was reversed, the spark became visible. Wishing you success in this very interesting field for discovery, I am, Sir,

Your very humble Servant,

P. M.

Gentlemen,

Returning to the city yesterday, I discovered the attached letter: it is anonymous, and I have no way of identifying its author. But since it describes an experiment in which chemical decomposition was first obtained by means of an induced magnetoelectric current, I am sending it to you for publication if you think it worthy.

From the description I can't decide whether the effect is truly chemical; he may or may not be. A careful distinction must now be made between actual chemical decomposition and mere exposure to a sequence of electrical sparks. I hope that the author will describe the results more accurately and confirm them with other chemical experiments.

I believe that the author cannot object to the publication of his letter; For my part, I would prefer to avoid exclusive possession of anonymous philosophical information, so that there are no future errors in dates. But if you publish this letter, thank its author.

Yours M. FACADEY.
Royal Institution, 7 July 1832

Sir,

Having read your interesting articles on magnetism in the Proceedings of the Royal Institution, I decided to try an experiment which exceeded my expectations and which, if tried on a larger scale, as I hope, will prove very interesting.

I thought that instead of one powerful magnet, a much greater effect (as in a voltaic heap) could be obtained by using several smaller magnets connected by a single wire or spiral; Moreover, instead of getting a spark on contact or rupture, it would be even better to make the cause an instantaneous reversal of the poles. I was able to do this in a very simple way and with the help of a small battery of magnets I actually broke down the water. Therefore, you will excuse me for informing you about it in this way.

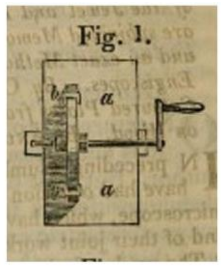
The wheel with an axle is connected to the frame and rotated by a handle; Several magnets are inserted around this wheel (their number should not be odd) and firmly fixed in their sockets, for which places are cut out in the wheel, as shown in Fig. 2; the two magnets are shown in place in Fig. 1, b b; The same figure shows lifts that are firmly secured in an arc to a board attached to a frame, as will be shown later. When placing magnets in a wheel, which, as you understand, is a "horse" wheel, every second magnet is placed differently. If for magnet No. 1 the north pole is at the edge of the wheel, and the south pole is at the axis, then for magnet No. 2 the south pole is at the circle, and the north pole is at the axis, and so on alternately; the ends of the magnets protrude slightly beyond the surface of the wheel. As many lifters as there are magnets are placed in a board exactly matching the wheel, but tied to the frame, and in such a way that the wheel can easily rotate, and the magnets pass next to them. When one magnet is in contact with the lift, all the others are in the same position. In passing the wire around these lifters, care must be taken that the turns of the helix are reversed at every other riser, so that the electric current flows in the same direction, although the poles of the magnets are reversed; If you connect the two ends of the wire to the protective points and insert them into a small test tube of water, then when the wheel rotates, decomposition will occur quickly.

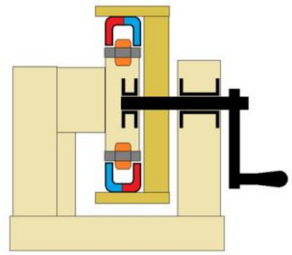
I placed a small projector on the wheel of each magnet, which, touching the spring, each time separated the two wires, and at the moment of the change of pole the spark became visible.

Sir I wish you success in this very interesting field of discovery,
Your humble servant, PM

One part of the researchers attribute the primary construction of the alternating current generator to the French physicist and researcher Hippolyte Pixii (1932), without reference to the date of publication. We do not know the exact date of creation of his device in 1832. We know the date of publication describing a more complex generator with the first magnetic rotor of an unknown *PM :*

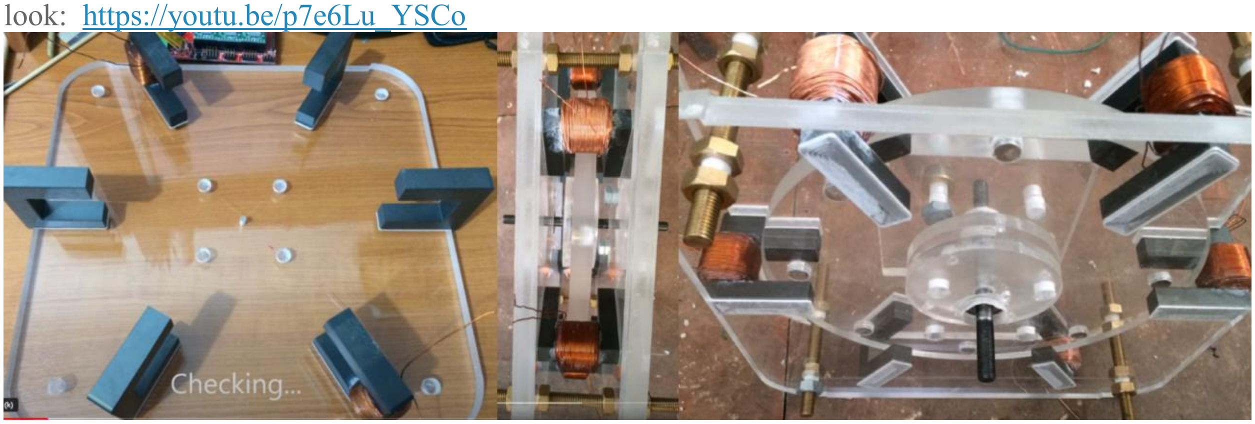
July 7, 1832. The author describes not only the design, but also the experiment carried out using this design. Thus, it takes time to create a generator and conduct experimental launches and evaluate your experiments. Considering that such events take enough time, it is possible to determine the time interval when this happened before sending the letter to Faraday: *the end of 1831 - June 1932* . It was during this period of time that the electromagnetic alternating current generator described in the letter was invented, created and tested. Schematically, *the PM* design of the first full-fledged alternator looks like this



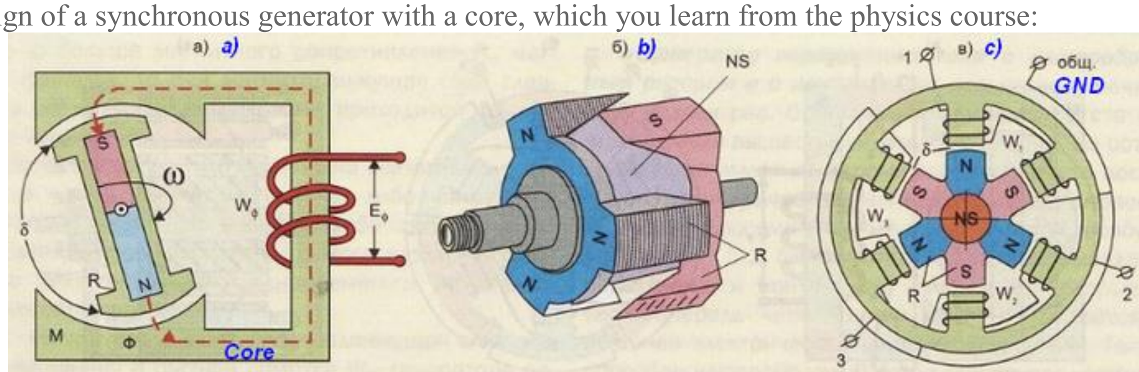


What makes this solution special and revolutionary is the multi-pole rotor (*six pairs of poles, the figure shows six magnets*) which are attached accordingly to the moving (rotating) part of the device, in fact the first magnetic rotor. The coils on the core are connected in series, in such a way that when the polarity changes when the next magnet passes over the coils in the coil circuit, current flows in one direction.

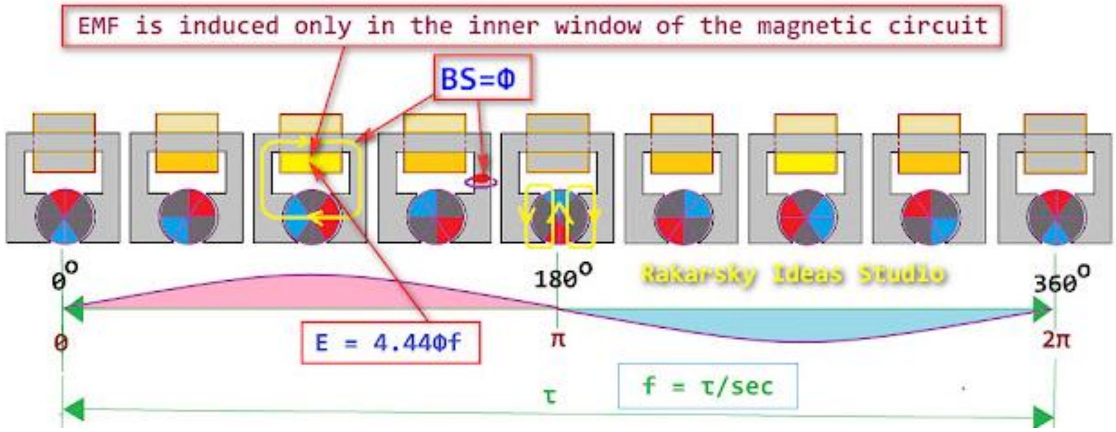
In fact, this solution is the simplest generator with a core. In modern conditions, with the development of technology for creating permanent magnets, the design will have a familiar look: https://youtu.be/p7e6Lu_YSCo



It is the first designs of the Pixie and *PM* alternating current generators that are read in the simplest design of a synchronous generator with a core, which you learn from the physics course:

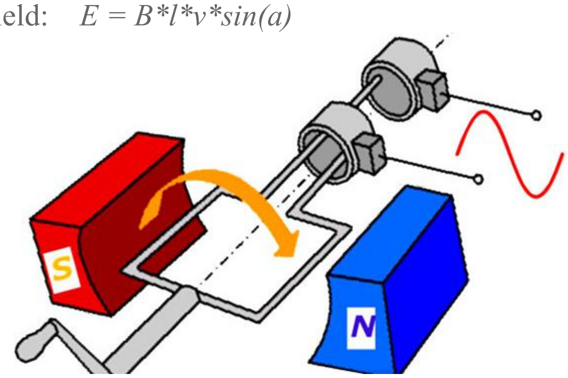


Rice. 1 Magnetic rotor generator model



A feature of the operation of this type of generator is the impossibility of magnetic lines crossing a conductor or disk as in the first unipolar Faraday generator. From this point in the development of history, physics cannot answer the question of how an EMF is induced on a conductor that is located inside a magnetic flux concentrated in a closed ring state.

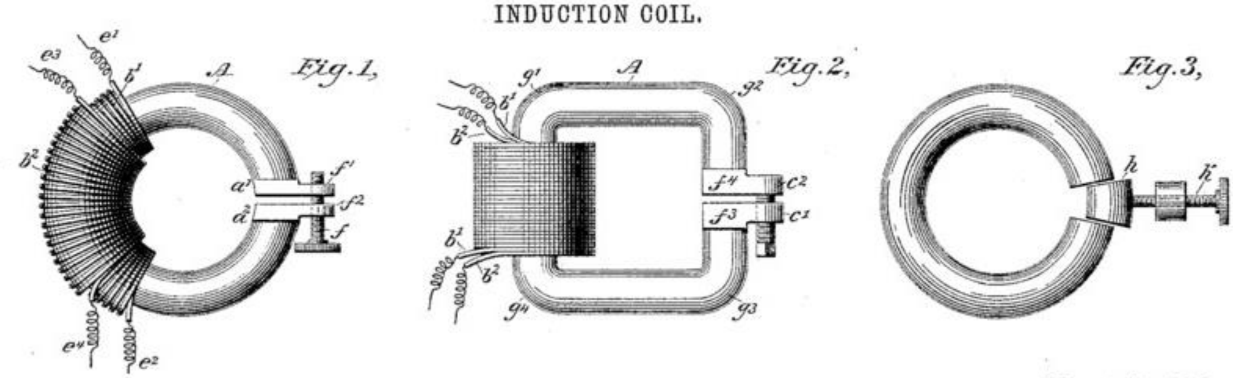
Physics operates, as a primary source, with another type of the simplest generator, where the simplest frame rotates in a magnetic field: *E = B*l*v*sin(a)*



Based on this principle of inducing EMF in a conductor, modern generators with a core, when the wires are laid in the stator groove or the coils are wound on the stator cores, do not work. Magnetic force lines cannot physically cross the stator winding wires. The magnetic flux is concentrated entirely in the electromagnet core (or permanent magnet body) of the rotor and the magnetic conductive material of the stator. Actually the same moment as that of a transformer. Transformers took on their modern form after the invention of the Stanley induction coil:

W. STANLEY, Jr.

INDUCTION COIL.



Patented Sept. 21, 1886.

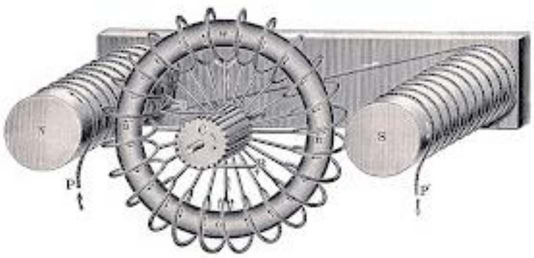
No. 349,611.

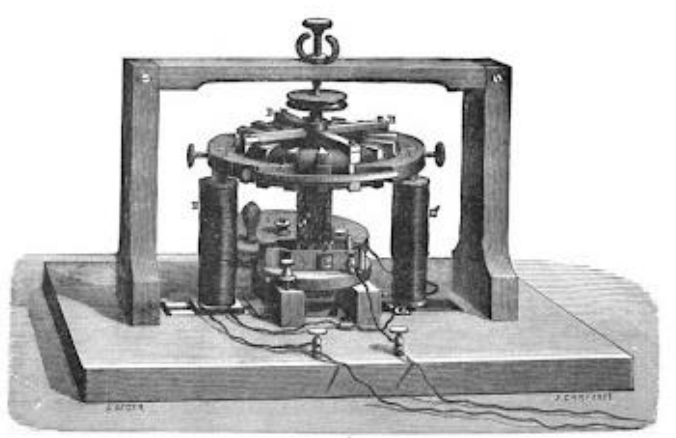
In synchronous generators with a core, another formula is used to calculate the EMF, which is called transformer by engineers: $E = 2\pi\phi f/\sqrt{2}$

These two formulas have completely different principles:

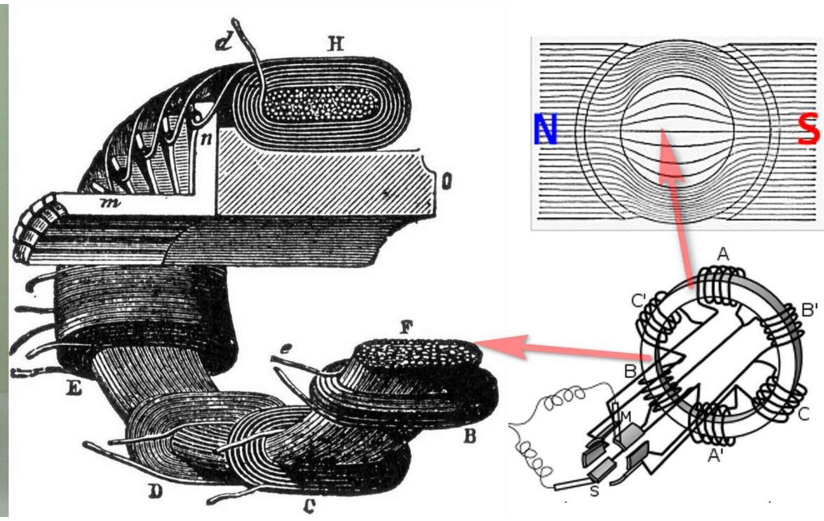
- $E = B*l*v*sin(a)$ - *contact method (formula 1)*
- $E = 2\pi\phi f/\sqrt{2}$ - *non-contact method (formula 2)*

To calculate EMF in synchronous generators, an EMF calculation formula called the transformer or non-contact method is used. True, the first industrial generator was [the Gram Machine - a direct current electric generator](#) , named after its Belgian inventor Zenob Gram. It was the first generator to produce electricity on an industrial scale for industrial needs. It consisted of 30 coils wound on a rotating iron ring (Gram ring). It was inspired by a machine [invented by Antonio Pacinotti in 1861](#) . Antonio Pacinotti was an Italian physicist who invented the dynamo in 1860. In 1861 he published his results in the journal Il Nuovo Cimento.



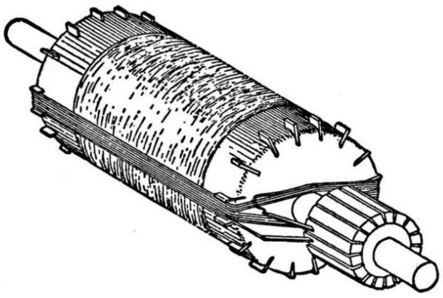


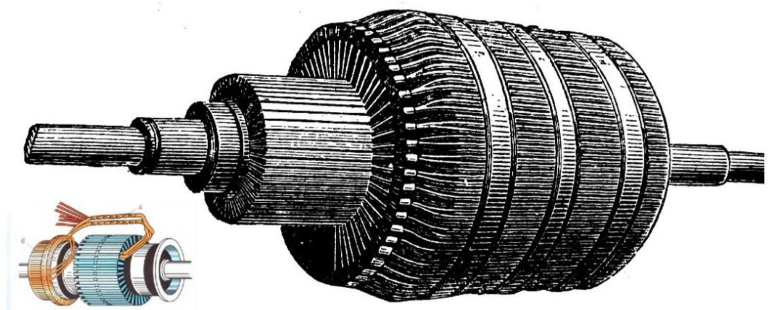
Gram demonstrated this apparatus to the Paris Academy of Sciences in 1871. at the Vienna Exhibition, where it was demonstrated that the device is reversible and can be used as an electric motor.

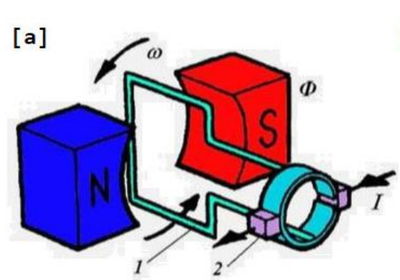
The Gramme generator became the starting point in the industrial revolution in the production and use of electrical machines. While the Gram ring provided a more stable power output, it suffered from technical inefficiencies in the design due to the way the magnetic field lines passed through the ring armature. The field lines tend to concentrate inward and follow the surface metal of the ring to the other side, with relatively few field lines penetrating the inside of the ring.
It was later discovered that it was more efficient to wind one loop of wire through the outside of the ring and simply not pass any part of the loop through the inside. This also reduces design complexity since one large winding spanning the width of the ring can take the place of two smaller windings on

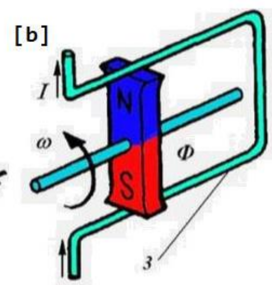
opposite sides of the ring. All modern armatures use this externally wrapped (drum) design, although the windings are not fully extended in diameter; They are more like chords of a circle, in geometric terms. Adjacent windings overlap, as can be seen in almost any modern motor or generator rotor that has a commutator. In addition, the windings are placed in slots with a rounded shape (*as seen from the end of the rotor*). On the surface of the rotor, the slots are exactly as wide as necessary to allow the insulated wire to pass through them when winding the coils .

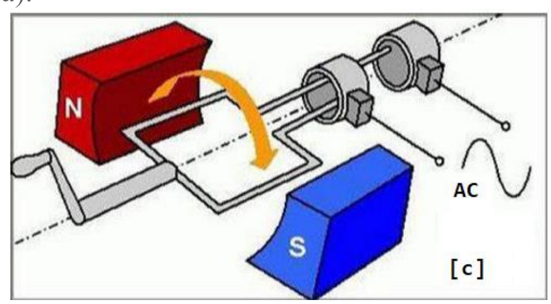




In fact, this is how the concept of the simplest frame generator was formed, which I drew attention to above. All generators of the MAGNETO (field excitation from a permanent magnet) and DYNAMO (self-excitation) type were built on this principle (Figure a).



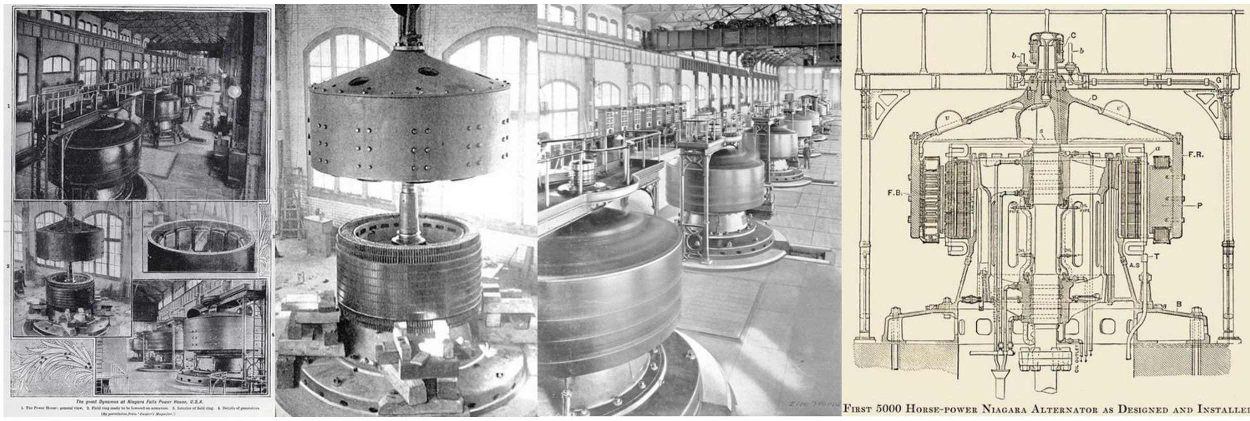




If you place the excitation magnetic field in the moving part (magnetic rotor), the generator will produce alternating current (Figure b). In 1884, Thomas Edison hired a young Serbian engineer, Nikola Tesla, whose duties included repairing electric motors and DC generators. Tesla proposed using alternating current for generators and power plants. Edison perceived Tesla's new ideas rather coldly, and disputes constantly arose. Tesla claims that in the spring of 1885 Edison promised him 50 thousand dollars (*at that time an amount approximately equivalent to 1 million modern dollars*) if he could constructively improve the direct current electric machines invented by Edison. Nikola actively got to work and soon introduced 24 varieties of Edison's alternating current machine, a new switch and regulator, which significantly improved performance characteristics. Having approved all the improvements, in response to a question about the reward, Edison refused Tesla, saying that the emigrant still did not understand American humor well. Offended, Tesla immediately quit. If schematically, the essence of the alteration comes down to switching the armature frame to slip rings (Figure c). Subsequently, a similar topology was used in the construction of a generator for the Niagara Hydroelectric Power Station. A monument to the history of the Niagara Hydroelectric Power Station and Tesla stands precisely for this type of generator. The paradox is that in reality, even during the construction of the Niagara Hydroelectric Power Station, generators designed by Nikola Tesla turned out to be very fire hazardous due to an imperfect unit for collecting the generated current from the armature windings. Scaling this type of generator turned out to be a difficult and expensive task. The first generators that were used at the Niagara Hydroelectric Power Plant were of the synchronous type, with a rotating external electromagnetic rotor, of the Umbrella type, George Forbes (1849–1936) , who was a Scottish electrical engineer, astronomer, explorer, writer and inventor, some of whose inventions are used still. About his participation in the work at the Niagara Hydroelectric Power

Station, Wikipedia modestly says that from 1891 to 1895, Forbes was a consulting engineer for the Niagara Falls hydroelectric power station. But there is also this information: " *On August 10, 1893, new proposals were solicited based on the design of Professor Forbes of the Cataract Company for a two-phase generator at 20,000 volts with an external rotating field of the "umbrella" type, while a rotating armature was standard practice.* "

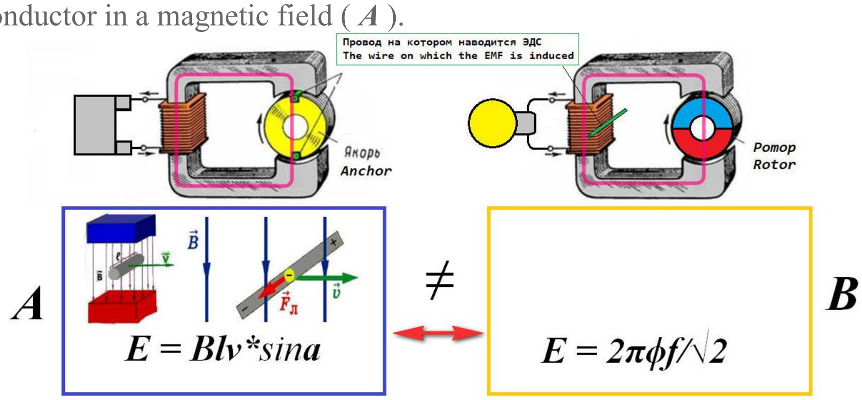
https://teslaresearch.jimdofree.com/niagara-falls-power-project-1888/



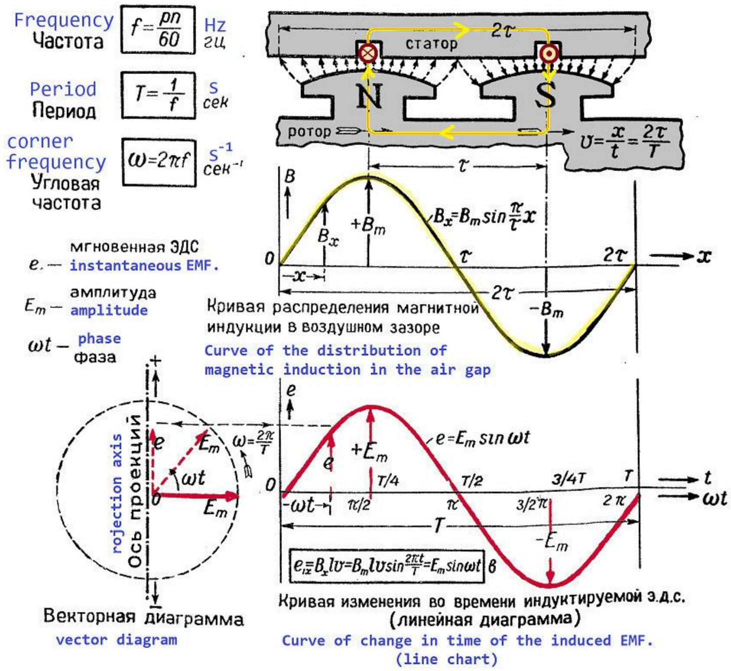
In fact, he is the author of the heart of the Niagara Hydroelectric Power Station. His two-phase, synchronous alternating current generator, the Umbrella type, was installed at the Niagara Hydroelectric Power Station in 1895. It had an external electromagnetic rotor shaped like an umbrella with 12 poles and could generate up to 5000 kW of power. In addition, another invention of George Forbes was used in the generator, this was the power supply of the excitation electromagnets of the rotating external rotor of the umbrella type, through the copper carbon brushes and slip rings he invented, which was a revolutionary solution. In fact, the design (topology) implemented by Forbes in this generator is still used today.

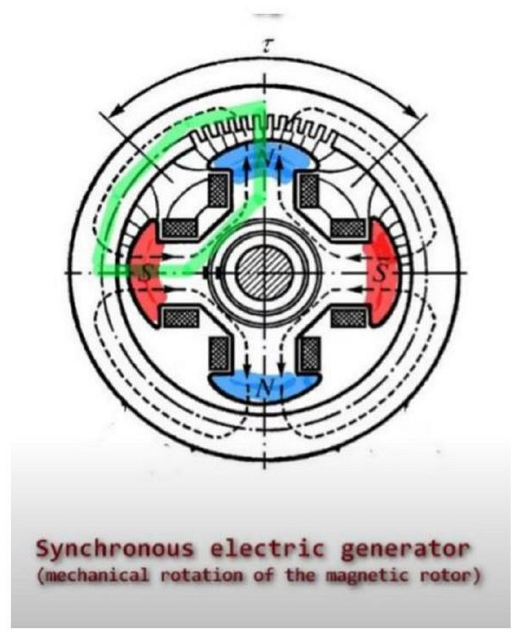
When the wire is laid in the stator groove, namely this type of rotor design, a two-phase Forbes generator had, or on windings on rod cores with a stator pole piece, the magnetic lines of the magnetic flux cannot reach the phase wire to perform the contact method of inducing EMF, since they all magnetic lines are located in the body of the groove rods, and the wires are laid in the air space between the groove rods in the grooves. It is enough to do the appropriate software modeling of the corresponding magnetic circuit with slots, gaps and a source of magnetic excitation field to see the picture I described.

If we consider the formulas for induced emf (*figure below*), then the transformer emf formula (***B***) does not have a vector topology for the intersection of a wire with magnetic lines, unlike the emf formula for a conductor in a magnetic field (***A***).



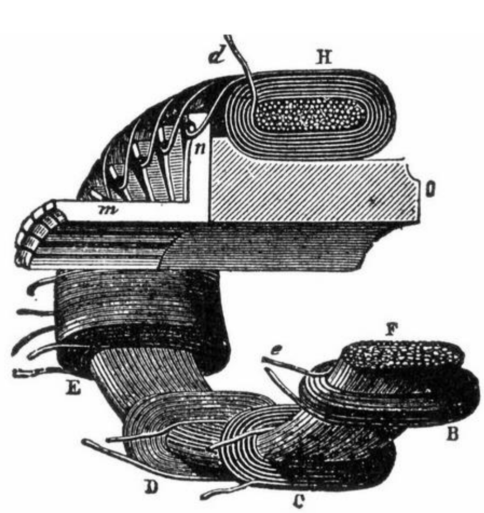
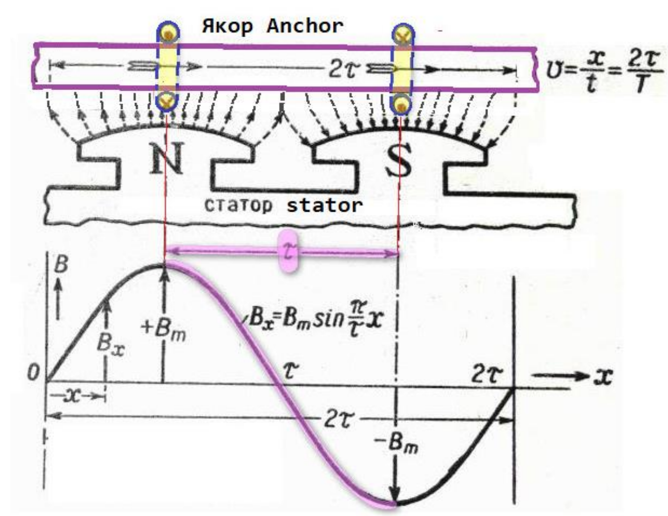
While studying the operation of generators and the technology for inducing EMF for a synchronous generator, you can come across a very detailed and well-illustrated slide:





*slide for definition: E = B*l*v*sin(a)*

The paradox is that this slide simply perfectly explains the topology of a frame generator with a contact method of inducing EMF, which is actually confirmed by the corresponding formulas. If we apply this figure/slide to the topology of a Gramme generator with a ring armature, we get an exact match.

Unfortunately, this topology is absolutely unacceptable for calculating and understanding the operation of modern synchronous generators.

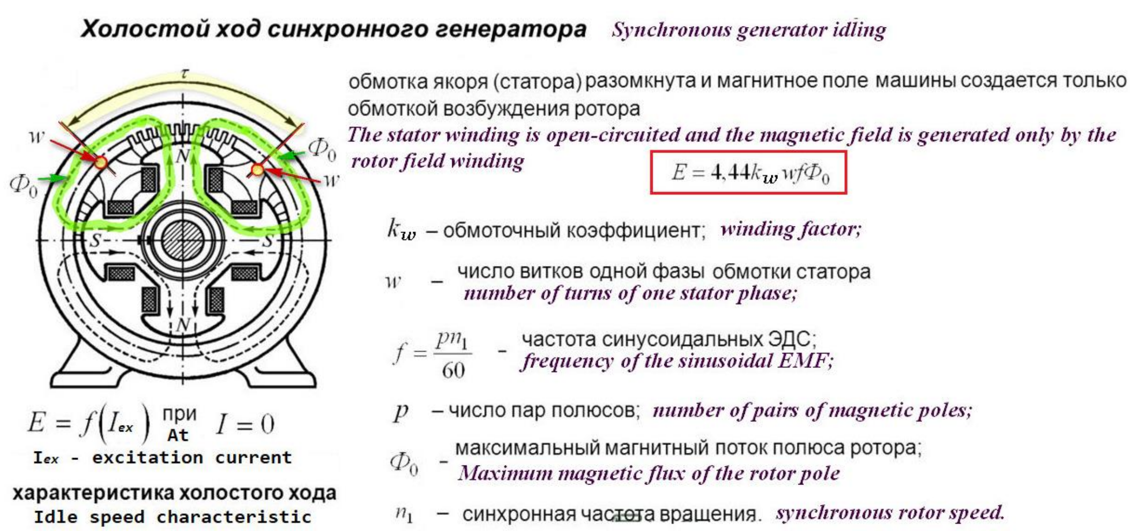
An example of the calculation of modern synchronous generators: **Calculation of a synchronous generator** .

Currently, synchronous generators are the main source of electricity. Their power ranges from several kilowatts to hundreds of thousands of kilowatts. Synchronous generators are installed in thermal and hydroelectric power plants, aircraft, ships, and are used to power various mobile power sources.
The main properties of a synchronous generator are given by the characteristics that determine the relationship between the voltage at the armature terminals, the excitation current, the load current at the rated speed and the constant power factor in steady state.
Designing an electric machine is an ambiguous task, since the number of initial design equations describing the electromagnetic connections in it is less than the number of unknown quantities. Therefore, nominal data can be provided for different ratios of the main dimensions and electromagnetic loads of the machine. The optimal result largely depends on the experience of the designer and is usually achieved by comparing several options. The minimum total costs are most often taken as a universal optimality criterion, i.e. cost of materials, manufacturing and operating costs. Operating costs, in turn, depend on efficiency, power factor, quality, maintainability and a number of other factors .

The main tasks when calculating a synchronous three-phase generator:
Introduction ; Calculation of nominal parameters ; Stator sizing ; Calculation of the stator tooth zone. Segmentation ; Calculation of slots and stator windings ; Air gap selection. Calculation of rotor poles ; Calculation of damper winding ; Magnetic circuit calculation ; Determination of stator winding parameters for steady state operation ; Calculation of MMF of the excitation winding under load. Vector diagram ; Excitation winding calculation ; Determination of parameters and time constants of windings ; Calculation of masses of active materials ; Determination of losses and efficiency ; Calculation of the temperature rise of the stator winding ; Determination of short circuit currents ; Calculation and construction of generator characteristics ; List of sources used .

This calculation is based on the calculation of the magnetic circuit and magnetomotive force. Magnetomotive force (MF) is a physical quantity that characterizes the ability of electric currents to create magnetic fluxes. MMF is an analogue of EMF in electrical circuits. The unit of measurement of magnetomotive force in the SI system is ampere-current, in the CGS system it is hilbert.

Surprisingly, in this calculation we did not encounter the basic primary principle of calculation from Faraday’s law of electromagnetic induction, which applies to any synchronous generator with a contact method when the magnetic lines of a magnetic pole are crossed by a conductor. The EMF of this type of generator is traditionally calculated for idle speed:



As you can see, the formula is radically different from the formula for the contact EMF method (*formula 1*). if we remove the winding coefficient and the number of phase turns, leaving the action for one conductor, we get: $E = 4.44\phi f$. Does the coefficient of 4.44 used by engineers remain unknown to us? Education claims the formation of this coefficient based on the condition of the magnetic lines crossing the conductor " Electromotive force of the synchronous generator winding " When the rotor of an excited synchronous machine rotates, the magnetic flux crosses the active sides of the stator (armature) winding sections and induces an alternating EMF in them. At the same time, the EMF of a synchronous generator is characterized by three main parameters: frequency, magnitude (rms value) and curve shape. As follows from the formula and definition. A synchronous machine is an AC machine in which the number of revolutions and the frequency of the current in the stator are related by the relation: *[n=60f/p]*, where: ***n*** is the number of rotor revolutions, *rpm* ; ***f*** is the frequency of the current in the stator, *Hz* ; ***p*** is the number of pairs of poles. Thus, the EMF frequency is determined by the expression: $f = pn/60$

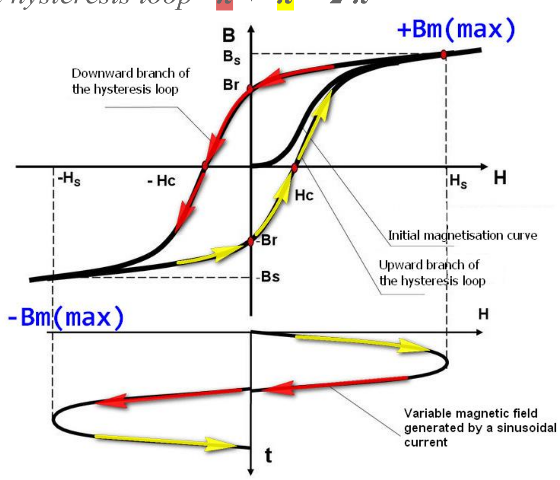
According to the educational material (*Electromotive force of a synchronous generator winding*) coefficient 4.44 is the sum of the value of the instantaneous emf for a conductor in a groove that crosses the magnetic flux ϕ in the stator slot from the magnetic pole of the rotor: permissible for the maximum value of the emf for a conductor laid in one stator slot: $E_{max} = k_{es} V \times l v$ [$k_{es} = 1.11$], for two conductors in two slots connected in series $k_{es} = 2.22$, and for the full amplitude of a sinusoidal signal of two conductors $k_{es} = 4.44$. Everything would be great if: $B \times l = \phi = B \times S$.

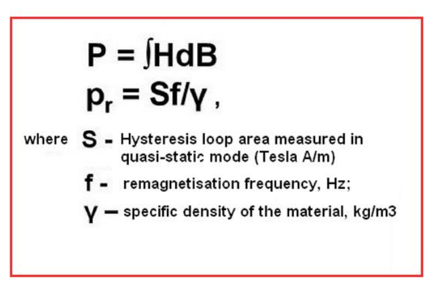
Just look at the slide " *idling of a synchronous generator* " and see that the coefficient ***4.44*** is multiplied by all turns of the winding of phase ***w*** : $E = \mathbf{4.44}\, k_w\, w f \phi_0$. This indicates a clear discrepancy between the applied formula and the " *academic explanation* " for this coefficient, discussed above.

The rate of flux change is measured over the period interval τ, between the maximum magnetic induction vectors ***B*** *x*. If you look at *the slide for determining the EMF of a synchronous generator: E = B*l*v*sin(a)* above , then in the analysis of the action of the EMF of the contact method, you will see that the period τ is determined from the point [+ ***B*** *(max)*] to points [- ***B*** *(max)*]. If you look at the slide " *idling of a synchronous generator* ", this period is already indicated in a completely different interval of points and the position of the magnetic poles of the rotor. Let's say this is an accident and an artist's mistake, or are there different approaches to design? But this is not an accident. There is a model of the magnetic circuit of a transformer (*the EMF formula is called transformer*), where the conductor is laid in the window of the transformer iron, inside a closed magnetic circuit. This coefficient is calculated for a harmonic sinusoidal signal based on the formula: $E = 2\pi\phi f/\sqrt{2}$

Where:

2π *- equal to the change in speed from maximum to zero or it is zero to maximum in the magnetic induction hysteresis loop* $\pi + \pi = 2\pi$





$1/\sqrt{2}$ *is the root mean square value (0.7) and if we calculate the equation in constant values in the numerator and denominator of the formula, we get the result:* $2\pi / \sqrt{2} = 2 * 3.14 * 0.7 = 4.44$.

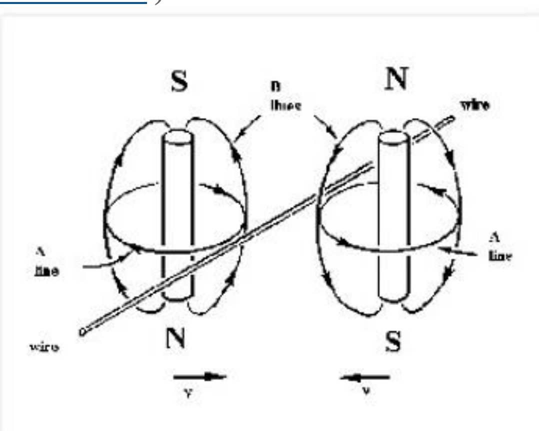
The formula with the constants already calculated will take a familiar form: $E = 2\pi \phi f / \sqrt{2} = E = 4.44\, \phi f$

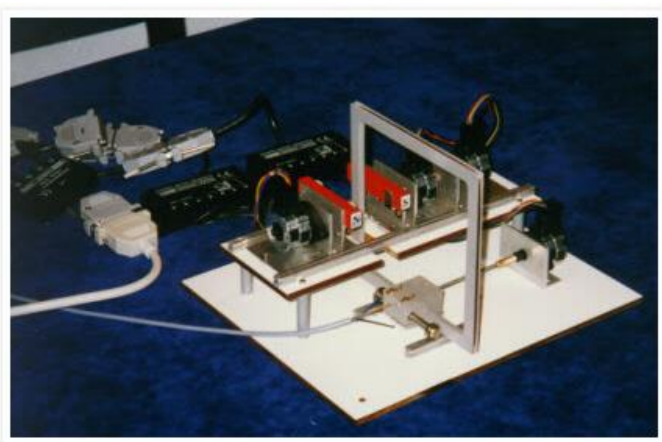
Thus, the reading in this version is logical. The only question that remains unknown is what physical processes cause the formation of an EMF in a section of the conductor limited by the window of the magnetic circuit (core), in which corresponding changes in magnetic induction occur. Unfortunately, this formula does not work in the transformer version of mutual induction; other processes take place there.

We can conclude that Michael Faraday, his comrades and followers, missed the understanding of the topology of non-contact EMF, which was in fact in Faraday's induction ring and the first synchronous generators of Hippolyte Pixia and the unknown PM, as well as the first industrial synchronous generator of George Forbes (at the Niagara Hydroelectric Station) . This fact of the presence of non-contact EMF is ignored by official physics to this day.

All powerful mechanical synchronous generators of all power plants on the planet use this principle. This principle completely cancels the statement of physics that a mechanical generator is a converter of mechanical energy into electrical energy. It is impossible to convert the mechanical power ***Pk,*** the effective force vector ***F,*** at the corresponding speed ***v,*** [***Pk=Fv***], into the electromagnetic power ***Pe*** , which is the product of the effective current ***I*** , at the corresponding voltage ***U*** , at the generator terminals, [***Pe=IU***]. Mechanical power is a condition for creating movement of a magnetic constant excitation flux and overcoming the electromagnetic attraction of the rotor/stator, which occurs when inducing EMF and current in the windings of the generator phase. For information, a synchronous generator with a solid-state rotor (without mechanical rotation) has been patented and implemented in the USA. **Holcomb Energy System** . This device is direct proof of the absurdity of the "scientific" statement that a mechanical generator is an energy converter: mechanical into electrical!

What is my guess based on without contact electromagnetic induction at the focus of a closed magnetic flux, which changes its density, saturation, vector. Firstly, logic, these actions are observed in fact. Secondly, I wasn't the only one who noticed this phenomenon. Experiment by Christian MONSHTEIN. Switzerland. 1997 [PDF], in which conditions were created for the conductor when it fell into the focus of a changing non-uniform magnetic flux. (*link to my material about this phenomenon*)



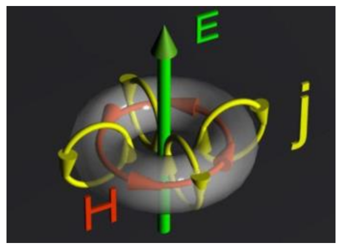


The experiment just proves that an EMF pulse is induced at the focus of a changing closed magnetic flux. Which fits very well into the well-known formula:

E = 2πϕf/√2 .

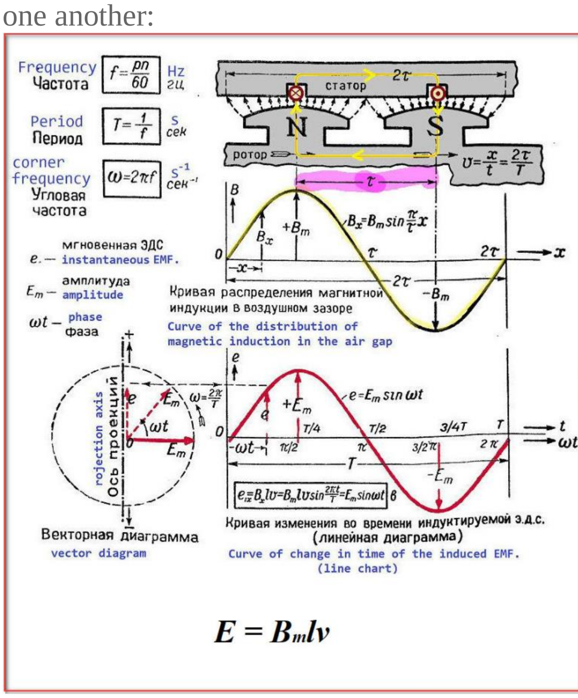
In physics the phenomenon of ANAPOLE is also described:

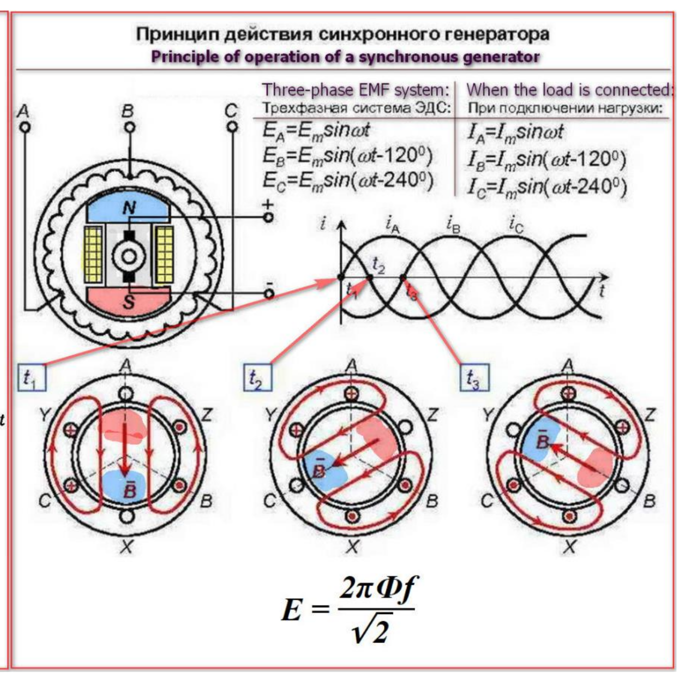
ANAPOL (*from the Greek* ***an*** *- negative particle and* ***polos*** *- pole*), a toroidal dipole is a system of currents, the electromagnetic field of which is characterized ***by the anapole moment vector*** . A change ***in the anapole moment*** over time generally leads to the emission of electromagnetic waves by the system.
ANAPOLE (toroidal dipole), a system of currents, the magnetic field of which is entirely concentrated inside the system. The anapole moment has the form



When the magnetic intensity ***H*** (magnetic flux ***B) changes, the electric field vector E*** appears at the focus . When a closed magnetic circuit is superimposed on the model, in the focus of which a conductor is laid, we have the induction of an electric field limited by the volume of this focus. Thus, if simply in the hole of a closed ferromagnetic core, in which the *field moment of magnetic intensity* ***H*** changes , an electric moment is formed at the focus of this core. If there is a magnetic circuit of a conductor at the focus, an electrical potential difference appears on it. Which is actually the non-contact method of electromagnetic induction.

If you look at the slides explaining the operation of modern synchronous generators, they contradict one another:

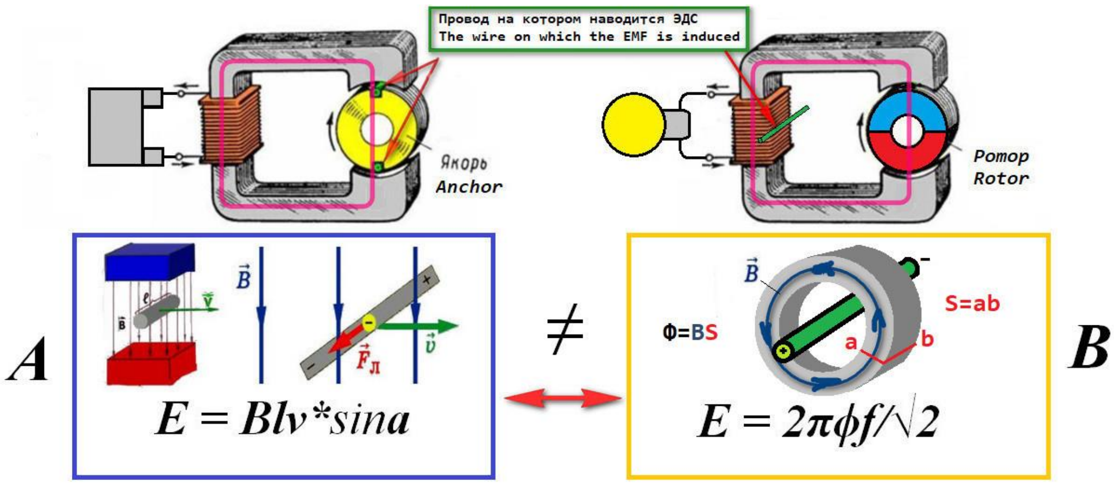




https://elektronchic.ru/elektrotexnika/princip-raboty-i-ustrojstvo-generatora-peremennogo-toka.html

But these are the principles of two different generators with a guidance system for two different EMFs, which we discussed above.

We can record two types of electromagnetic induction: The first is contact when a conductor moves in a constant magnetic field, where the force lines of vector magnetic induction cut the moving conductor. The second is based on the phenomenon of anapole moment, when the conductor is at the focus of an anapole (toroidal dipole), and when the vector and density of magnetic induction changes in a toroidal closed flow of magnetic induction, an emf occurs at the focus.



It was the action of the anapole moment that occurred in Faraday's induction coil when he opened the first winding of his coil from the galvanic battery, and the second winding of the coil was connected to the galvanometer. This is exactly what happens in my version of a flyback converter (**Transformer with a riddle - "how"?**). It is this phenomenon that occurs during the operation of synchronous generators with cores in which the phase wires are laid at the focus of a changing magnetic flux.

To be fair, various researchers have pointed out in their works the existence of two different EMFs.

George R. Cohn - Electromagnetic Induction 1949.

Transformer induction: *In the case of purely transformer induction, there is no movement of material bodies as such.*
Motor induction: *In the case of pure motor induction, there is no change in the magnetic field with time as such.*

For me personally, there are no more uncertainties. We have restored the lost topology of electromagnetic induction that Faraday, his comrades and followers missed.

Serge Rakarsky, Kiev, Ukraine
Glory to Ukraine! Glory to heroes!