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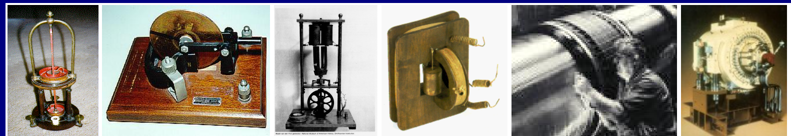
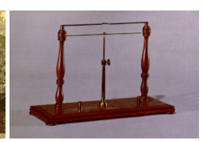
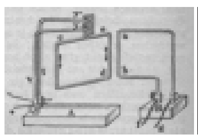
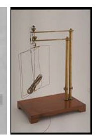
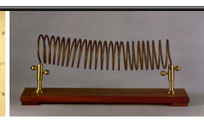
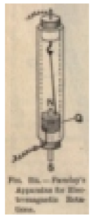
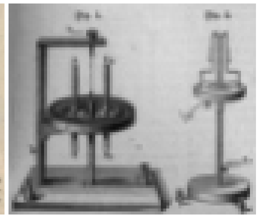


Click to View Pictures	Date / Event & Personage
No Picture	**Prior to 1800**, many mariners had observed that nearby lightning strikes seemed to momentarily affect the position of their compass needles, and that this also occurred during the formation of St. Elmo's fire on their ship's masts. Lightning discharges were also known to magnetize knives and other iron or steel objects. However, no-one had been to reconcile these magnetic effects with the flow of electric currents.
Picture Soon	1799 - 1800 ~ Allesandro Volta....
No Picture	**1802 ~ ROMAGNOSI** vaguely observes that the connection of a **Voltaic Pile** (i.e., battery) to a closed electrical circuit seems to affect a nearby compass needle (he made mention of this in an obscure Italian publication), but he does not realize the possible connection between **Electricity** and **Magnetism**.
 	**1819 ~ DEFLECTION OF A MAGNETIC NEEDLE BY AN ELECTRIC CURRENT** **OERSTED** (?accidentally?) discovered this effect (**Electromagnetism**) in the winter of 1819 during a demonstration to his students of the heating of a platinum wire by the electric current from a voltaic pile. He had planned to demonstrate both the heating of the wire and to also to carry out some general demonstrations of magnetism, for which he had provided a compass needle mounted on a wooden stand. While performing the wire heating demonstration, Oersted noted to his surprise that every time the electric current was flowing, the nearby compass needle moved to a position **more perpendicular** to the wire. However, Oersted does not seem to have immediately understood that the electric current actually generated a magnetic field about itself (i.e., the circular magnetic field surrounding an electrical conductor when current is flowing.) Three months later (March, 1820), having confirmed the effect through further experiments, he further investigates this phenomena and in the summer he publishes a treatise thereon (in Latin and in almost unreadable natural philosophical terminology) without any explanation for the effect and sends it to many leading scientific journals and to a number of scientists. Oersted's announcement appeared in the *Annales de Chimie et de Physique* in July of 1820 and gains further publicity when the distinguished scientific statesman François Arago calls attention to the discovery at a meeting of the Académie des Sciences in Paris in September, 1820. Shown on the left is a lithograph depicting Oersted's original demonstration and on the right is an 1851 example of an experimental apparatus to demonstrate this electromagnetic

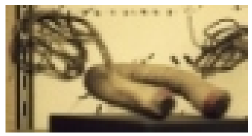
	effect.
Picture Soon	**1820 ~ GALVANOMETER** **SCHWEIGGER** creates the world's first **Galvanometer** (i.e., **galvanoscope**.) While experimenting with electromagnetism, Schweigger became delighted when the deflection of a magnetic needle was doubled as long as the needle's position was maintained within the plane of a doubled loop of wire (i.e., a coil.) Schweigger then wound a conducting wire on itself for 100 turns to provide for an effect far greater than a single loop of wire. Applying Oersted's principle to his device, he reported the operation and effect of his galvanomagnetic multiplier just two months after Oersted's announcement in July 1820 of his experiments with electromagnetism. Schweigger presented a paper on his discovery at the University of Halle on 16 September 1820, and published the same in the November 1820 issue of Literary Gazette. Schweigger also called his new device an electromagnetic multiplier or galvanometer multiplier (or a galvanomagnetic kondensator.)
 	**1820+** **AMPERE**, who had been in the audience when Arago announced Oersted's discovery in Paris, investigates electromagnetism and presents his interpretation thereof in early 1821. Besides confirming Oersted's results, Ampere made careful studies of the effects of electric currents on one another. He found that if currents traveled in the same direction along two parallel wires, there was attraction between them; if the currents traveled in the opposite directions there was repulsion. Over the next six years, he worked out a detailed mathematical treatment of the interactions, on the basis of the assumption that current-carrying elements of the wire interacted with one another according to the inverse square law. By integrating the effects of all the elements he arrived at expressions that were consistent with the experimental results and by 1827 he had developed a comprehensive **Electrodynamic Theory** with the aid of his unique apparatus (i.e., Ampere's Table.) A drawing of Ampere's original table is shown on the left, as well as an example of his table circa. 1865 on the right.
	**1820 ~** **ARAGO** and **DAVY** produce the spiral wound planar **solenoid** (one from Faraday's laboratory circa. 1824 is shown here.) **Wollaston** advances the possibility of electromagnetic rotations, and he and Davy attempt to cause the rotation of an electrical conductor about its own axis, but fail.
 	**1820 ~ AMPERE** (as well as Arago and Davy) develop the helical air-cored solenoid. The example on the left is from Faraday's laboratory circa. 1824, the example on the right is circa. 1851.

 	**1821 ~ ROTATION OF A CONDUCTOR IN A MAGNETIC FIELD *(FIRST ELECTROMAGNETIC MOTOR & FIRST ACYCLIC / HOMOPOLAR MOTOR)*** **FARADAY** is asked to investigate electromagnetism and quickly produces his "**Electromagnetic Rotator**", which is the world's first **Electric Motor** (and is powered by **DC** and is non-commutated), and it is also the world's first **electromechanical power converter** that is both **homopolar** in structure and "**Acyclic**" in operational nature. Faraday then went on to cause a **magnet to rotate** around an electric current-carrying (DC) wire, another case of a homopolar and acyclic apparatus. Shown on the left is a drawing of Faraday's apparatus for producing the rotation of an electric current-carrying conductor around a magnetic pole (which was manufactured and sold to other investigators in 1822.) Shown on the right is a two-figure drawing of an 1850's modification of Faraday's two electromagnetic rotator apparatus. Fig. 1 shows the rotation of magnets around a conductor and Fig. 2 shows the rotation of conductors around a magnet.
	**1822 ~ BARLOW** produces electromagnetic rotation with his star-shaped wheel ("**Barlow's Wheel**"). The wheel rotated when it was traversed radially by an electric current, while between the poles of a horseshoe magnet. This device is also a DC motor and is homopolar (but not acyclic.) Shown is a model probably made for Faraday in 1823 (notice the difference in the intersection between the wheel and the magnetic poles in Faraday's model and that in the background sketch from Barlow.)
No Picture Yet	**1823 ~ STURGEON** produces electromagnetic rotation with a round copper disk (in action the same as Barlow's wheel above), and which is in fact, identical to the first "**Faraday Disk**" as later used by Faraday in his investigation of electrical induction in 1831.
Picture Soon	**1824 ~ ARAGO** discovers that a rotating non-magnetic (but electrically conductive) disk would drag a magnet around with it. This physical phenomenon (due to what are now commonly called "**eddy currents**") was then studied by **Gambey**, Ampere, **Poisson**, **Babbage** and **Herschel** without a resultant explanation, because all were unaware of their (i.e., eddy currents) existence and their mechanism of action or their cause.
Picture Soon	**1825 ~ ELECTROMAGNET** **STURGEON** constructs an **electromagnet** (i.e., a helical solenoid wound on an iron core), but he used uninsulated conductors and the magnetic field produced was weak.



1825 ~ ELECTROMAGNETIC ROTATIONAL APPARATUS

The top picture shows a collection of experimental apparatus used by **NOBILI**, which includes his version of Barlow's wheel (in that it did not use a star-shaped wheel) and three devices for demonstrating the motion of conductors in a magnetic field, two using mercury as the moving conductor and one using a vertical copper conductor. The picture on the bottom left shows an electromagnetic rotation apparatus for interaction with the magnetic field of a coil and the picture on the bottom right shows an electromagnetic rotation apparatus for interaction with the earth's magnetic field. Both of these are circa 1868.



1828 ~ FIRST PRACTICAL ELECTROMAGNET

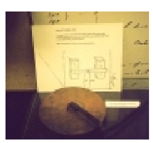
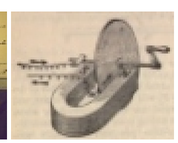
HENRY produces the first practical electromagnet (i.e., a helical solenoid wound around an iron core) by using insulated conductors. This vastly improved upon Sturgeon, who had produced the first electromagnet in 1825 (but had used uninsulated conductors.) Shown here is an early horseshoe shaped electromagnet from Faraday's laboratory.

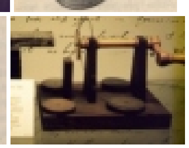
Picture Soon

1831 ~ HENRY constructs a small electromagnetic engine (i.e., the world's first **"Cyclic"** motor, although it was a reciprocating "balance" beam form of machine, rather than a rotary machine.)

Pictures Soon

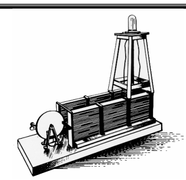
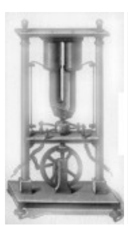
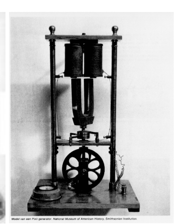
1831 ~ Faraday discovers **Electromagnetic Induction** and first experiments with **Mutual Inductance** (i.e., **transformer induction**) and then the electromagnetic induction of **EMF** due to **variational magnetic flux**) and almost reports the effect of **self-inductance**, but does not. (**Henry** reports in 1832 on his experiments with self-inductance in electromagnets and large iron-cored coils.)

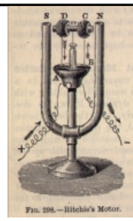
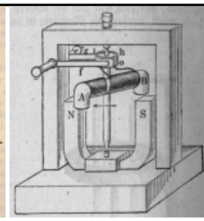
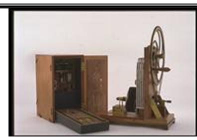
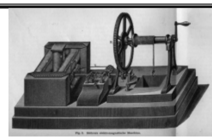
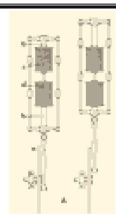
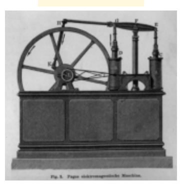



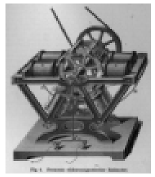


1831 ~ ELECTROMAGNETIC INDUCTION ***(FIRST DC ELECTRIC GENERATOR & FIRST HOMOPOLAR / ACYCLIC GENERATOR)***

FARADAY in discovering and investigating electromagnetic induction, produces the world's first **Electric Generator**, the **"Faraday Disk".** This was the world's first **continuous uni-directional electric current** generating apparatus, and was also the world's first **DC Generator** which was also **homopolar** in structure. Shown here first on upper the left, is the disk as used in Faraday's laboratory. (**Note:** Henry is said to have discovered electromagnetic induction independently of and prior to Faraday, but in actuality Henry had concentrated on self-induction because of his previous work with electromagnets and Henry did not make his discoveries until a few months after Faraday's, nor did Henry publish his findings until the summer of 1832.) Shown secondly on the upper right, is a graphical depiction of the above first **"Faraday Disk"** apparatus, followed thirdly on the lower left by another depiction of Faraday's first form of disk generator (in particular, showing the induced "**eddy currents**".) Faraday later revisited his first form of disk generator using adjacent parallel magnetic poles and investigated the electrical induction effect using disks of various types of conductive materials, as seen fourthly on the lower right in his 1851

	experimental apparatus.
Pictures Soon	**1831 ~ FARADAY** constructs his second version of a continuous uni-directional electric current generator apparatus, which comprised a copper disk whose edges floated in mercury and which rotated in a magnetic field. This was also **homopolar** in structure, but was "**acyclic in operational nature.**" **FARADAY** further constructs a third continuous uni-directional electric current generator apparatus, which was comprised of a copper disk rotating or co-rotating with a cylindrical magnet. This was again **homopolar** in structure and **acyclic** in its nature of operation. His third construct led to the famous **Faraday paradox** concerning the electrodynamic interactions at play within homopolar / acyclic apparatus.
	**1832 ~ FARADAY** demonstrates a large version of his first continuous uni-directional electric current generator apparatus, by using the large horseshoe magnet at the **Royal Institution**. (**Note:** This demonstration concerned a homopolar apparatus that was "**not**" acyclic in its nature of operation.)
Picture Soon	**1832 ~ LINEAR AC GENERATOR *(LINEAR ALTERNATOR)*** **FARADAY** constructs the world's first **alternating current electric generator** apparatus (i.e., **alternator**), one which converts the input of mechanical energy into electricity by using **linearly reciprocating** permanent magnetic poles and stationary induction coils.
No Picture Yet	**1832 ~ ROTARY AC GENERATOR *(ROTARY ALTERNATOR)*** **PIXII** and **DAL NEGRO** both construct alternating current (**AC**) electrical generator apparatus as per Faraday's discoveries, but both use **rotating** permanent magnetic poles.
 	**1832 ~ ROTARY DC GENERATOR *(COMMUTATED DC GENERATOR)*** **PIXII** constructs the world's first **pulsating direct-current electric generator**, one which uses rotating permanent magnetic poles with stationary induction coils and an electrical switching or **commutation** mechanism called a **commutator** for converting (i.e., **rectifying**) the induced alternating current to direct-current (**DC**.) Shown on the left is Pixii's 1832 **commutated** DC generator and on the right is another view. (**Note:** Ampere suggested the use of such a switching mechanism to Pixii.)

 	**1832 ~ ROTARY DC MOTOR *(COMMUTATED DC MOTOR)*** **RITCHIE** constructs a small electromagnetic engine, the first commutated rotary DC motor, two different versions of which are shown here. (**Note:** One can see that this motor is almost a reciprocal form of Pixii's generator, but with moving coils and stationary permanent magnet poles.)
Picture Soon	**1833 ~ SAXTON** builds a commutated DC generator.
	**1834 ~ CLARKE** builds a version of Pixii's generator, an 1871 reproduction is shown here.
Picture Soon	**1835 ~ PAGE** builds his first commutated DC generator.
	**1836 ~ STOEHRER** constructs his first generator.
No Picture Yet	**1838 ~ JACOBI** constructs the world's first electrically propelled boat (using a large battery bank and a reciprocating solenoidal electromagnetic engine of about 1 hp) and publicly demonstrates it on the river Neva in Russia.
  	**1838 ~ LINEAR RECIPROCATING DC ELECTRIC MOTOR** **PAGE** designs and constructs various electromagnetic engines using reciprocating iron plungers and solenoid coil arrangements (this is similar to Henry's engine from 1831.) Shown first is a diagrammatic drawing of one of Page's solenoid motors. The second picture shows a full version of Page's motor and the third picture shows a reproduction from 1858.

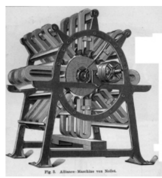


1840 ~ DC MOTOR WITH A PERMANENT MAGNET ROTOR

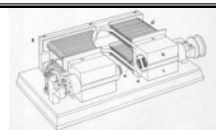
FROMENT constructs an interesting motor, in structure and function almost like current **Permanent Magnet Brushless** motors (i.e., having a **rotor** with multiple **salient** poles and a commutated **stator**.)

No Picture

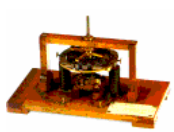
1842 ~ DAVIS appears to have been the first to recognize (more than twenty years before anyone else, i.e., Pacinotti in 1864 or Gramme in 1873) that the electromechanical action of an electric motor is the inverse of that of the electric generator.



1850+ ~ NOLLET (with **van Malderen's** help) develops several high-current generators that were (incredibly!) used for the electrolysis (dissociation) of water in order to provide an H_2 & O_2 gas supply for intense gas fired luminaires (using limelight wicks/blocks.) After Nollet's death (1853), the **Alliance** Company, with the help of **Wilde** and **Holmes** and under **Faraday's** supervision, modified and commercialized these generators for use in powering carbon arc-lights for the production of illuminant flux. These lighting systems were employed in several European lighthouse installations (South Foreland in 1858, Dungeness in 1862 and La Heve in 1863.) They were also used to light the construction of the Cherbourg Docks and onboard ships such as the Lafayette and the Jerome Napoleon.

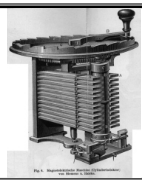
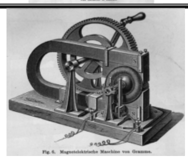
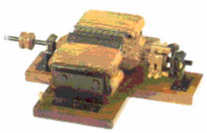
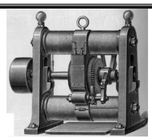


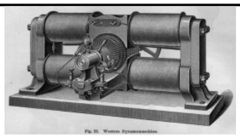
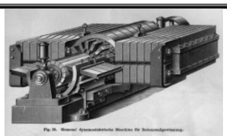
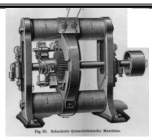
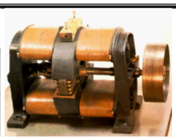
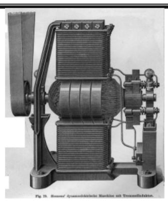
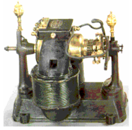
1856 ~ SIEMENS invents the shuttle wound (T-anchor) form of armature. A double armature machine is shown here.

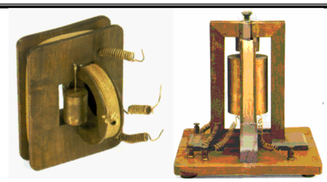
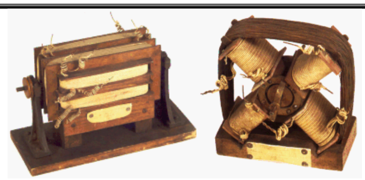


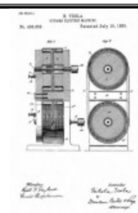
1860 ~ RING WOUND ARMATURE

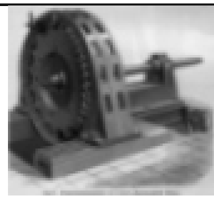
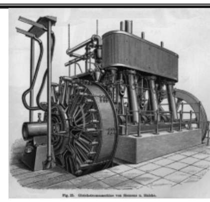
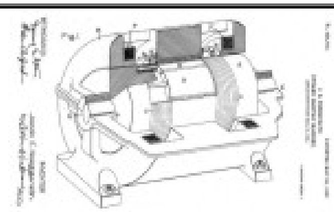
PACINOTTI invents and develops the **ring wound** form of armature winding and produces both a **surface winding** and **slotted winding** of that type. By 1864 Pacinotti already knew of and had demonstrated, generator and motor reciprocity (i.e., reversibility of their action) using his particular apparatus. (**Note:** Both **Foucalt** and **de Romilly** are said to have helped Pacinotti with his development of the ring winding.) By 1867, Pacinotti had also proposed the long distance transmission of DC power between generators and motors.

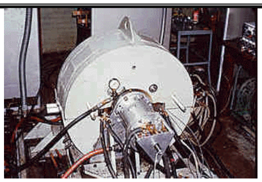
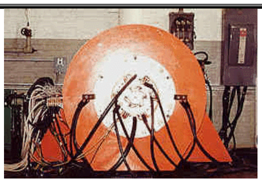
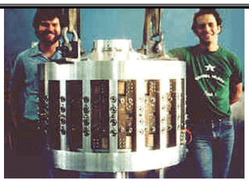
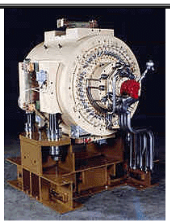
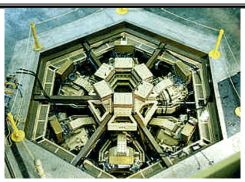
	**1863 ~ GRAMME** produces (for laboratory use) a form of Pacinotti's ring wound generator.
Picture Soon	**1866 ~ WILDE** creates a powerful generator using field electromagnets energized by a small secondary generator of the Siemens shuttle type.
Picture Soon	**1866 ~ DYNAMO PRINCIPLE** **SIEMENS**, **Varley**, **Wheatstone** and Wilde (and actually preceded in 1865 by **Farmer**) simultaneously invent the field self-energizing **dynamo** (eliminating the need for permanent magnet field structures or a secondary field excitation generator.)
	**1867 ~ SIEMENS** constructs a further form of his shuttle wound magnetoelectric generator which finds great service in railway signalling applications. It is also reported that with the aid of his good friend **Kirchhoff**, he constructs a small **unipolar**, acyclic permanent magnet generator (picture not yet available.)
	**1870 ~ GRAMME** produces another form of ring wound generator, still using a permanent magnet field structure.
	**1872 ~ DRUM WOUND ARMATURE** **von HEFNER ALTENECK** invents the **drum wound** form of armature winding and Siemens and Halske produce the first commercial drum wound dynamo.
	**1872 ~ GRAMME** and **BREGUET** commence commercial production of this ring wound dynamo.
Picture Soon	**1873 ~ GRAMME** is reported to have accidentally re-discovered? (see Davis 1842 & Pacinotti 1864) the reciprocity between motor and generator action, at an industrial exhibition in Vienna.

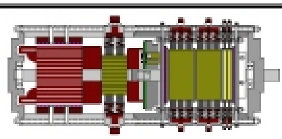
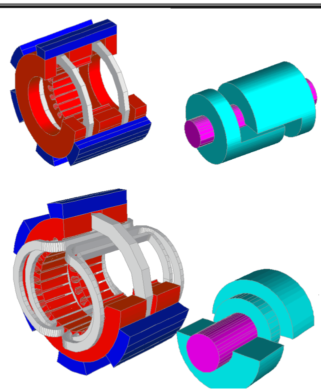
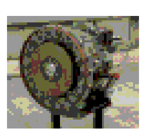
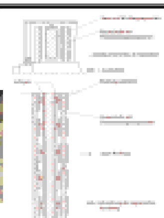
	**1874 ~ WESTON** produces this ring wound dynamo.
Picture Soon	**1876 ~ ROWLAND** proves that a moving charged disk (i.e., static electricity) acted the same as do any moving charges (i.e., convection current) in producing a magnetic field. He thereby dispelled any doubt that there might be a difference between "static electricity" and "current electricity."
	**1876 ~ SIEMENS** constructs a low-impedance dynamo for the electrowinning of metals.
 	**1876 ~ SCHUCKERT** produces his disk type (ring wound) dynamo.
	**1877 ~ SIEMENS** produces the type D15 dynamo, the second dynamo (drum wound) commercially produced by Siemens and Halske.
	**1878 ~** A larger Siemens dynamo of the D15 style.
Picture Soon	**1881 ~ SIEMENS** produces this unipolar (i.e., acyclic & homopolar) generator.
	**1884 ~ SIEMENS** produces the type H drum wound dynamo.

No Picture Yet	**1884 ~ POLYPHASE AC INDUCTION MOTOR** **TESLA** ***"claims"*** to have built (in late 1883) and demonstrated (in early 1884), a two-phase **rotating field** AC induction motor in Strassburg (i.e., **AC polyphase induction motor**.) Tesla did not build another model of his motor until 1887, when he filed US patents thereon after emigrating to the United States. (Note: the concept of rotating fields due to polyphase currents was not new, in 1878 Gramme produced di-phase and tri-phase alternators, and in 1879 **Baily** suggested the use of rotating magnetic fields to effect the rotation of conductors and also constructed a two-phase induction motor that used rectangular excitation instead of sinusoidal excitation.
No Picture Yet	**1885+ ~** The slotted form of armature construction is slowly being adopted by manufacturers and the ring form of winding is rapidly displaced by the drum form of winding.
	**1885 ~ POLYPHASE AC INDUCTION MOTOR** **FERRARIS** produces and demonstrates his first two rotating field motors for polyphase alternating current.
	**1885 ~ OERLIKON** produces this **Manchester** form of dynamo.
	**1886 ~ FERRARIS** produces his third and fourth versions of a rotating field AC motor.
	**1887 ~ EDISON** produces his distinctive (i.e., large vertical field pole) style of dynamos for DC lighting plants.

Picture Soon	**1887 ~ TESLA** builds several models of his AC polyphase induction motor and files for patents. (**Note:** He discloses his AC motor ideas to Westinghouse at this same time.)
No Picture	**1888 ~ WESTINGHOUSE** purchases all of Tesla's patent rights relating to AC polyphase motors and to AC polyphase power distribution. The Westinghouse company then goes on to develop the commercial AC induction motor. Tesla acts as a consultant to the company until the end of 1889, attempting to develop a single- or split-phase AC induction motor.
	**1889 ~ GANZ** produces this alternator.
	**1889 ~** A **SIEMENS** alternator with attached DC excitation dynamo.
	**1889 ~ TESLA** patents a unipolar (i.e., homopolar / acyclic) DC generator employing a series connection between two induction cylinders (in this case, a conductive belt between the two cylinders) for EMF summation. (**Note:** US Patent No. 406,968)
Picture Soon	**1889 ~ AC SQUIRREL CAGE INDUCTION MOTOR** **Dolivo-Dobrowolski** (chief electrical engineer of **AEG**) invents the alternating current **squirrel-cage** induction motor.
	**1893 ~ BROWN** produces this AC motor of essentially modern form.

	**1894 ~ BROWN** produces this large 3 phase alternator.
	**1897 ~** A large **SIEMENS** dynamo (with the commutator on the periphery of a large diameter, shallow armature.)
	**1898 ~ SEI** produces this DC motor of essentially modern form.
	**1907 ~ SERIES CONNECTED DISK TYPE HOMOPOLAR GENERATOR** **NOEGERRATH** investigates acyclic machinery and constructs a series connected (via multiple slip rings) machine rated at 500 V @ 600 A (300 kW.)
Picture Soon	**1912 ~ LAMME** at Westinghouse, designs and produces a 2000 kW acyclic generator (260 V @ 7.6 kA.) employing multiple series connections for EMF summation.
Picture Soon	**1930 ~ CYLINDRICAL HOMOPOLAR GENERATOR** **POIRSON** develops the cylindrical form of acyclic / homopolar generator and constructs a machine for the Paris Exhibition rated at 14 V @ 50 kA (i.e., 700 kW.)
Picture Soon	**1947 ~ LINEAR SYNCHRONOUS MOTOR** **LAITHWAITE** develops the **Linear Synchronous Motor** (LSM).
Picture Soon	**1956 ~ FAULHABER** invents the diagonally wound basket (i.e., rhombic) form of armature winding (used for ironless armatures.)

No Picture Yet	**1964 ~ GENERAL ELECTRIC** produces an acyclic generator rated at 67 V @ 150 kA (i.e., 10 MW) for naval propulsion research.
	**1972 ~ UNIVERSITY OF TEXAS AT AUSTIN CENTER FOR ELECTROMECHANICS (CEM) & PARKER KINETIC DESIGN** construct a homopolar generator rated at 7 V @ 14 kA (0.5 MJ.)
	**1974 ~ UNIVERSITY OF TEXAS AT AUSTIN (CEM) & PKD** develops a homopolar generator rated at 42 V @ 560 kA (5 MJ.)
No Picture Yet	**1975 ~** First permanent magnet DC motor using **SmCo** field magnets.
Picture Soon	**1982 ~ FAULHABER** invents statically controlled electronic commutation for small DC motors employing ironless armatures.
	**1982 ~ UNIVERSITY OF TEXAS AT AUSTIN (CEM) & PKD** produce a homopolar generator rated at 6.2 MJ (50 V @ 1 MA.)
	**1986 ~ UNIVERSITY OF TEXAS AT AUSTIN (CEM) & PKD** develop a homopolar generator rated at 10 MJ (100 V @ 1.5 MA.)
	**1986 ~ UNIVERSITY OF TEXAS AT AUSTIN (CEM) & PKD** construct a homopolar generator array rated at 60 MJ.

Picture Soon	**1987 ~ ANTONELLO** invents dynamically controlled electronic commutation for small DC motors.
No Picture Yet	**1987 ~ KIESEWETTER** invents the **magnetostrictive** motor.
No Picture Yet	**1987 ~** First permanent magnet DC motor using **NdFeB** field magnets.
No Picture Yet	**1990 ~** Fan & Tai develop the **silicon micromotor**.
Pictures Soon	**1990 ~** Roberts et. al. obtain a patent on a homopolar "Tether Power Generator For Earth Orbiting Satellites." **(US Patent # 4,923,151)**
Pictures Soon	1994 ~ Precise Power Co. introduces the Written Pole Synchronous Motor.
	**1996 ~ EMBEDDED ELECTRONIC COMMUTATION FOR DC MACHINES** **BLUM** invents and develops intelligent autonomous embedded electronic commutation (ECE.)
	**1997 ~ BATH UNIVERSITY** develops novel heteropolar (upper picture) and homopolar (lower picture) alternator topologies.
 	**1998 ~ BRANDENBURG UNIVERSITY AT COTTBUS** develops high power density axial-flux excited alternators using permanent magnets.

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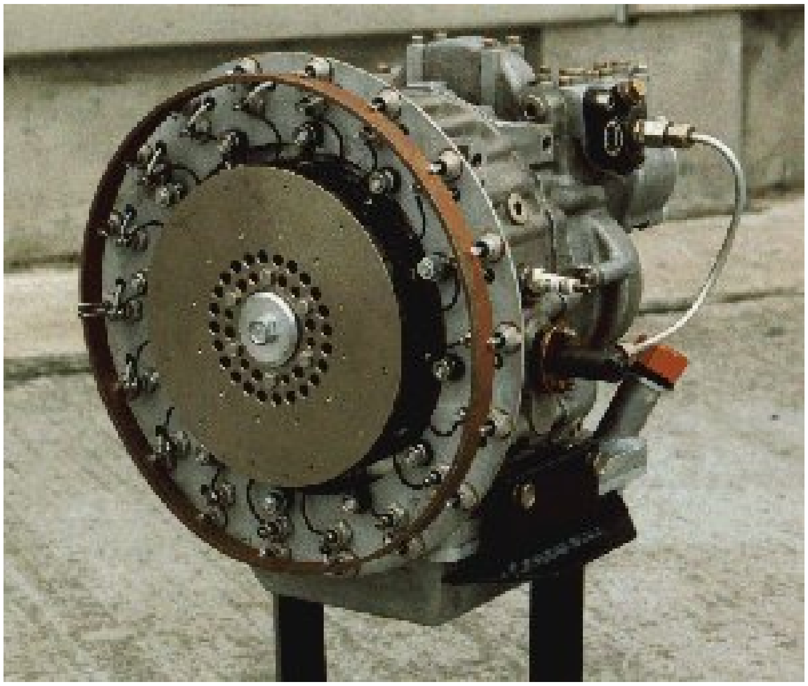

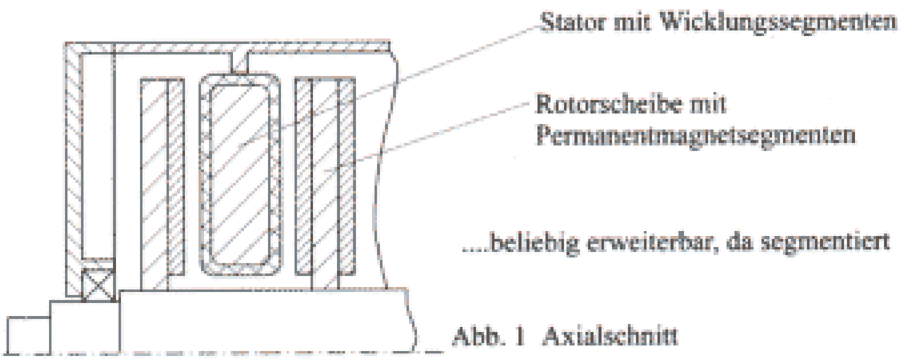

Abb. 1 Axialschnitt

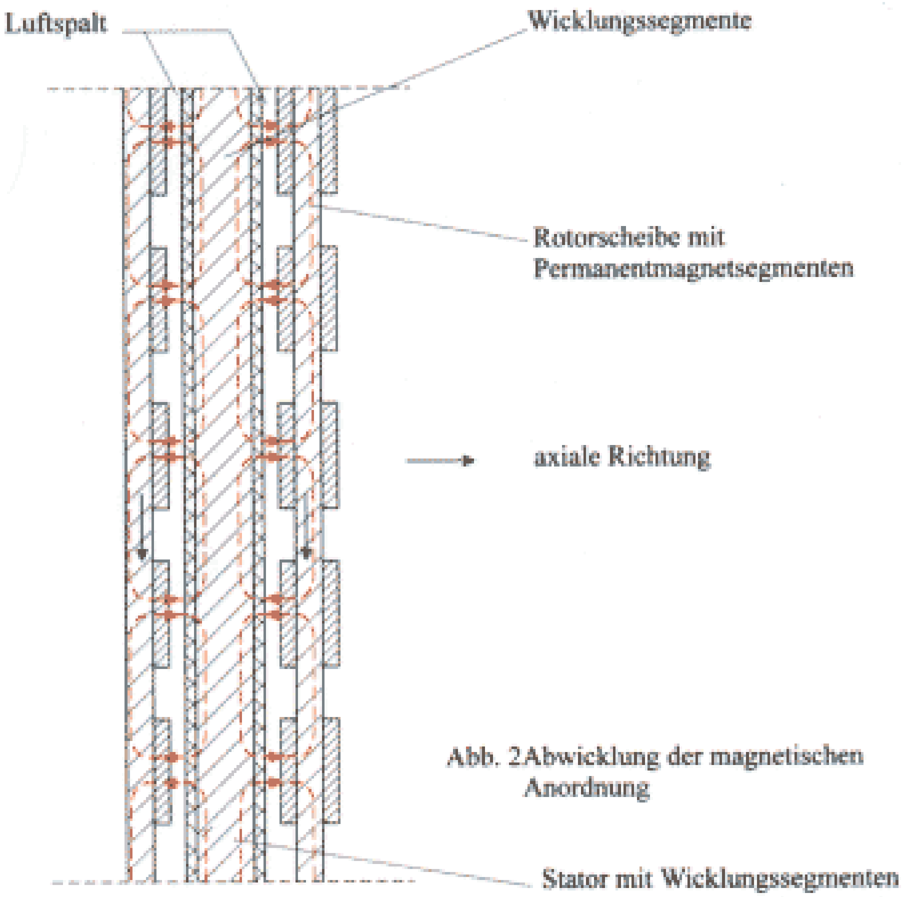

Abb. 2Abwicklung der magnetischen Anordnung