ECONOPHYSICS Section

MAGNETO-VOLTAIC EFFECT IN FERROMAGNETIC MATERIALS WITH VERY HIGH VALUES OF THE MAGNETIC FIELD INDUCTION $\vec{B}$

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Abstract. *In addition to developing econophysical models that are, for example, those proposed in different publications [6-10], Econophysics also deals with the elaboration and study of new physical phenomena or technological processes for the development of different economic domains or industries. In this respect, the paper presents the theory and applications of the magneto-voltaic effect for obtaining electricity through unconventional and totally non-polluting technologies, without resorting to the use of hydrocarbon fuels or other technologies applied so far (wind, solar or hydroelectric energy) etc.*

Keywords: *atomic-molecular currents, Neodymium magnets, threshold magnetic induction, ferromagnetic materials, magneto-voltaic effect.*

1. Introduction

In this paper the theory of the magneto-voltaic effect manifested in rotating electric machines generating electric current is presented.

We will begin the study on the magneto-voltaic effect in rotating electric machines starting from the presentation below of two observations whose analysis and conclusions will be deepened in the next sections of this paper.

Observation no. 1. Experience shows that if a direct current I_c is introduced into a copper conductor coil, then according to Oersted's hypothesis and experiences, in the coil will appear a magnetic field $\overrightarrow{H_0}$ with the induction $\vec{B}_0$.

If a compact bar of *ferromagnetic* material (such as iron, for example) is inserted axially inside the coil then the value of magnetic field induction B' arising in the bar (Figure 1) it is several tens or hundreds of times greater than the induction B_0, of the coil without a magnetic core that adds up with the field $\vec{B}_0$ of the coil having the same direction and axial orientation as the latter:

$$B = B_0 + B'. \tag{1.1}$$

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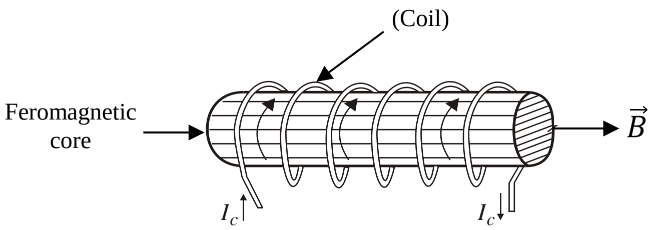

Figure 1. *Coil (solenid) with ferromagnetic core.*

The aditional value B' which appear in presence of the of the metal bar depends on the nature, characteristics and properties of the ferromagnetic material from which the bar is made.

This also happens in the case of iron cores or other ferromagnetic materials called polar (or pole) parts in the construction of the rotor or stator of rotating electric machines such as electric motors or electric current generators of various types. In these machines, the direct current I_o which travels through the coil wrapped around an ‟apparent” pole in the construction of the rotor or of a ‟drowned” pole in the construction of the stator is called an excitation current, producing a magnetic field whose (magnetic field) lines are closed by the polar parts (‟poles”) of the stator and of the rotor, respectively, whose mutual magnetic interaction allows the appearance of mechanical torques leading to its rotative motion, symmetrically surrounded by the stator which has the role of induced part, the rotor acting as an inductor. The roles of inductor and induced parts can also be reversed in different construction forms of rotating electrical machines, with the mention that electromotive forces (e.m.f) occur in the induced part when the assembly operates as a electrical current / power generator.

Observation no. 2. A dry 9V battery does not light up a 2W LED bulb. Instead, a Neodymium magnet generator powered by the 9V (for the motor drive rotor in the generator) turn on that bulb, because in this case it also uses a supplementary energy other than the 9V battery. This additional energy is provided by the presence of Neodymium magnets inserted into the construction of the generator. If the Neodymium magnets are removed, the generator also driven by the 9 Volts applied to the input will not produce enough electromotive force to light the bulb. Thulse the generator therefore uses an energy supplementary to that received at the input by the mechanical rotation of the rotor with a motor powered by 9V from a battery.

Where does this additional energy come from?

The correct answer can only be found on the basis of experiences made with different prototypes of generators that fully confirm hypotheses or theoretical calculations regarding the explanation of the appearance of magnetism and the magneto-voltaic effect in ferromagnetic materials.

During our numerous experiences, several variants of generators with Neodymium magnets have been built, modifying different constructive and functional parameters of the prototypes used. The most plausible hypothesis confirmed by the experimental results leads to the conclusion that this additional energy arises as a result of the intensive use of atomic-molecular currents in magnets with very high values of remanent (residual) magnetization such as Neodymium magnets and even highly magnetized ferrite magnets.

Neodymium magnets, characterized by very high values of residual magnetization belong to the category of ferromagnetic materials. They were invented and accomplished in 1982-1984 by General Motors and at the same time by the Japanese company Sumitomo, based on the structure (NdFeB) – i.e. Neodymium – Iron – Boron, but may also contain other elements from the rare earth category, such as Samarium, for example, including in their structure Samarium Cobalt, i.e. SmCo.

In the construction of electric motors but also generators, in order to eliminate disadvantages such as the appearance of sparks in collector brushes, sliding contacts and the presence of rotor winding, etc., in the construction of polar parts it was required to use special magnetic materials, respectively Neodymium magnets, characterized by a very high residual magnetization (magnetic field induction) of over 500-700 militeslas (mT), or even higher (depending on the manufacturer).

Using such very powerful magnets, it was no longer necessary to resort to excitation coils fitted especially on the rotor, which consume electrical current from the outside, leading at the same time to weight gain of the machine and decrease its efficiency.

The Neodymium magnet generator is capable of generating much higher voltages and electrical powers, respectively, with the reduction of losses and the proximity to unity of the power factor $cos\varphi$ in the equation expressing the active output power whose value averaged over a period is [1]:

$$P_a = u.i = UI \cos \varphi. \tag{1.2}$$

In equation (1.2), quantities u and i represent instantaneous values, and quantities U and I represent the maximum (peak) values of voltage and current in the circuit, respectively, and φ represents the phase shift angle between current i and alternating voltage u.

Under certain special conditions it is found that due to an increase in the factor $\cos\varphi$ which it can even become equal to the unit, the active power P_a at the output becomes equal to or even higher than the power consumed at the input, that is:

$$P_{out} = U_{out}I_{out} \geq U_{in}I_{in} \tag{1.3}$$

a situation that arises as a paradox where the law of conservation of energy would no longer be respected. Practically, the laws of physics and the principles of thermodynamics are not violated and this will be explained in sections 2 and 3 of this paper, where it is shown that in the equilibrium equation of consumed and generated powers must be taken into account the contribution of an additional power factor, a factor that intervenes only in the case of using very powerful magnets such as those with Neodymium and sometimes ferrites.

In recent years, due to their special properties, Neodymium magnets – and sometimes ferrites – have begun to be used in the construction of rotating electric machines such as electric motors and generators, although there is still no exist a plausible theory to explain the emergence causes of high electromotive forces and high yields of generators and electric motors equipped with permanent Neodymium magnets in the structure of these engines/machines.

The use of Neodymium magnets has led to other advantages in the engineering of electric rotative machines, consisting, as has been said before, in eliminating sparks and winding for excitation current etc., reducing current consumption (at the motor), decreasing the weight and dimensions of motors, and implicitly increasing their efficiency etc.

2. Magnetic field in substance. Atomic-molecular currents

After the Danish scientist Oerstedt discovered the phenomenon of the interaction between the magnetic field and a conducting wire traveled by a direct current, the French scientist Ampère hypothesized that the magnetic properties of a solid body are due to the existence inside the solid body of a very large number of small loops of currents that arise due to the movement of electrons in closed orbits around the nucleus of each atom that enters the composition of molecules. This hypothesis is based on the fact that any electrical current represents electric charges in an orderly movement in the closed circuit. Electric charges in a closed circuit are just like the closed orbitals of electrons moving eternally in atoms (and in molecules formed by atoms). This reasoning is true for any solid body, and therefore also for the ferromagnetic material rod (bar) inserted in a coil (solenoid) traveled through by current as shown in Figure 1 and Figure 2,a, respectively, in which electrons in eternal motion in quantized orbits of atoms are driven by the magnetic induction field $\overrightarrow{B_0}$ created by the current I_0 passing through the external coil. This field induces closed currents in the material in the form of loops of molecular currents from atoms (or molecules). This interaction essentially constitutes the phenomenon of **diamagnetism** that is present in all substances [1-3], since any material contains atoms and molecules in which electrons are moving. It is obvious that current loops can also be imagined in other forms (not necessarily circular, but elliptical or square form etc. as shown in Figure 3,b), but in whatever form the currents running through these loops they are tangent to each other, and at the same time being of opposite directions they compensate each other inside the ferromagnetic material (Figure 3,a,b).

From Figure 3,a,b it can be seen that only the currents loops at the surface of the bar material do not compensate each other for magnetic actions, so that the action of all "molecular" currents is reduced to the action of a surface current I_M surrounding the magnetic body (bar) in the same direction as the current I_c flowing through the conductor of the solenoid (coil) (Figure 3,a,b).

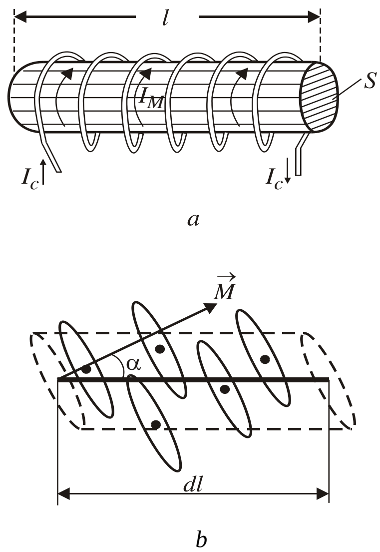

Figure 2. a) *Solenoid with ferromagnetic core.*
b) *Calculation of magnetization M in ferromagnetic core.*

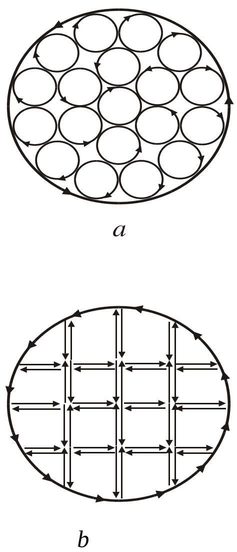

Figure 3. *Shapes of current loops in solid material.*

It can therefore be said that this current will produce an additional induction field $\overrightarrow{B'}$, as if a number of invisible ampere-turns appeared on the surface of the magnetic cylinder (bar) that were added to the ampere-turns of the solenoid (coil) that produces magnetization of the sample of ferromagnetic material inside. It is obvious that this phenomenon does not occur in the case of non-magnetizable substances called diamagnetic substances (in which the induction vector $\overrightarrow{B'}$ has the opposite orientation to the direction of the field magnetizing the bar). In the case of ferromagnetic substances belonging to the more general class of paramagnetic materials where the induced field has the same direction end orientation as the magnetizing field H_0, the resulting total induction $\overrightarrow{B_t}$ will therefore be given by the sum of the two inductions (equation (1.1) and Fig. 1) i.e.:

$$\overrightarrow{B_t} = \overrightarrow{B_0} + \overrightarrow{B'}. \tag{2.1}$$

According to quantum mechanics (see Louis De Broglie's principle of wave-particle dualism) electrons that have a continuous motion in atoms (or molecules) can be present at any point in the "orbit" or orbital* on which they move around nuclei; thus, moving in closed loops, electrons possess mechanical moments as well as magnetic moments when they move in a magnetic field. Thus, by moving the electron in an orbit, it possesses an orbital mechanical momentum and, in addition, due to circular motion around its axis (spin motion), it possesses a mechanical spin moment and respectively a spin magnetic moment [1,3].

In the case of atoms with more electrons, the total magnetic moment for atoms or molecules is taken into account. Thus, all atoms and molecules in the substance possess magnetic moments due to the totality of microcurrents in the material under consideration, thus giving rise to the additional magnetic field $\overrightarrow{H'}$ with induction $\overrightarrow{B'}$ as already mentioned.

Thus, the ferromagnetic material under the action of any magnetic field (including that created by currents in external conductors) can acquire a total magnetic moment, i.e. magnetize (see equation 2.1). The magnetization of the substance consists in the appearance of the additional field $\vec{B}'$ which, in the case of ferromagnetic materials such as the bar material inserted into the coil in Figure 1 and Figure 2,a respectively, overlaps the initial (magnetizing) field $\vec{B}_0$ created by the current through the external coil. In the case of paramagnetic substances (including ferromagnetic substances), both fields having the same direction and orientation, they are added so that, in ferromagnetic substances, as

* By orbital we mean a region of a certain thickness that would surround the "orbit" on which the electron moves, which in the classical conception would have a point shape of mass m.

in the case of the coil bar, a resultant field $\vec{B}$ given by the equation (2.1) or (1.1) is obtained.

Note that for one and the same current I_c through the external conductor that includes the magnetic material that is placed in different (magnetic) media, the magnitude of the induction $\vec{B}'$ and implicitly the magnitude of the resultant induction $\vec{B}$ will be different, i.e. the induction vector of the magnetic field depends on the substance. In order to characterize the magnetic field, created by the current through the conductor, the notion of **magnetic field strength** $\vec{H}$ is introduced, which does not depend on the properties of the medium. As shown in Appendix 1 (see 5 section), between $\vec{H}$ and the magnetic induction vector there is the equation [1-3]:

$$B = \mu H, \tag{2.2}$$

where the dimensionless quantity μ shows how many times the magnetic field $\vec{H}$ created by macro-currents (through the conductive coil) is amplified by presence of micro-currents in the substance of the ferromagnetic cylinder inserted into the coil (solenoid), which is called **magnetic permeability** (sometimes also called magnetic constant).

The summation equation (2.1) is applicable in situations where the magnetic medium is entirely encompassed by the magnetizing field $\vec{B}_0$, as is the case with the metal cylinder where a current I_c that creates the induction field $\vec{B}_0$ passes (Figure 2,a). The magnetic (microscopic) field in the magnetic material (of the metal bar) changes strongly within the limits of intermolecular distances and therefore by the quantity $\vec{B}$ is meant the average, macroscopic field taken over the entire volume considered.

Currents associated with atomic or molecular magnetic moments, including the spin magnetic moment, are bound currents, being analogous to bound electric charges, with the density ρ_{bound} (or σ_{bound}) of the molecules in a dielectric [1]. These bound currents correspond to the loops of molecular currents predicted by Ampère (Figure 2,a,b). In contrast, the conduction currents flowing on macroscopic trajectories, such as the current I_c flowing through the solenoid shown in Figure 2,a, are currents determined by free charges moving in the solid, therefore they can be called free currents of density $\vec{j}_{free}$*.

The magnetic moment of a current loop is defined as the product of the current intensity through the loop and the area of the loop [1,3]:

$$p_m = I_{S_b} S_b \tag{2.3}$$

where I_{S_b} is the loop current and S_b is the current loop area.

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* *These currents are also called ohmic currents; they flow into the conductor that has resistance R.*

In the case of the rod (bar) in Figure 1 and Figure 2,a respectively, the total magnetic moment is given by the sum of p_{m_b}:

$$M_t = \sum p_{m_b} = S_b \sum I_{S_b} = S_v I_M \tag{2.4}$$

where $\sum I_{S_b} = I_M$ is the total molecular current through the bar surface and S_v is the cross-sectional area of the bar.

The magnetization of the substance is therefore produced by all the magnetic moments of each loop summed up throughout volume V of the rod, which define the magnetization M of the sample under consideration. The magnetization M is defined as the total magnetic moment per volume unit [1-4]:

$$\mathrm{M} = \frac{\sum P_{m_b}}{V} = \frac{I_M S}{V}\,. \tag{2.5}$$

In the equation (2.5) instead of I_S we consider I_M which represents the intensity of the total surface current, and M represents the magnetization specific to the material under consideration as shown further in Appendix 1.

Also in Appendix 1 it is shown that magnetization M is closely related to the intensity $\vec{H}$ of the magnetic field and respectively to the induction $\vec{B}$ of the magnetic field or as it is also called, in short, with magnetic induction $\vec{B}$.

In conclusion, taking into account the above considerations it can be stated that the current loop is equivalent to a small magnetic dipole orienting itself under the action of the external magnetic field B_0, and the totality of the dipoles thus oriented gives rise to an additional induction field B' due to the summation and orientation of the elementary magnetic moments of each electronic or atomic loop, after an axis coinciding with the axis and direction of magnetic induction $\overrightarrow{B'}$ [1,3].

3. Threshold magnetic induction in Neodymium magnets

In the case of Neodymium magnets, when assembled as polar pieces in the rotor structure of an electric machine, having by design an appreciable residual magnetization, induction $\overline{B}$, there is no need for an excitation coil to surround the polar piece as in the case of the selenoid in Figure 1 or Figure 2,a) and therefore in the equation 2.1 the term $\overline{B_0}$ disappears from the second expression and in the end, only the magnetic induction field $\overrightarrow{B'}$ created with the initial magnetization of the Neodymium magnet remains. In fact, due to the special properties of Neodymium magnets, the induction B' is much higher than the magnetic induction field $\overrightarrow{B_0}$ that was required to start the motor or generator with ordinary polar parts made of materials that could be magnetized by I_c currents through the solenoid. Here, however, the question arises: how large should be the field $\overline{H'}$ and implicitly the initial magnetic induction $\overrightarrow{B'}$ so that the generator produces an electromotive force (e. m. f.) and efficiencies/yelds as high as possible and anyway higher than the B_0 value, considered as a **threshold value** in generators that can produce voltages and powers much higher than those produced by conventional electric *generators* (with coils assembled on polar parts, collecting brushes etc.)?

The answer is that in order to deliver a voltage or power when a consumer is connected to the output for practical use, it is necessary to first exceed a threshold value of induction B' of Neodymium magnets assembled on the rotor that is equivalent to the starting value B_0 of the electric machine that would have been given by assembling of an excitation coil on the polar part through which to pass a conduction current $I_0 = I_c$ as shown above in the case of Figure 1 and/or Figure 2,a). Therefore, instead of doing so, mentally divide the value of the term B' into two parts: the first being equal to B_0 and the remaining one constitutes the additional induction B_{supl} which is responsible for producing the additional energy from the equilibrium equation of powers from the input of the respective generator to its output.

It may then be that, in light of the above, the induction B' in Neodymium magnets, which will be denoted by B'_N to by expressed as:

$$B'_N = B_{thr} + B_{supl} = B_0 + B_{supl} \tag{3.1}$$

where B_{thr} represents threshold value of magnetic field induction.

It is found that in the first equality of the equation 3.1 the term given by an eventual external coil giving separate induction B_0 is missing, but an induction equal to B_0 has been delimited by definition.

It follows from this that the induction vector B_N, further denoted by B'_N, must be intense enough to produce high e.m.f and high power output of the generator. Comparing with B_t in equation 2.1 can be written:

$$B_N = B_{thr} + B_{supl.} = B_0 + B' = B_t \tag{3.2}$$

in which B_{supl} plays role of B' and $B_{thr} = B_0$. It is worth noting that the two equations 2.1 and 3.1 respectively have identical expressions for the magnetic induction B that arises in the ferromagnetic material but their content refers to different actions: in equation 2.1 the additional induction B' occurs under the influence of conduction current in the external winding, while in the case of equation 3.1, the total induction that arises B_N occurs after magnetization of the special Neodymium magnet (see also notation N to B_N). It is clear, then, that the value of the additional induction field B_{supl} delimited from the total value of the induction field $B_t = B_N$ is different from the additional value B' in equation 2.1 in the sense that B_{supl} can be much higher than B'.

In conclusion, the two equations for the total field B_t are formally written the same, but have different contents. The similarity of the two expressions also suggests how to find (or calculate) B_{supl} from equation 3.1, just as the value B' from equation 2.1 was calculated using Ampère's Theorem (see also Appendix 1).

B_{supl} occurs as a result of magnetization of the material (bar) above the threshold value that is equal to B_0, i.e. (see equation 3.1):

$$B_{supl} = B'_N - B_0. \tag{3.3}$$

It is obvious that the term B_{supl} determined by equation (3.3) is at the origin of the electromotive force E_{supl} and implicitly of the additional electrical energy W_{supl} delivered to the output of the generator with Neodymium magnets, so that the apparent paradox expressed by the equation (1.2) is elucidated. Indeed, considering the powers of the Neodymium magnet generator and setting its energy, it can be written that:

$$P_{out} = U_{in} I_{in} + P_{supl} \tag{3.4}$$

where P_{supl} is:

$$P_{supl} = U_{supl} I_{out}\,. \tag{3.5}$$

In equation 3.5 the U_{supl} voltage is determined by the electromotive force ε_{supl} generated by the increase in magnetic induction from B_0 (in the absence of Neodymium magnets) to the B_N value generated in the presence of Neodymium magnets given by the equation 3.2.

The appearance of an additional electromotive force U_{supl} due to the existence of an appreciable magnetic induction B_N (with values higher than the threshold induction B_{thr}) in magnets with strong magnetization such as Neodymium magnets constitutes the magneto-voltaic effect encountered in rotating electrical machines (generators or motors). There are also known other collateral aspects that are attributed to the magneto-voltaic effect without referring to the prospects of practical application of these variants of the effect itself.

4. Electric generators with Neodymium magnets. Experimental data

In order to verify the hypotheses and theoretical considerations presented above, several experimental set up were prepared, in order to measure parameters and operating characteristics with different types of generators with Neodymium magnets in their construction. In particular, experiments and measurements were made to determine generated voltages, currents in input circuits and output circuits when connecting different loads or load resistors, as well as power balances (electrical) spent at the input for driving the rotor of the generator and measured at the output. For this purpose, measuring instruments such as voltmeters, ampermeters, teslameters, various oscilloscopes etc. were used, as well as various types of power supplies for motors used to spin the rotor in electric generators. It should be mentioned that only rotating electric machines (generators or electric motors) that were driven or operated only after using rotational motion were used exclusively, as is the case with rotating electric machines in practice (industry, domestic use, research etc.). In all cases, energy losses in the experimental chain of operation or measurement have also been taken into account, such as friction losses in bearings, P_f, losses by thermal effect, P_t resulting from friction in bearings, by Joule effect in conductors or component parts, losses by hysteresis P_h in ferromagnetic materials of massive polar parts or sheets, from various fittings or consoles used in the construction of those electric machines etc.

Such total losses marked with P_t cannot be avoided, but it is aimed to reduce them to a minimum, admitting, in the most convenient way, not to exceed about 10-15 precentes of the generated power. In this case it can be written that from the initial power P_{in} applied to the generator input, the term P_t of losses must first be subtracted, and the rest will be delivered to the output, that is, if the power loss values are taken into account to have:

$$P_{in} = P_t + P_{out} \tag{4.1}$$

where:

$$P_{out} = U_{out} I_{out}\,. \tag{4.2}$$

Below will be presented some examples of experimental installations with generators with Neodymium magnets, having different constructions or generated powers.

4.1. The 40 Watt electric generator with Neodymium magnets

This generator was made by modifying a low power DC (direct current) motor of approx. 40W.

As specified, several types of generators with Neodymium magnets of increasing power were used: 40W, 200W and an automobile/car alternator.

The block diagram for the operation of the 40W motor-generator assembly containing sources and measuring instruments is given in figure 4, and in Photo 1 is presented the photo image of the experimental assembly for the 40W generator where the ferrite rotor was replaced with a Neodymium magnet rotor.

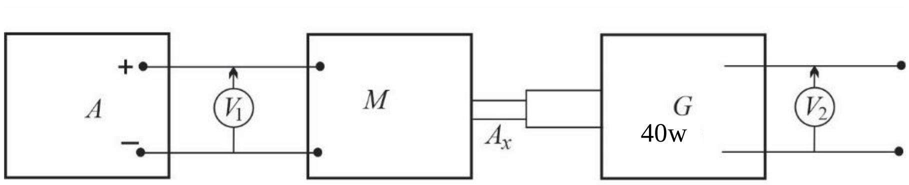
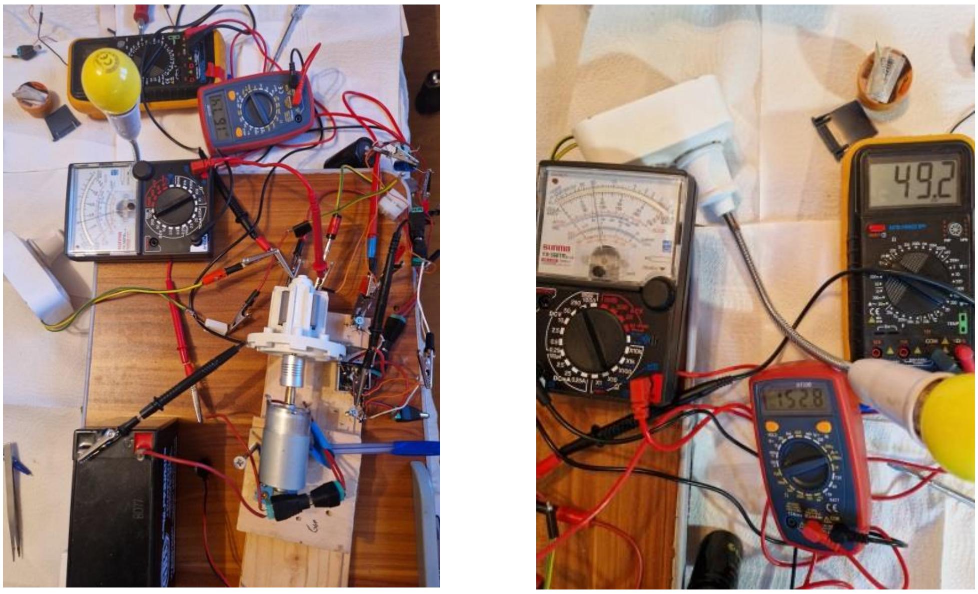


Figure 4. *Block diagram of the 40 watt generator: A – power supply; V_1 – voltmeter to measure input voltage V_{in}; M – DC motor; G – 40 watt generator with Neodymium magnets; A_x – mechanical coupling shaft; V_2 – voltmeter for measuring of output voltage, V_{out}.*



a) *b)*

Photo no. 1.

a) *General assembly with the 40 W generator.* b) *Details of measuring instruments of the assembly.*

Since for many applications DC motors of small power and size are currently used, equipped with ferrite rotor magnets or Neodymium magnets (to avoid winding and sliding contacts etc.), it was resorted to using such motors to make low power generators. For the 40 W generator used in the diagram in Figure 4, the motor of a small water pump from a washing machine already equipped with a magnetic rotor in the form of a ferrite cylinder was used, which, if rotated from the outside by another small motor, could generate a voltage of about 45 Volts. Replacing the ferrite tube by a small Neodymium magnet of rectangular shape with dimensions of 40×15×5mm and rotating the shaft with a DC motor of about 10 Volts (DC voltage of 9-10 Volts), values of 50 Volts were obtained at the output for the generated voltage, i.e. about 5.2 times higher than the value of the voltage applied to the input of the DC motor driving the rotor with Neodymium magnets, characterized by a very high residual magnetization (Neodymium magnet of type N45 or N48).

4.2. The three-phase 200 Watt generator made with Neodymium magnets

The block diagram for measurements in rated working mode of this generator is the same as in Figure 4 (see Figure 5 and Photo no. 2). To drive the 200 W generator – bearing the G_5 indicator, a small DC motor of approx. 30-35 W was used (Figure 5).

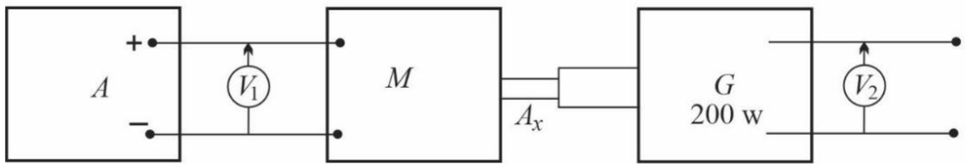


Figure 5. *Block diagram of the 200 watt generator: A – power supply; V_1 – voltmeter to measure input voltage V_{in}; M – DC motor; G – 200 watt generator with Neodymium magnets; A_x – mechanical coupling shaft; V_2 – voltmeter for measuring of output voltage, V_{out}.*

Both the generator and the drive motor were purchased commercially, but the working assembly and measuring instruments etc., belong to the laboratory where the respective research and measurements were made.

a) *b)*

Photo no. 2.

a) *General assembly with the 200 Watt generator.* b) *Details of measuring instruments of the assembly.*

The DC motor at the input was powered from a small source (battery type) supplying 12-13V. Since the supply voltage was rather high, the currents obtained in the input circuit were 1.5A-2.12A depending also on the load (consumer) coupled to the output of the G_5 generator. In order not to put too much strain on the DC (direct current) motor used to drive the generator shaft, no loads were coupled to the generator output, but the dependence of the output voltage was analyzed, idle, depending on the rotational speed. The electromotive force (abbreviated e.m.f) at the output directly depends on the rotation speed of the rotor in the generator, which directly depends on the supply voltage of the DC motor at the input. As a result, at input DC model power values of about 12-13 volts, between the three phases at the output of the generator very high voltages were obtained of approx. 430 volts (as can be seen from the indications of the voltmeter in the Foto 2.b).

Using a simple rheostat consisting of high-wattage resistors (10-15W) when powering the DC motor from the input, much lower voltages were achieved at the generator output; for example, to supply the drive motor with 9.5V then approx. 85Volts appear at the output, i.e. approx. 9 times the input voltage.

4.3. Neodymium magnet generator made by modifying an alternator from an automobile

In the case of this experiment, an experimental montage like the one in Figure 4 was also used (see Figure 6).

In order to avoid the difficulties of assembly and alignment of the component parts of the artisanal generator, the structure of an industrial AC (alternative current) generator was used, such as the car alternator, in which the rotor with the Neodymium magnets and the stator are very well aligned and centered through bearings fixed in the two metal covers of the alternator. After the alternator rotor was fitted with Neodymium magnets and dropped the excitation coils and brushes for sliding contacts, during operation the output voltages changed to a small extent, given the special structure of the alternator construction designed to supply 12-14 Volts which, after rectifying, would charge the car's 12 Volt batteries. However, there were no interruptions in operation following the increase in the number of load at the output (by increasing the number of consumers), which denotes a much greater stability of the current delivered to the outside, which keeps its constancy over time due to the specific structure of the stator and the control elements with which the alternator is equipped, especially the voltage regulator and the bridge with current rectifying diodes in order to constantly charge the car's battery.

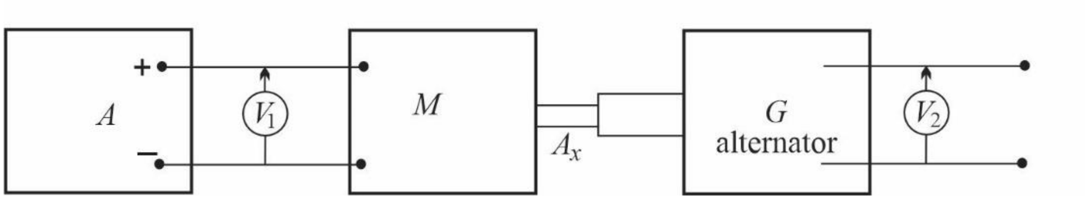


Figure 6. *Block diagram of the assembly with current generator made with an automobile alternator: A – power supply, M – DC 200Watt motor; G – alternator; A_x –mechanical coupling.*

5. Calculation of induction $\vec{B}$ of magnetic field $\vec{H}$ induced in magnetic (ferromagnetic) materials placed in an external magnetic field produced by a coil (solenoid) travelled by direct current

The calculation of magnetic fields and magnetic induction $\vec{B}$ from a solenoid traveled by a current I can be done using the law of magnetic circuit expressed by Ampère's theorem defining the circulation of the induction vector $\vec{B}$ or the magnetic field $\vec{H}$ along a contour L surrounding current I inducing field B' in the magnetic sample under consideration (see Figure 1):

$$\oint_L \vec{B}\mathrm{d}l = \mu_0 I. \qquad (A_1)$$

In equation (A_1), I represents the current intensity that lies within the contour L that delimits a surface through which current passes [1]. If several currents pass through the surface bounded by the contour L, then Ampère's theorem takes the form [1,3]:

$$\oint_L \vec{B}\mathrm{d}l = \sum_k \mu_o I_k = \mu_0 \sum_k I_k \,. \qquad (A_2)$$

where the index k denotes only the currents, respectively the conductors contained inside the contour L after which the integration is made, and dl is the differential element.

Since all atoms and molecules in the substance possess magnetic moments due to microcurrents (current loops), therefore their contribution under the influence of an external induction field B_0 gives rise to an additional induction field B' inside the substance. In the case of paramagnetic substances (including ferromagnetics) both fields add up having the same direction and orientation, while in the case of diamagnetic substances the additional field B' has the opposite orientation to the external field that produces magnetization, therefore diamagnetic substances have a much smaller magnetic field of paramagnetic substances in particular, much smaller than that of ferromagnets that can get appreciable values.

In the case of the ferromagnetic sample (metal bar) in Figure 1 or Figure 2,a) for the application of Ampère's theorem it must be taken into account that in this case molecular currents and total surface current I_M do not produce thermal or light effects etc., but produce magnetic effects, giving rise to the additional magnetic field B' inside the ferromagnetic metal bar (see Figure 1 and Figure 2,a).

As already mentioned, if on the free (conduction) currents in the copper conductor coil in Figure 1 or Figure 2,a, we can have control by suppressing or inserting them into the circuit (by means of a switch etc.), on the bound currents induction from the magnetic material (metal bar), such control is not possible. To find out the vector B' and implicitly the total magnetic induction B the only possibility is to separate their magnetic effects, because as mentioned, bound ("molecular") currents do not produce thermal or light effects, chemical effects etc. For this purpose, Ampère's theorem (or magnetic circuit law) will be used (see Appendix 1).

The application of Ampère's theorem to magnetized materials must consider not only free currents (for conductors or coils placed in vacuum, but the total current density of currents passing through the area bounded by a closed contour L (according to the equation):

$$\vec{j}_{total} = \vec{j}_{free} + \vec{j}_{bound}. \qquad (A_3)$$

Returning to the total magnetic field induction $\vec{B}$ given by equation 2.1, let us write for this the law of circulation on a closed contour L on which rests the surface of the magnetic substance placed in the solenoid magnetic field [1]:

$$\oint B_l \, dl = \oint (\vec{B}_0 + \vec{B}')_l \, dl = \oint \overline{B}_{0l} \, dl + \oint B'_l \, dl. \qquad A_4$$

In equation A_4, vector B was taken on the portion dl (see Figure 2,b) so that:

$$B_l \, dl = B \, dl_B, \qquad A_5$$

in which dl_B represents the projection of the element dl in the direction of the vector $\vec{B}$ tangent to the field line (Figure 7).

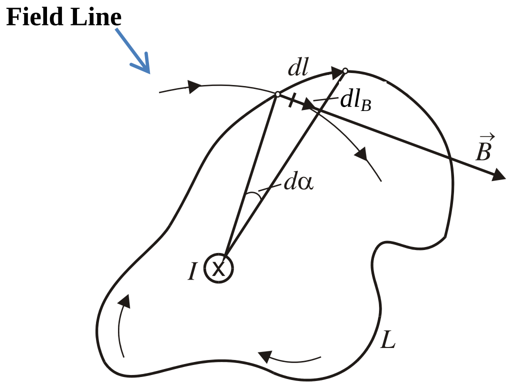


Figure 7. *For calculating magnetic induction* $\vec{B}$ *using Ampère's theorem.*

If Ampère’s theorem given by equation A_1 is considered, the vector circulation $\vec{B}_0$, expressed by the first integral in the second member of relation A_4, is proportional to the algebraic sum of macroscopic currents I_i surrounded by the contour L:

$$\oint B_{0l} dl = \mu_0 \sum I_i. \qquad A_6$$

where $\sum I_i$ represents the sum of all currents contained by the contour in the metal bar in the coil, so it coincides with the solenoid comprising the ferromagnetic material cylinder.

Similarly, the circulation of the vector $\vec{B}'$ must be proportional to the sum of all molecular currents forming the total current I_M that the contour comprises (which coincides with the perimeter of the solenoid surrounding the cylinder of magnetic material), so the surface area is common for the coil and the metal bar:

$$\oint B'_l \, dl = \mu_0 \sum I_M. \qquad A_7$$

Substituting in relation A_4, it becomes:

$$\oint B_l \, dl = \mu_0 \sum I_i + \mu_0 \sum I_M, \qquad A_8$$

It can be seen that for its determination we need to know both the “free” currents passing through the conductors (I_c in the case of the solenoid in Figure 1 and Figure 2,a), as well as the “bound” currents I_M that cannot be measured directly. To overcome this difficulty, a new factor should be introduced which is directly related to induction $\vec{B}$ and thus allows induction to be calculated by macroscopic currents alone. As mentioned above, the actions of *all* individual "molecular" currents (for each current loop) are reduced to the action of a total surface current I_M surrounding the magnetic material, determined by the sum of the molecular currents at the surface, which do not compensate each other for magnetic actions. In order to find a connection between the magnetization vector $\vec{M}$ and the molecular currents, we will consider the sum of the molecular currents intersecting with the contour (from the sample surface) for which the flow of the vector $\vec{B}$ (and implicitly of the vectors $\vec{B}_0$ and $\vec{B}'$ see equations A_6 or A_8) is calculated. As seen from Figure 2,b, the contour element dl forms with the direction of the magnetization vector $\vec{M}$ the angle α and intersects the molecular currents whose centers are found inside an oblique volume cylinder V_c:

$$V_c = S_M \cos\alpha \, dl, \qquad A_9$$

where S_M is the surface area traversed by each separate molecular current I_M. If n is the number of molecules in the unit volume, then the "total" current surrounded by the dl element is given by:

$$nI_M V_c = nI_M S_M \cos\alpha \, dl = nP_m \cos\alpha \, dl, \qquad A_{10}$$

where $P_m = I_M S_M$ represents the magnetic moment for total molecular current I_M. According to equation 2.4, the total magnetic moment $\vec{M}$ is given by $M = np_m$, such that the magnitude $nP_m \cos\alpha$ in relation A_{10} represents the projection of the vector in the direction of dl element (Figure 2,b and Figure 7) and as such the total current "surrounded" by the element dl is equal to:

$$I_M = M_l \, dl. \qquad A_{11}$$

The sum of the molecular currents contained in the closed contour on which the vector's circulation $\vec{B}$ is calculated (and implicitly of the vectors $\overline{B}_0$ and $\overline{B}'$) is then given by (see A_{11}):

$$\sum I_M = \oint M_l \, dl. \qquad A_{12}$$

Substituting the equation A_{12} into the equation A_8 is obtained:

$$\oint \left(\frac{\vec{B}}{\mu_0} - \vec{M} \right)_l dl = \sum I, \qquad A_{13}$$

where I represent the free (conduction) currents in the solenoid, i.e. I_c which can be easily determined by measurement with a measuring instrument (ampermeter).

The expression in the parenthesis below the integral represents the very helper quantity sought. It is denoted by $\vec{H}$ and called magnetic field strength*.

So **the strength of the magnetic field** represents the physical quantity determined by the equation:

$$\vec{H} = \frac{\vec{B}}{\mu_0} - \vec{M}. \qquad A_{14}$$

Using this quantity, the formula A_{13} can be written as:

$$\oint H_l dl = \sum I. \qquad A_{15}$$

If macroscopic currents I are expressed by current density $\vec{j}$, then the formula A_{14} can be written as:

$$\oint H_l dl = \oint_S j_n dS \qquad A_{16}$$

where S represents an arbitrary surface bounded by the contour L on which the vector $\vec{H}$ circulation is calculated. According to the equation A_{15}, the circulation of vector – strength of the magnetic field – on any contour is equal to the algebraic sum of the macroscopic currents surrounded by this contour.

In a vacuum we have $\vec{M} = 0,$ therefore from A_{14} follows:

$$\vec{H} = \frac{\vec{B}}{\mu_0} \qquad A_{17}$$

or:

$$\vec{B} = \mu_0 \vec{H} \qquad A_{18}$$

where μ_0 represents magnetic permittivity for vacuum.

The first member of equation A_{16} can transform into a surface integral (using Stokes' Theorem):

$$\int_L \vec{H} d\vec{l} = \int_S rot\,\vec{H} d\vec{S} = \int_S (rot\,\vec{H})\vec{n} dS \qquad A_{19}$$

where S stands for any surface resting on the contour L.

Replacing A_{19} in the first part of the A_{16} relationship, the latter becomes:

$$\int_S rot\,\vec{H} dS = \int_S j_n dS \qquad A_{20}$$

* *The primordial name was (and is sometimes still used) that of "magnetic field* $\vec{H}$*".*

or:

$$\int_S [rot\,\vec{H} - \vec{j}\,]dS = 0. \qquad A_{21}$$

This equation is true for any surface *S* resting on the contour *L*. It follows that the equation A_{21} is true if the expression below the integral is equal to zero, i.e.:

$$rot\,\vec{H} = \vec{j}_{free}, \qquad A_{22}$$

where, according to the equations A_{15} and A_{16}, j_{free} is the density of macroscopic currents, i.e. free currents (through the solenoid).

The equation A_{22} is the well-known Maxwell-Ampère equation. It expresses the fact, already established experimentally (and theoretically), that just like the lines of magnetic induction $\vec{B},$ the lines of magnetic field strength are closed lines, that is, there are no magnetic "charges", the magnetic field having a rotational character (see equation A_{22}).

As mentioned, total induction $\vec{B}$ depends on total current, i.e. one can write:

$$\nabla\times\vec{B} = \mu_0\vec{j}_{total} = \mu_0(\vec{j}_{free} + \vec{j}_{bound}). \qquad A_{23}$$

Applying the operator ∇ to the magnetic field given by the relation A_{14} yields:

$$\nabla\times\vec{H} = \nabla\times(\mu_0^{-1}\vec{B} - \vec{M}) = \frac{1}{\mu_0}(\nabla\times\vec{B}) - \nabla\times\vec{M}. \qquad A_{24}$$

Substituting $\nabla\times\vec{B}$ on from A_{23} is obtained (also considering A_{22}):

$$\nabla\times\vec{H} = \vec{j}_{free} + j_{bound} - (\nabla\times\vec{M}) = \vec{j}_{free} \qquad A_{25}$$

or:

$$\nabla\times\vec{M} = \vec{j}_{bound}\,. \qquad A_{26}$$

The comparison of the equations A_{23} and A_{22} between them shows the convenience, and therefore the usefulness of use, instead of magnetic field induction $\vec{B} = \vec{B}_0 + \vec{B}',$ of the magnetic field $\vec{H}$ which can be easily controlled by controlling macroscopic currents (free currents), the only ones that can be measured by means of an instrument (ampermeter) connected in the circuit forming the closed contour *L*. This free (total) current is determined by the current density $\vec{j}_{free}$ by the known equation (see also A_{15}; A_{16}):

$$\oint_L \vec{H}d\vec{l} = \oint_{S_L} \vec{j}_{lfree}\; d\vec{S} = I_{lfree}\,. \qquad A_{27}$$

where $I_{free} = I_c$ is the conduction current through the solenoid [1].

6. Conclusions

The paper shows, both theoretically and through the analysis of experimental results that the magneto-voltaic effect is obtained only for ferromagnetic materials with a very high residual magnetization used in the construction of rotating electric generators, such as Neodymium magnets or ferrites.

The magneto-voltaic effect by which high voltages can be obtained at the output of generators with Neodymium magnets can also be highlighted – as a result – it can be used in practice, only for very strong magnets – at which a threshold value of the magnetic field induction B_{thr} generated by those magnets is present.

The occurrence of high electromotive forces in these generators is based on the synergistic action of atomic-molecular moments that makes it possible to strongly increase the induction $\vec{B}$ of the magnetic field in ferromagnetic materials used in the construction of rotating electric generator machines.

The physical measurements made on the prototypes of electric generators made with very powerful magnets (Neodymium or ferrite) confirmed the hypotheses, as well as the theoretical calculations presented in this paper.

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