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The Device of Clemente Figuera

Julio C. Gobbi[1]
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ABSTRACT: This article aims to demonstrate that Clemente Figuera developed a self-powered device that used atmospheric electricity to function as an electric generator. Its operating principle is based on the production of alternating magnetic fields that induce an electric potential in the secondary coil and that, at the same time, collects electrostatic charges from the atmosphere. So, it will be developed a mathematical approach to quantify this electrical energy system.

KEYWORDS: atmospheric electricity, electrostatic charge, electrostatic current, electric generator, exciter electromagnet, induced coil, magnetic poles, potential induction.

Contents

1 Introduction

Engineer Clemente Figuera, from the Canary Islands, was a university professor of physics for many years at St. Augustine's College in Las Palmas. He obtained several patents on magnetic devices and invented an electric power generator that did not require fuel, external actuation force or chemical reactions, because it used energy from the atmospheric electrostatic field. The self-powered device he built generated 550 Volts for his home, as well as powered a 20 HP engine. [1]

A New York Times article of June 9, 1902 writes about the generator:

> **ELECTRICITY FROM THE AIR**
> **Engineer Discovers a Method of Using it Without Chemicals or Dynamos.**
>
> LONDON, June 9 – A dispatch to The Daily Mail from Las Palmas, Canary Islands, says that a prominent engineer of that town named Figuera claims to have discovered a method of utilizing atmospheric electricity without chemicals or dynamos, and that he is able to make practical application of his method without employing any motive force.
>
> Señor Figuera believes that his invention will bring about a tremendous industrial revolution.

1 E-mail: solismagnus@gmail.com

In the May 1902 edition of the journal The Reading in Science and Arts is written:

> In the English newspapers are extensive references to an important discovery conducted by D. Clemente Figuera, forest engineer in Canary Islands and physics professor at College San Agustin from Las Palmas. Mr. Figueras has been working silently in order to find a method to use directly, ie, without dynamos and chemical agent, the huge amounts of electricity which exist in the atmosphere and are being renewed constantly, constituting an inexhaustible reservoir of this form of energy. Our compatriot (…) has achieved his purpose, having managed to invent a generator which can collect and store the atmospheric electric fluid in a position of being able to use later for pulling trams, trains, etc., or to run machinery in factories to light the houses and streets. Although no one knows the details of the procedure that Mr. Figuera reserves until he will get it completely perfected, he states that his invention will produce a tremendous economic and industrial revolution. The apparatus devised by Mr. Figuera has been built in separate pieces, in accordance with the drawings made by him in different companies in Paris, Berlin and Las Palmas. Received the parts, the engineer has put them together and articulate in his workshop. The company from Berlin which built some of the pieces, got curious about what they would be used for, sent an engineer to the Canary Islands, with the pretext of helping set up and with real purpose to study and sketch the whole device, but has not achieved his objective. Apparently, Mr. Figueras' apparatus consists essentially of three parts: a collector, a transformer and an accumulator, so that, in short, what it does is to collect atmospheric electricity, transforming it from static to dynamic and store it in a secondary battery for later use in the form and amount required. We have understood that the inventor will soon come to Madrid and, later he will depart to Berlin and London, and then you will be able to know the procedure in detail.

Several other reports publicized the invention claiming that the generator could collect electrical fluid from the air, or obtain the force of the atmosphere, or directly use atmospheric electricity: Washington Times of June 9, 1902, Los Angeles Times of June 9, 1902, Chicago Daily Tribune of June 9, 1902, Chicago Star of June 1903, Herald's European Edition of June 9, 1907.

However, although these articles publicize his invention stating that the generator's operation is based on the use of electrostatic charges dispersed in the atmosphere, none of its patents confirms this possibility. As we will see below, in the patents there is a description of the parts and their operation, but there is no theory about the origin of the extra energy that allows the generator to be self-energized and still provide additional electrical energy.

2 Device Description

Its Spanish patent No. 30378 of 1902, with the title "Generador Eléctrico Figuera-Blasberg", describes a circular arrangement device similar to the dynamos built at that time. The comments in the patent regarding the dynamo's operation explain that the dynamos are devices for transforming mechanical energy into electrical energy and that its generator, due to the fact that it has no moving parts, does not transform energy. Here is the initial presentation of his device given in the patent:

> In the arrangement of the excitatory magnets and the induced, our generator has some analogy with dynamos, but completely differs from them in that, not requiring the use of motive power, is not a transforming apparatus. As much as we take, as a starting point, the fundamental principle that supports the construction of the Ruhmkorff induction coil, our generator is not a cluster of these coils which differs completely. It has the advantage that the soft iron core can be constructed with complete indifference of the induced circuit, allowing the core to be a real group of electromagnets, like the exciters, and covered with a proper wire in order that these

electromagnets may develop the biggest attractive force possible, without worrying at all about the conditions that the induced wire must have for the voltage and amperage that is desired. In the winding of this induced wire, within the magnetic fields, are followed the requirements and practices known today in the construction of dynamos, and we refrain from going into further detail, believing it unnecessary.

The text continues to describe the excitation current of the primary electromagnetic inductors as intermittent or alternating, which allows induction without mechanical mobility. The inductive electromagnets have a sweet iron core, but the induced coils do not have an additional core, separate from the primary inductor cores, because they are placed in the space between the cores of the internal and external exciter electromagnets, that is, in their air gaps. The calculation of the voltage induced in the secondary coils considers the magnetic field existing in this space, and follows the procedures for calculating dynamo or electromagnetic transformers with air gap. The description in the patent continues:

Several electromagnets are arranged opposing each other, and their opposite pole faces separated by a small distance. The cores of all these electromagnets are formed in such a way that they will magnetize and demagnetize quickly and not retain any residual magnetism. In the empty space remaining between the pole faces of the electromagnets of these two series, the induced wire passes in one piece, or several, or many. An excitatory current, intermittent, or alternating, actuates all the electromagnets, which are attached or in series, or in parallel, or as required, and in the induced circuit will arise currents comprising, together, the total generator current. That allows suppressing the mechanical force, since there is nothing which needs to be moved. The driving current, or is an independent current, which, if direct, must be interrupted or changed in sign alternately by any known method, or is a part of the total current of the generator, as it is done today in the current dynamos.

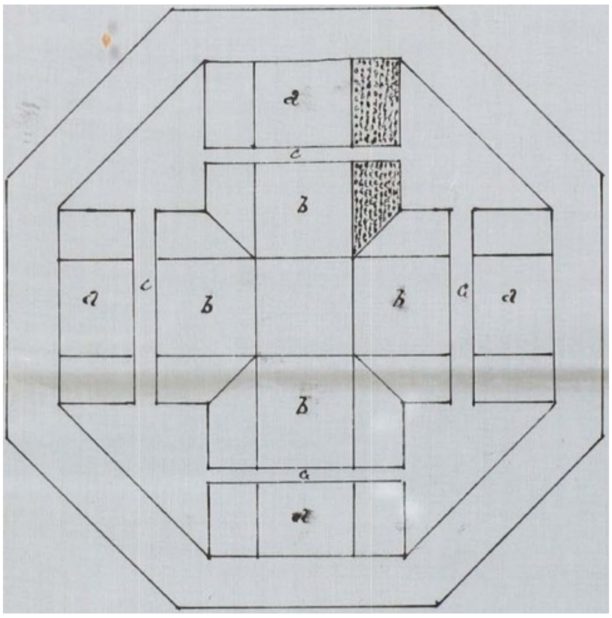

Figure 1: Drawing from patent 30378.

a = external exciter electromagnets.
b = internal exciter electromagnets.
c = place for the induced coils.

In the drawing of the patent there are no references to the switching sequence of the electromagnets or the polarity of the magnetic fields, and the first indication of the polarity of the electromagnets is given by “opposite pole faces”, which suggests that they are faces with opposite magnetic poles North and South that create the magnetic field in the air gap.

The electromagnetic device described in its Spanish patent No. 44267 of 1908 with the title “Generador Eléctrico ‘Figuera’” has different characteristics, mainly because the arrangement of the inductive electromagnets is not circular, but the windings of the secondary induced circuit do not contain a core, similarly to the 1902 patent.

The machine comprise a fixed inductor circuit, consisting of several electromagnets with soft iron cores exercising induction in the induced circuit, also fixed and motionless, composed of several reels or coils, properly placed. As neither of the two circuits spin, there is no need to make them round, nor leave any space between one and the other.

Here what it is constantly changing is the intensity of the excitatory current which drives the electromagnets and this is accomplished using a resistance, through which circulates a proper current, which is taken from one foreign origin into one or more electromagnets, magnetize one or more electromagnets and, while the current is higher or lower the magnetization of the electromagnets is increasing or decreasing and varying, therefore, the intensity of the magnetic field, this is, the flow which crosses the induced circuit.

The exciter electromagnets used by Figuera are made with coils wound on a common iron core; they are not made of silicon steel sheets commonly used in transformers. The induced circuit coils have no core. The induction is performed by the constant variation of the electric current that circulates in the coils of the exciter electromagnets, due to the variation in the value of an electrical resistance formed by resistive elements, placed in series with those.

A motor is coupled to the axis of the rotary switch to close and open the contacts connected to the resistive elements. By properly dimensioning the value of the resistors, the electric current intensities applied to the primary electromagnets can simulate a complete sinusoid with each rotation of the axis. Thus, to induce a potential in the secondary coils with an alternating frequency of 60 Hz, the motor must rotate at 3,600 RPM.

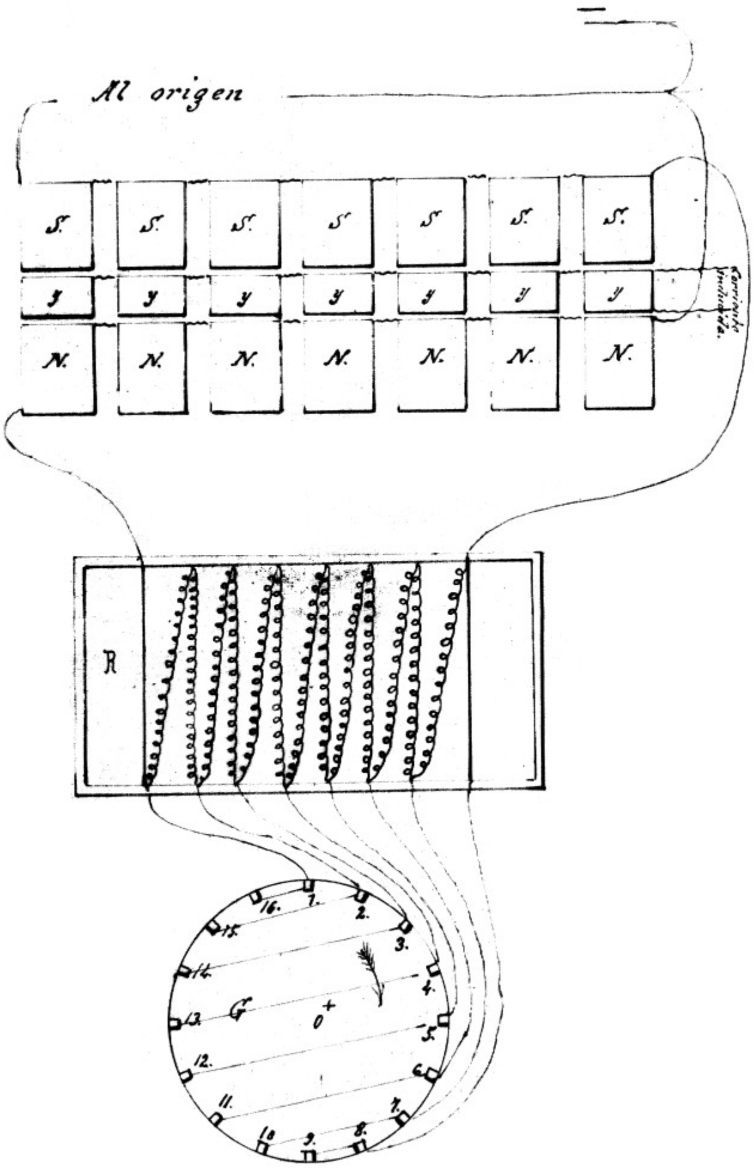

Figure 2: Drawing from patent 44267.

A battery is connected between two sets of inductive electromagnets and the brush of the rotary switch to provide oscillating electric current to the electromagnets. With one pole of the battery connected to the electromagnets N and S and the other pole connected to the brush of the rotary switch, for half a sine wave one set of electromagnets reaches maximum current and the other set reaches minimum current, and during the other half sine occurs the reverse.

The patent design defines a magnetic polarization N and S for the electromagnets, and the wiring that connects the two sets of 7 electromagnets indicates that the beginning of one set is connected to the end of the other. Supposing that the indications N and S refer to the faces of the cores, both indications would be contrary, that is, in the first case the magnetic fields are of the same direction and the faces of the seven pairs of cores have opposite magnetic polarities to the space that separates them, where the induced coils are positioned; in the second case the magnetic fields of the electromagnets are opposite and have the same magnetic pole for the induced coils.

However, due to Faraday's law of induction, only the second possibility provides the secondary coil set with a variable magnetic field source, which induces alternating potential in the secondary coils, therefore the indication N and S refers to the opposite magnetic fields. With the series connection of each set of primary electromagnet coils and due to the fact that the sets are connected to the same pole of a battery, the primary electromagnets do not receive alternating current, only electric current in a single direction that varies between a maximum and a minimum, never reaching zero, just oscillating in intensity. Therefore, a minimum magnetic field is maintained in the air gap of each pair of cores.

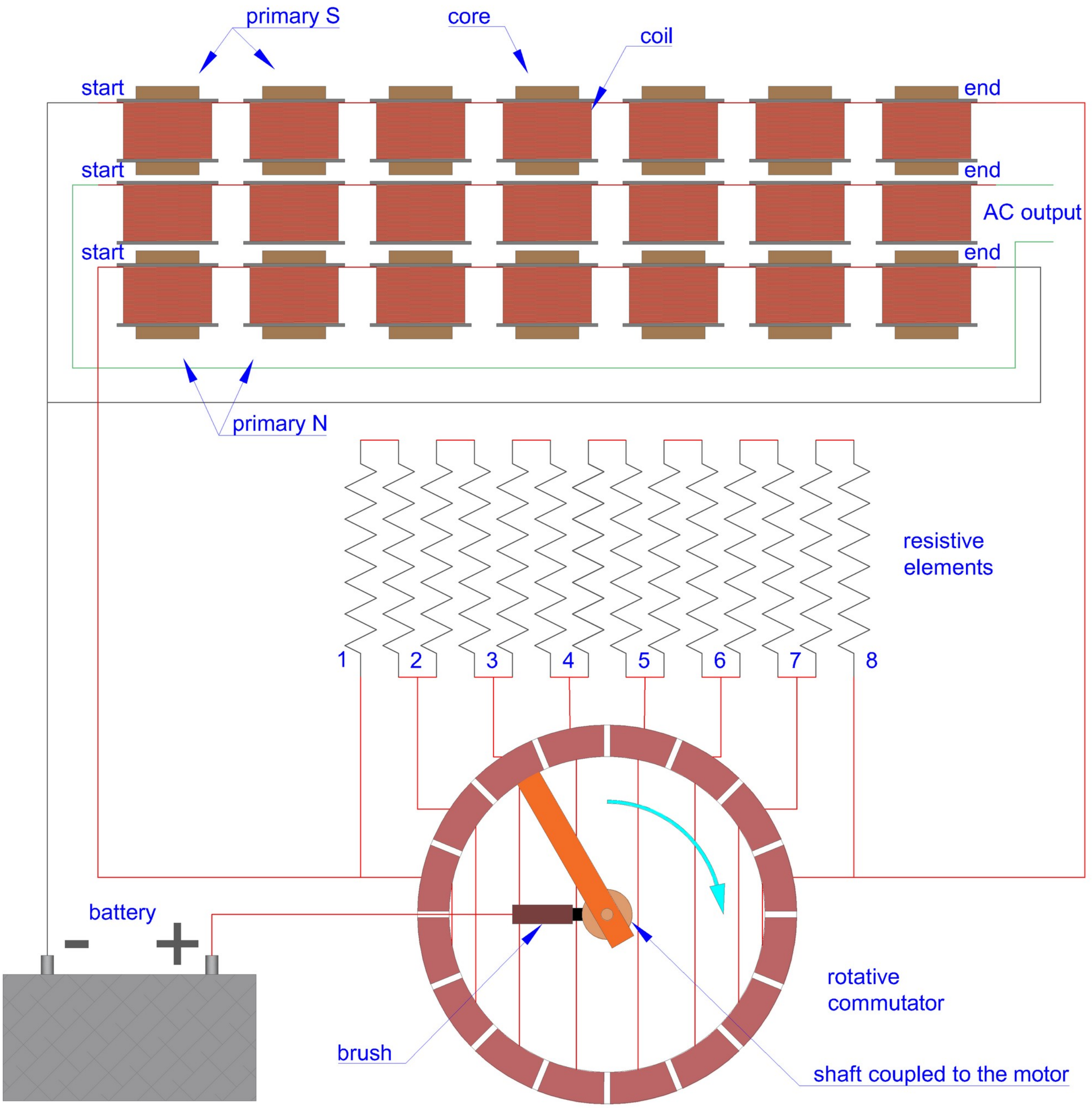

Figure 3: Detailed diagram of the Figuera's generator.

The parts that make up the electric generator, in a more detailed arrangement than that provided in the patent, are shown in the figure above. We can identify the following constituent parts of the Figuera's electrical generating device:

1. A Battery, which feeds the coils of the inductive electromagnets through the resistance segments;
2. Two sets of 7 primary (inductor) electromagnets with sweet iron cores with their coils connected in series, whose magnetic field polarity is identified by the letters N and S;
3. A set of 7 (induced) coils or secondary coils/windings without core connected in series, which provide an alternating output voltage to the load;
4. A set of 7 resistive elements (resistors connected in series) that provides 8 current levels for the coils of primary electromagnets;
5. A 16-position rotary switch electrically connected to the set of 7 resistive elements that provides, through the rotation of its axis coupled to a motor, increasing and decreasing levels of current to the coils of the primary electromagnets.

2.1 Description of Device Operation

The basic operation of the self-excited generator equipment is described in the same patent No. 44267 of Figuera:

> The applied patent for 20 years is requested upon a “NEW GENERATOR OF ELECTRICITY, so-called “FIGUERA” of variable excitation, designed to produce electrical currents for industrial applications without using neither driving force, nor chemical reactions. The machine is essentially characterized by two series of electromagnets which form the inductor circuit, between whose poles the reels of the induced are properly placed. Both circuits, remaining motionless, induced and inductor, are able to produce a current induced by the constant variation of the intensity of the magnetic field forcing the excitatory current (coming at first from any external source) to pass through a rotating brush which, in its rotation movement, is placed in communication with the commutator bars or contacts of a ring distributor or cylinder whose contacts are in communication with a resistance whose value varies from a maximum to a minimum and vice versa, according with the commutator bars of the cylinder which operates, and for that reason the resistance is connected to the electromagnets N by one of its side, and the electromagnets S at the other side, in such a way that the excitatory current will be magnetizing successively with more or less strength to the first electromagnets, while, oppositely, will be decreasing or increasing the magnetization in the second ones, determining these variations in intensity of the magnetic field, the production of the current in the induced, current that we can use for any work for the most part, and of which only one small fraction is derived for the actuation of a small electrical motor which make rotate the brush, and another fraction goes to the continuous excitation of the electromagnets, and, therefore, converting the machine in self-exciting, being able to suppress the external power which was used at first to excite the electromagnets. Once the machinery is in motion, no new force is required and the machine will continue in operation indefinitely.

To better visualize the Figuera electrical generator, the figure bellow shows the connection of only a pair of primary electromagnets with an induced coil as a secondary between them, which provides the AC output where the load will be connected. The variable resistance represents the connection of the resistive elements through the rotary switch. The coils of the primary electromagnets N and S, in the way they are connected, have opposite magnetic fields, so the polarity of these fields, at the ends of the cores that point to the secondary, is the same, North pole. Due to the variation in the intensity of the opposite magnetic fields, the North magnetic pole will be alternately intense to the left and to the right of the secondary coil, providing an alternating inversion of the magnetic field, so it is guaranteed that Faraday's induction law applies to the calculation of the secondary induced voltage. The same occurs with the rotation of a coil in front of a single pole of a magnet, therefore the reference in the patent to the functioning of the dynamo.

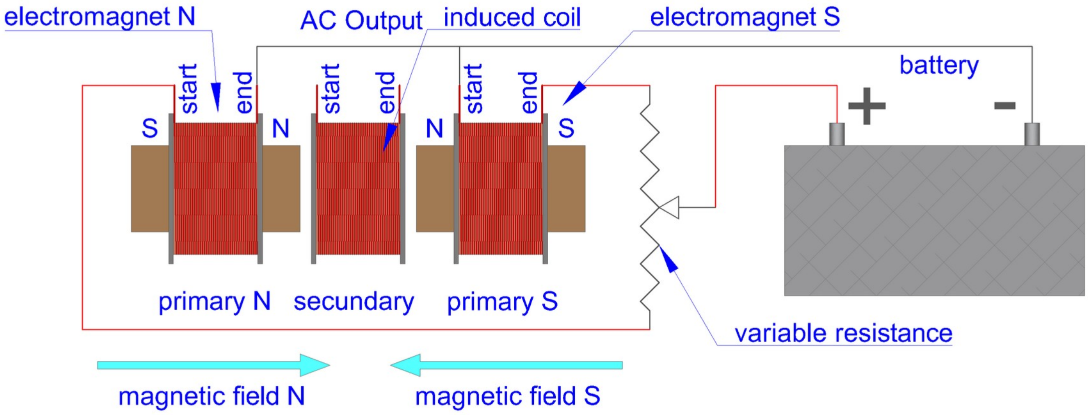

Figure 4: Simplified model of Figuera's device.

If we consider that the magnetic fields of the pairs of electromagnets are of the same direction, with the connection of the ends of the two sets of electromagnets to the negative of the battery, the alternating variation in the intensity of these fields will not provide variation in amplitude or inversion of field in the secondary, because while one field is increasing, the other is decreasing, therefore without variation in amplitude and always with only one direction of field. The consequence is that there would be no electromagnetic induction.

This simplified model allows us to know that, due to the maintenance of a minimum electric current in both N and S primaries, there will always be a residual magnetic field created inside the secondary coil with the intersection of opposite magnetic fields, which is a neutral magnetic field or pole. The resistance variation provides variable electric current to the primaries in such a way that, when the electric current is maximum in the primary electromagnet N, it will be minimal in the primary electromagnet S, and vice versa, but without reaching zero or changing the polarity.

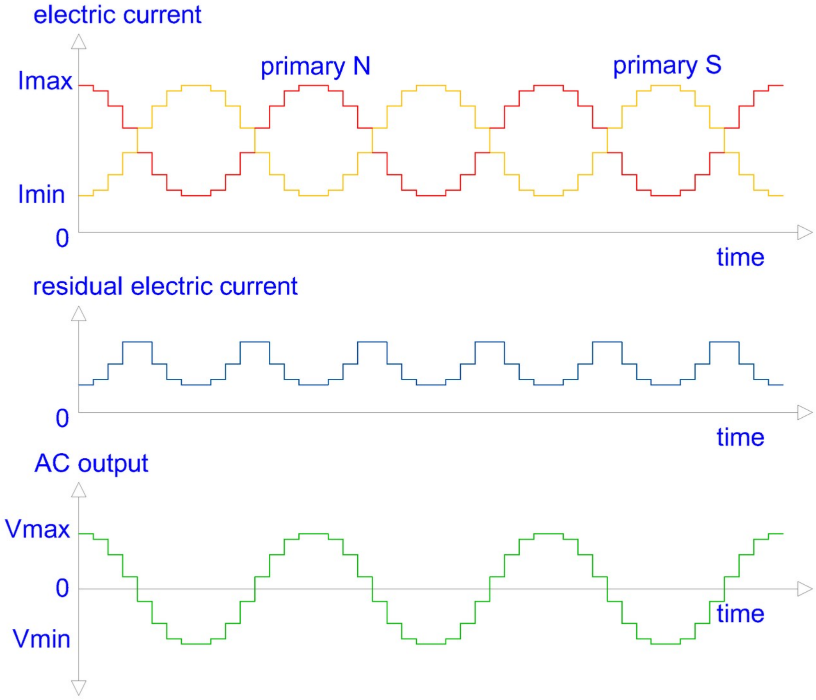

Figure 5: Primary and AC output waveforms.

At the point where the electric current is maximum in the primary N, it will be minimal in the primary S, the voltage of the AC output will reach the peak of the sinusoid and the residual magnetic field formed in the space between the cores will be at its minimum intensity, with the neutral pole positioned near the primary S. When the resistance is at its average value, both primaries will have the same intensity of opposite magnetic field, therefore, the AC output voltage reaches its zero value, the residual magnetic field will be at its maximum intensity and the neutral pole positioned at the center of the core, equidistant from the primaries. With the maximum electric current in the primary electromagnet S, it will be minimal in the primary N, the AC output of the secondary will present the sinusoid valley and the neutral pole of the residual magnetic field will be at minimum intensity, positioned close to the primary N.

For the secondary, which follows the sinusoid of the primary N, the magnetic field will be alternating – for half a sinusoid the coil will have maximum north intensity on the left, when the primary N has maximum electric current, and in the other half sinusoid it will have maximum north intensity at right, when the primary S has maximum electric current. This variation to the left and right of the North pole results in an alternating magnetic field, which induces by Faraday's law an alternating electric potential in the secondary coil.

But what inexhaustible source of energy does this equipment benefit from? In none of the patents is the origin of the extra energy exposed, only the publicized articles that disclose the invention indicate that it is from the atmosphere, in this case, the electrical charges dispersed in the terrestrial electrostatic field, also called the electrical fluid of the atmosphere. This is the reason why the induced coils have no core, they are arranged in the air gap of the primary exciter electromagnets taking advantage of the production of induced electrostatic currents.

The alternating magnetic field of the exciter electromagnets forces the electrostatic charges of air that occupy the space between their cores to follow a circular path, equivalent to countless turns of electrostatic current, similar to the induction process that occurs in the secondary coil itself. If these charges collide with any metallic surface electrically connected to the output circuit, they can flow into the load circuit. Such a need is also not indicated in Figuera's patents.

Thus, the wire used to wind the secondary coil can be non-insulated metal (exposed to air) mounted on an insulating support, or a metal strip wound like a flat coil, or enameled wire mounted on metal cross-shaped supports, to prevent the circulation of induced electric current, or each cylindrical layer of the enameled wire winding separated by a thin metallic layer electrically connected to a single point of the secondary (because there is induction of electric potential in the metallic layer).

On the one hand, the secondary coil provides an alternating electric potential induced by the alternating magnetic field of the primary electromagnets, on the other hand, the electrostatic charges in the atmosphere that are circulated add to the electric current that circulates in the secondary winding when the load is connected, acting as an inexhaustible source of electric current. The maximum electric current that can be extracted from the device depends on its constructive details, such as the intensity of the magnetic field and the volume of air that occupies the air gap, this is the reason why the Figuera’s generator was made with 7 pairs of electromagnets.

Thus, the principle by which this generator produces excess electrical energy is that the space between each pair of inductive electromagnets contains, in addition to the induced coil, atmospheric air with a density of electrostatic charges. The alternating magnetic field present in this space induces, through Faraday's Law of Induction, an alternating potential in the secondary (induced) coil and electrostatic current rings (eddy currents). Such current rings add to the load circuit electrically connected to the coil, and electrostatic charges from the atmosphere flow into the load circuit to replace the free electrons of the secondary coil metal, because they have greater mobility than these. The consequence is that the electrical power available by the device is much greater than the electrical power consumed by it, when producing the alternating magnetic field in the electromagnets.

Considering that the principle of Faraday's Law of Induction refers to the production of an electric potential through the variation of a magnetic field (or variation of its surface density of magnetic charge), each loop of electrostatic current is associated with an electric potential, similar to what happens in the coil turns of any electromagnetic transformer. However, unlike transformers, the current loops remain circulating under the action of the magnetic field and, while the electrostatic charges are collected and led to the load circuit, more electrostatic charges from the atmosphere move, maintaining the homogeneity of the air charge density.

Understanding the principle of operation of the device allows us to arrange the set of electromagnets in other ways, as long as they provide the same effect. Thus, we could use 8 primary electromagnets spaced apart with 7 secondary coils in their intervals, to have the same power as 7 pairs of primary electromagnets.

Currently, with the advent of switched-mode and microprocessor-controlled power sources, it is perfectly possible to replace the electromechanical rotary switch with a microprocessed electronic switch. The primary coils are controlled by pulse width modulation (PWM) to synthesize alternating sine waves for the primary electromagnets and also control the intensity of the magnetic field to collect electrostatic charges as a function of the output current. It is also possible to work with alternating magnetic fields of higher frequencies and electromagnets with ferrite cores, so we would have compact and high-powered equipment.

3 Mathematical Model for the Figuera's Generator

There are three calculations to be made for the Figuera's generator: coils of primary electromagnets with ferromagnetic core, secondary induced coil and amount of electrostatic charges moved by the device to define the maximum electric current the device may produce.

3.1 Coil of Primary Electromagnets

The calculation method for the original generating device follows the procedure for calculating electromagnetic circuits considering that the primaries are inductors. The inductance of the electromagnets will be calculated so that, at the operating frequency, the electric current that circulates in their coils produces a maximum magnetic field that does not saturate the ferromagnetic material of their cores. The electric current is limited by its inductive reactance, which is the reactive resistance that an inductor presents with the passage of alternating current.

The self-inductance of an air core coil (without ferromagnetic material) that has multiple layers can be roughly calculated by:

$$L_E = \frac{0.8\, a^2 N^2}{25.4(6a + 9b + 10c)} \quad .$$

With:

L_E = Electrical inductance [μH];
a = Average coil radius [mm];
b = Coil length [mm];
c = Coil thickness [mm];
d = Coil internal diameter [mm];
N = Number of layers.

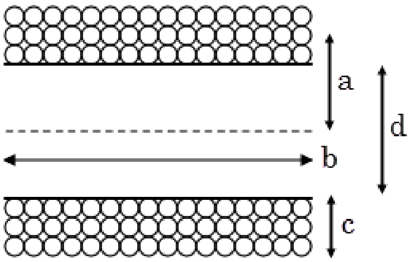

Figure 6: Multilayer coil.

The above equation has a minimum error for 6a ≈ 9b ≈ 10c. The introduction of a cylinder of ferromagnetic material with diameter **d** inside the coil increases its inductance in proportion to the relative permeability μ_r of the material:

$$L_E = \mu_r \frac{0.8\, a^2 N^2}{25.4(6a + 9b + 10c)} \quad .$$

The inductive reactance of the coil (resistance to the passage of sinusoidal electric current) is given by the relation:

$$X_E = \omega L_E = 2\pi f L_E \quad .$$

With:

X_E = Inductive reactance [Ω];
ω = Angular frequency [rad s^{-1}];
f = Frequency [Hz];
L_E = Electric inductance [H].

The electric current flowing through the coil inductance of the electromagnet, when an alternating sine voltage V_E is applied, is given by:

$$I_E = \frac{V_E}{X_E} = \frac{V_E}{2\pi f L_E} \quad .$$

The relationship between the electric current of the coil and the magnetic field produced inside it, as well as the surface distribution of the magnetic charge, is given by:

$$N I_E = \int \vec{H} \cdot d\vec{l} = H l \quad \Rightarrow \quad H = \frac{N I_E}{l} \quad \Rightarrow \quad B = \mu H = \mu \frac{N I_E}{l} \quad .$$

With:

H = Magnetic field [A m^{-1}];
B = Surface density of magnetic charge [Wb m^{-2}] [T];
N = Number of coil turns;
I_E = Electric current [A];
l = Length of coil (letter b of the inductance equation) [m];
μ = Magnetic permeability of material [Wb A^{-1} m^{-1}].

The calculation of the coil inductance, depending on its electromagnetic characteristics, can be derived from the above relations:

$$L_E = \frac{V_E}{2\pi f I_E} = \frac{\mu N V_E}{2\pi f B b} \quad .$$

From the mechanical and electromagnetic relationships that define the inductance, we can determine the number of coil turns N as a function of the mechanical measurements **a**, **b** and **c** of the winding, the working frequency **f**, the alternating voltage applied $\mathbf{V_E}$ and the surface density of the magnetic charge **B**:

$$N = \frac{25.4(6a + 9b + 10c)}{0.8 a^2} \frac{\mu_0 V_E}{2\pi f B b} \quad .$$

Certainly it will be necessary to make some mathematical iterations when defining the diameter of the enameled wire of the coil as a function of the adopted electric current and when verifying if the mechanical measures of the coil are adequate to the wire used. The surface density of magnetic charge **B** to be considered is the maximum supported by the ferromagnetic material, and must correspond to the applied peak $\mathbf{V_E}$ voltage. Knowing the effective voltage – RMS, the peak voltage is given by $V_E = \sqrt{2} V_{E_{RMS}}$. It is also possible to decrease/increase the electric current by increasing/decreasing the number of turns **N**.

3.2 Secondary Coil

It is recommended that the length of the air space where the secondary coil will be placed is not greater than the radius of the cores of the primary electromagnets, to maintain uniformity in the magnetic field. The winding of the coil can be of multiple cylindrical or flat layers, with its number of turns calculated to meet the voltage of the load circuit.

In the calculation of secondary coils of electromagnetic transformers, the electric potential induced in it is given by the relation: [2]

$$V_E = -I_M = -N\frac{dq_M}{dt} = -N\,S\frac{dB}{dt} = -N\,S\,B\,f \quad .$$

With:

V_E = Electric potential [V];
N = Number of coil turns;
q_M = Magnetic charge [Wb];
B = Surface density of magnetic charge [Wb m^{-2}] [T];
S = Surface of magnetic core [m^2];
t = Time [s];
f = Frequency [Hz].

The above equation considers that the electric potential is induced by the magnetic current that passes inside each secondary loop. In the case of the Figuera’s generator, the turns of the secondary winding are housed within the magnetic field produced on the surface of the electromagnet cores, so they are not subjected to the total magnetic field, but only part of it. If the iron core is 10 cm in diameter and a loop is 4 cm in diameter, we must consider the magnetic field area limited by 2 cm in radius – the magnetic field outside the loop circumference does not contribute to the induced electric potential in this loop.

For a flat or cylindrical coil, the average electric potential induced, when its radius varies from r_1 to r_2, is given by the average winding area:

$$V_E = -N\,S\,B\,f = -N\,B\,f\,\pi\frac{\left(r_2^2 + r_1^2\right)}{2} \quad , \quad S = \frac{1}{2}\pi\left(r_2^2 + r_1^2\right) \quad .$$

The number of turns calculation for the secondary coil follows the conventional procedure for calculating transformers, whose classic formula is:

$$N = \frac{V_E}{4.44\,B_{MAX}\,S\,f} \quad .$$

With:

N = Number of coil turns;
V_E = Secondary RMS electric potential [V];
B_{MAX} = Maximum core surface density of magnetic charge [Wb m^{-2}] [T];
S = Section area of magnetic core [m^2];
f = Frequency [Hz].

Due to the fact that the collection of electrostatic charges behaves as a source of electric current, it is recommended that the electric potential induced in the secondary coil is high so that the device supplies high power to the load circuit.

3.3 Quantity of Electrostatic Charges Displaced

The amount of electrostatic charges from the atmosphere that the device displaces in the form of circular electric currents is restricted to the air volume under the influence of the magnetic field, as seen in the chapter Electric Charge Gathering by Magnetic Vortex of the article Power from Electrostatic Charges [3], and is determined by the following variables:

- Electric charge density of the atmosphere, which is given by n_E q_E;
- Area of the electromagnet core faces that create the magnetic field for the secondary coil;
- Distance between the faces of the cores.

The total displaced electric charge is calculated by:

$$Q_E = n_e q_E S d \quad .$$

With:

Q_E = Total electric charge [C];
n_e = Ion density of atmosphere = $4*10^{25}$ electrons m^{-3};
q_E = Electric charge of ion [C];
S = Area of the electromagnet cores [m^2];
d = Distance between core faces [m].

Only part of this quantity will be conducted to the load circuit, which depends on the intensity of the magnetic field, the frequency used, the area of the metallic surface where the charges collide and the capacity of the atmosphere to replace charges, that is, the electrostatic charge density of the air where the device works. The approximate calculations below are for guidance only, as they do not consider collisions between accelerated charges and air gases.

When an electrically conductive metal is subjected to a variable magnetic field, circular electric currents (eddy currents) are formed due to a potential induction process similar to what occurs with the turns of a winding (Faraday's law of induction). The electric field formed between the ends of the turn accelerates the electrons in the metal conduction layer and, due to collisions with the metal atoms, acquire a finite drag speed.

In the case of air, electrostatic charges are not bounded to atoms, they are free and have much greater mobility, so we will consider that, being subjected to the magnetic field until its collision with the metallic support in electrical contact with the secondary coil, they will be in a constantly accelerated circular motion. If the metallic support is shaped like a cross (90° of separation between the faces), its average angular path will be 45°, that is, the electric field produced in a mean radius loop causes the electrostatic charges to travel 45° in a circular path until the collision.

With these approximations, we can estimate the amount of electrostatic charges that collide with the metal shield electrically connected to the output circuit, which defines the maximum current available by the device.

The average distance traveled by the accelerated electrostatic charges to find the shield is determined by the mean perimeter corresponding to 45°, and calculated by:

$$\theta = 2\pi \frac{45°}{360°} = \frac{\pi}{4} \quad \Rightarrow \quad d_\theta = \theta r_m = \frac{\pi}{4} r_m \quad .$$

With:

θ = Arc angle [rad];
d_θ = Arc length [m];
r_m = Mean core radius [m].

The mean electric field $\mathbf{E_m}$ which accelerates the charge $\mathbf{q_E}$ is determined by the induced electric potential $\mathbf{V_E}$ in the mean radius loop $\mathbf{r_m}$. The acceleration **a** is calculated as a function of the force **F** exerted by the mean electric field $\mathbf{E_m}$ and the mass of the electron $\mathbf{m_e}$ by:

$$E_m = \frac{V_E}{2\pi r_m} \quad \Rightarrow \quad a = \frac{F}{m_e} = \frac{q_E E_m}{m_e} = \frac{q_E V_E}{2\pi r_m m_e} \quad .$$

The average collision time is calculated by:

$$d_\theta = \frac{1}{2} a t^2 \quad \Rightarrow \quad t = \sqrt{\frac{2 d_\theta}{a}} = \pi r_m \sqrt{\frac{m_e}{q_E V_E}} \quad .$$

The average electric charges quantity per second (electric current) available is calculated by:

$$I_E = \frac{Q_E}{t} = \frac{n_e q_E S d}{\pi r_m} \sqrt{\frac{q_E V_E}{m_e}} \quad .$$

Example:

Two cylindrical electromagnets have an iron core (B_{MAX} = 1.36 T; μ_r = 3,700; H_c = 127 A/m) with a diameter of 100 mm and a length of 50 mm. The cores are separated by a distance of 30 mm, where the flat secondary coil is made of copper tape 25 mm wide and 0.5 mm thick to maintain the shape, and insulators that allow the flow of air between the layers of the tape. The electromagnets are powered by an uninterruptible power supply – UPS that supplies 220 V sine voltage, and the secondary coil delivers 220 VAC.

For sine waves, the relationship between the effective and peak values is given by:

$$V_{E_{MAX}} = \sqrt{2} V_E \quad , \quad I_{E_{MAX}} = \sqrt{2} I_E \quad , \quad B_{MAX} = \sqrt{2} B \quad .$$

To achieve the maximum surface density of magnetic charge in the iron core, we have:

$$N I_E = H l = \frac{B_{MAX} b}{\sqrt{2} \mu_0 \mu_r} = \frac{1.36 * 5 * 10^{-2}}{\sqrt{2} * 1.2566 * 10^{-6} * 3{,}700} = 10.34 A \quad .$$

With:

N = Number of coil turns of electromagnet;
I_E = Effective electric current [A];
B_{MAX} = 1.36 Wb m^{-2} [T];
b = Core length = 50 mm;
μ_0 = 1.2566*10^{-6} Wb A^{-1} m^{-1};
μ_r = 3,700.

Adopting N = 40 turns, we will have an electric current of I_E = 0.2585 A. The inductance, for the frequency of 60 Hz, is defined by:

$$L_E = \frac{V_E}{2\pi f I_E} = \frac{220}{2\pi 60 * 0.2585} = 2.258 H \quad .$$

With:

L_E = Inductance [H];

V_E = 220 V;
f = 60 Hz;
I_E = 0.2585 A.

This inductance value must be achieved with the mechanical dimensioning (letters a, b and c of the figure) of the coil, which we will not do here because it will probably be necessary to do some iterations. The number of turns of the secondary coil is calculated by:

$$N=\frac{V_E}{4.44\,B_{MAX}\,S\,f}=\frac{220}{4.44*1.36*\pi\left(5*10^{-2}\right)^2 60}=77.3\approx 78\,turns \quad .$$

With:

N = Number of coil turns;
V_E = 220 V;
B_{MAX} = 1.36 Wb m^{-2} [T];
S = $\pi r^2 = \pi(5*10^{-2})^2$ m^2;
f = 60 Hz.

Using 0.5 mm copper tape with 0.15 mm spacing between layers, the secondary coil will have a radius of 50.7 mm, therefore within the field of action of the magnetic field of the electromagnets. We will adopt the average collision distance with the metallic screen already dimensioned. The quantity of electric charges per second that can be drawn from the device is given by:

$$I_E=\frac{n_e q_E S d}{\pi r_m}\sqrt{\frac{q_E V_E}{m_e}}=\frac{4*10^{25}*1.602*10^{-19}*\pi\left(5*10^{-2}\right)^2*2.5*10^{-2}}{\pi*2.5*10^{-2}}\sqrt{\frac{1.602*10^{-19}*220}{9.109*10^{-31}}} \quad \Rightarrow$$

$$I_E=3.00*10^{10}\,C\,s^{-1} \quad .$$

With:

I_E = Electric current [A];
n_e = Ion density of atmosphere = $4*10^{25}$ electrons m^{-3};
q_E = Electric charge of electron = $1.602*10^{-19}$ C;
m_e = Electron mass = $9.109*10^{-31}$ kg;
S = $\pi r^2 = \pi(5*10^{-2})^2$ m^2;
d = 25 mm;
r_m = 25 mm;
V_E = 220 V.

Certainly only a fraction of this electric current will be available because several factors that reduce this amount have been disregarded, such as the rapid resorption of charges accelerated by the atmosphere, the air flow that carries and deflects charges from their trajectory, the mechanical characteristics of the electrostatic charge collection system etc. However, as a first theoretical approach, it looks like a promising portable device as a source of electrical energy.

4 Conclusion

The main principle behind the Figuera's generator is the gathering of electrostatic charges from atmospheric air by an alternating magnetic field. Any air volume submitted to this oscillating field produces electrostatic current rings in the same circular path of the secondary coil. If the electric charges that forms these currents collide with a metallic surface that is in electrical contact with the secondary coil, they will accumulate in it and may be conducted to the load circuit simply by electrical connection. So, this is an electric current power source.

The primary electromagnets have ferromagnetic cores, but the secondary coils do not have cores and are put in the air gap of the primary cores. This arrangement causes the induction of electric potential in the secondary coil and forces the electrostatic charges of the air volume in the gap to follow a circular path by Faraday's Induction Law.

A first approach for calculating this device, considering that the ion density of the atmosphere is $4*10^{25}$ electrons/m^3, gave us $3*10^{10}$ C/s that may be collected. Surely this is a super estimated value because the device is not so big and factors that may reduce the gathering were not considered. Since the atmosphere is an inexhaustible source of electrostatic charges, the gathering may continue indefinitely. So, this generator is a very promising electrical production system that deserves experimentation to get calculation refinements.

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