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MECHANICAL POWER REMOTE TRANSMISSION

Abstract

Remote transmission of mechanical energy would certainly be a dream two centuries ago. Nowadays we live with it and we may not even realize that we use mechanical energy wherever we want, but that it was actually produced hundreds, if not thousands of miles away. The transmission of mechanical energy from places where it is available to places where it is necessary, is nowadays achieved by means of machines that transform mechanical energy into electrical and electrical into mechanical energy. Electromagnetism plays a fundamental role in the conversion of energy and their understanding is important to have a complete mastery of the subject. The magnetic field that involves the operation of the electric machines can be originated in permanent magnets or can be created by coils. The approach to magnetism created by permanent magnets or coils is usually based on the observable effects and not on the atomic model explanation of these phenomena, using arguments associated with experimental observations, such as "equal poles repel" or "lines of magnetism are closed", without actually giving a physical interpretation. The purpose of this article is to explain the atomic processes associated with the remote transmission of mechanical energy related to magnetic and electrical phenomena, making clear and more transparent concepts such as magnetic poles, attraction / magnetic repulsion interaction, magnetic field, flow, induction, etc..

1. Introduction

Electric machines - generators, motors and transformers - have their working principle based on magnetic processes.

The interaction between a variable magnetic field and a coil is a common form of electricity production called "magnetic induction" present in the generators.

With two coils of different number of turns, a different voltage can be obtained from the original one, characteristic that is produced using transformers. Lastly, from the interaction between two coils where electric currents circulate, it is possible to develop torques that spin the shafts of the motors.

Rotating machines may have coils installed either in the moving part, "rotor" or in the static part, "stator". It should be noted that in several machines, one of these coils can be replaced by permanent magnets, and similar results can be obtained although with limitations due to the materials used. In order to understand the operation of electric machines it is fundamental to correctly understand magnetism. It´s magnetism that bears the interactions that determine their characteristics.

Since magnetism is invisible, its physical understanding is not obvious, although its effects can be easily observed or sensed, in a basic way, from the interaction of repulsion and attraction between two magnets. Thus it is simple to demonstrate the existence of forces between the created magnetic fields. Likewise, with the known experience of iron filings cast on a glass resting on a magnet, it is easy to demonstrate the formation of the imaginary "flow lines" because the filings are oriented in lines materializing the so called “flux lines”. Thus, by observation, it is simple to accept this "hidden" science as an acquired fact, although in fact it has not been explained.

There are always some doubts, that is, some unexplained questions such as, for example, "why do two magnets have the ability to repel without even touching each other physically?" It seems to be a process of pure magic that challenges our senses and which has been used in the mythical world and the term "magnetism" is often associated with transcendental phenomena as well.

2. State of art

The concepts associated with electromagnetism are usually presented using the laws of physics transcribed into expressions that make the real phenomena difficult to understand in physical terms. Examples are the following statements: "The line integral of the tangential component of the magnetic field strength H along a closed contour C is equal to the total current passing through any surface S delimited by that contour" [1]; "The magnetic flux across a surface is defined as the surface integral of the normal component of the magnetic field vector, B" [2]; "The magnetic field strength, H, is a measure of the "effort" of the current in establishing a magnetic field" [3]; "The exact description of the magnetic field requires the use of Maxwell's equations and the knowledge of the relations between the induction B and the magnetic field strength H" [4]; Facing the force between electric currents in a cause-and-effect perspective, the current creates a magnetic field around it that exerts forces on other currents possibly existing in that region [5]; "We know from Maxwell's electromagnetic theory that magnetic poles occur in pairs.

As such, when a magnet is cut into pieces, each piece will have a pair of poles. Equal magnetic poles exert force on one another, so that they repel each other, while the North and South poles attract" [6];

In his book "Physics - Electromagnetism", Knight [7] presents, in a simple way, some findings for which satisfactory explanations have not yet been shown:

a) "Magnetism is a force of action at a distance. Equal poles repel each other and opposing poles attract each other.

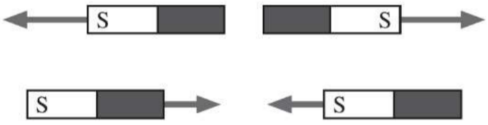

Fig. 1 - Attraction and repulsion of magnetic poles [7]

b) "It is a strange phenomenon that, by cutting a magnet in half, we have two weaker, but complete magnets, each endowed with a North pole and a South pole. An isolated magnetic pole, like a North pole in the absence of a South pole, would be called a magnetic monopole. No one has ever seen a magnetic monopole. On the other hand, no one has yet provided a compelling reason why isolated magnetic monopoles cannot exist, and some subatomic particle theories predict that they should exist. Whether or not magnetic monopoles exist in nature remains an open question at one of the most fundamental levels of physics."

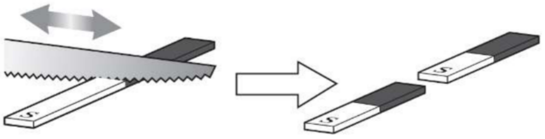

Fig. 2 - Cutting a magnet creates new dipoles [7]

c) "It is not at all obvious that the magnetic forces caused by currents correspond to the same type of magnetism as those exerted by "magnets". Perhaps there are two different types of magnetic forces, one originating from currents, and another, from permanent magnets. These two distinct ways of producing magnetic effects are, in fact, only two different aspects of a single magnetic force."

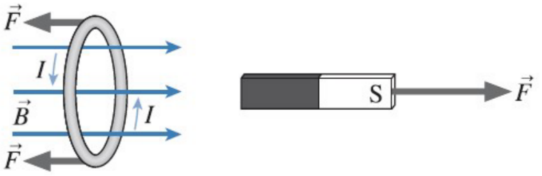

Fig. 3 - Similarity between magnetic field created by a coil and by a magnet [7]

d) "There are several ways of describing the magnetic field through its properties:

- All current flowing on a wire creates a magnetic field at all points in the space around it.

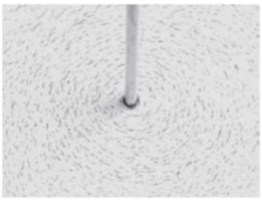

Fig. 4 - Magnetic field created by a conductor traversed by a current. [7]

- At each point in space, the magnetic field is a vector. It has both a module, which we call the magnetic field strength B, and an orientation.

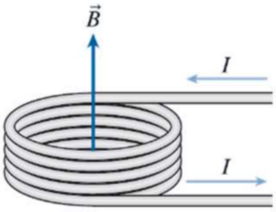

Fig. 5 - Magnetic field created by a coil driven by a current. [7]

- The magnetic field exerts forces on the magnetic poles. The force exerted on a North pole is parallel to vector B, and the force exerted on the South pole is opposite to vector B.

- Magnetic forces cause the compass needle to be aligned parallel to a magnetic field, with the North pole of the compass indicating the orientation of the magnetic field at that point.

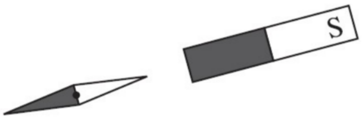

Fig. 6 - The needle of a compass aligns parallel to a magnetic field. [7]

- The magnetic field can be described through the use of magnetic field lines which are imaginary lines drawn in a region of the space so that the entire tangent to a field line is oriented in the direction of the magnetic field.

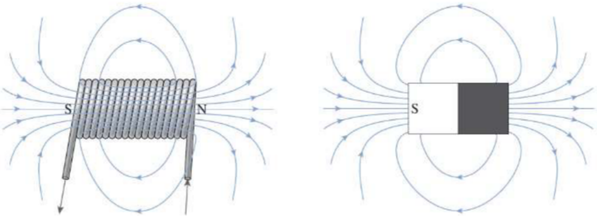

Fig. 7 - Magnetic field lines that are imaginary lines. [7]

- The magnetic field directly above the turns is opposite the field inside the turns. A coil acts as a grouping of chain turns."

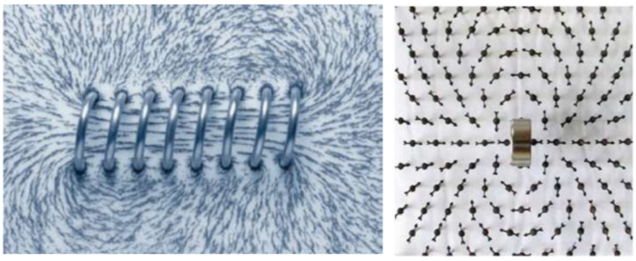

Fig. 8 - Magnetic field lines created by a coil [2] and by a magnet. [8]

e) "A voltage is induced when there is a change in the amount of magnetic field through a coil (Faraday's law)."

f) "The magnetic flux measures the amount of magnetic field that crosses a loop with a given area".

3. Understanding at the atomic level the magnetic field and the magnetic poles

"I feel it is a disillusion to think of the electrons and the fields as two physically different and independent entities. Since none of them can exist without the other, there is only one reality to be described, which has two different aspects; and theory should recognize this from the beginning instead of doing things twice." Albert Einstein [9].

The magnetism of solids is almost exclusively caused by the movement of electrons [10].

At the atomic scale, the intrinsic magnetic moments are associated with the spin of each electron and an additional contribution is associated with its orbital movement around the nucleus [11]. All magnetic fields are generated by circulating electric currents. [12]

The electric current (ordered movement of electrons) when circulating in the turns of a coil, Fig. 5, generates a magnetic field that has exactly the same characteristics of the magnetic field created by a permanent magnet.

Although we know that the electrons move in the opposite direction of the current, by reason of simplicity, in the following explanations it is assumed that the electrons have the same sense of current.

Since in a coil the circular motion of electrons creates a magnetic field identical to that created by a permanent magnet, Fig. 7, it leads us to admit that the electrons within a magnet may have equally circular orbitals in order to produce a similar effect.

Like a magnet, a coil has two poles, one having the designation North and another South. Thus looking at the end of a coil we could consider that the North pole of the coil would correspond to the side where the current circulates in the direction opposite to the one of the pointers of the clock and the South pole the opposite, Fig. 9.

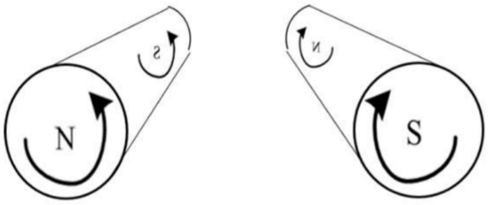

Fig. 9 - Poles and sense of the current in a coil.

Likewise, with the aid of a compass, we can identify the North pole of a magnet and also assume that on this side of the magnet the electrons move neatly in circular orbitals and counterclockwise, and from the opposite side the opposite happens.

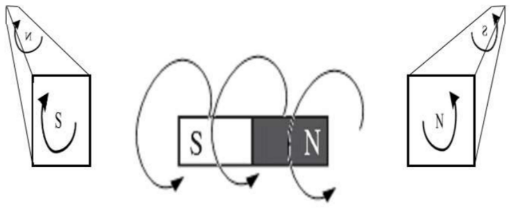

Fig. 10 - Direction of internal circulation of the electrons in a magnet.

In this way, the North and South pole designations of a magnet would be associated to the identification of the direction of internal circulation of the electrons. Thus, it is evident that when a magnet is split, two dipoles are created, since the direction of movement of the electrons does not change.

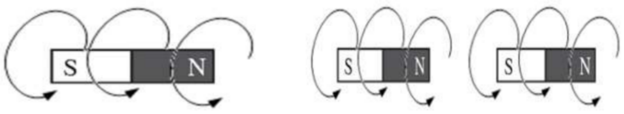

Fig. 11 - Cutting a magnet creates new dipoles.

In the same way, it is also evident that when dividing a coil in half, two dipoles are obtained. So, for example, if we divide a coil of 100 turns into two coils of 50 turns each, we get two dipoles, a similar phenomenon happens when a magnet is split in half.

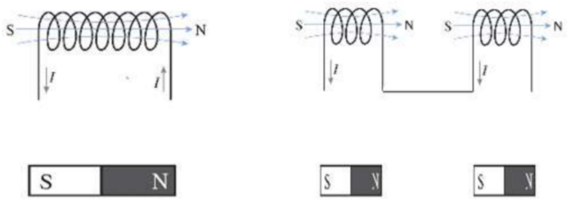

Fig. 12 - The split of a coil creates new dipoles and the same happens with magnets.

Now there is the question of why two equal poles repel each other and two different poles attract each other.

In the case of approaching different poles, the movement of the electrons in each magnet is circular and with the same direction, leading to believe that the trajectories of the electrons under the influence of both magnets fit without collisions allowing the two magnets to approach. On the other hand, it is important to keep in mind that the electrons that rotate around the nucleus are strongly attracted to their nucleus, and the distance between them is maintained by the centrifugal forces that push the electrons (negative charges) of their protons (positive charges). It turns out that the effect of these centrifugal forces only gives effect to the withdrawal of the electrons from their nucleus.

When different polarities of two magnets approach, since the orbits of the electrons are circular and have equal directions in said magnets, these allow their approximation being the electrons of a given magnet strongly attracted by the protons of the other magnet. That is, there are forces of attraction between the different polarities of the magnets.

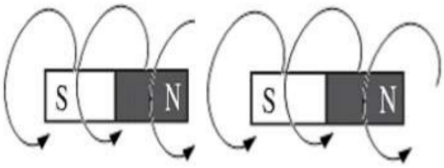

Fig. 13 - Different polarities of two magnets attract each other.

In the other situation of approaching equal poles of two magnets, the movement of the electrons in each magnet is circular, but with opposite directions, leading to believe that the electrons from both magnets suffer collisions between them, not allowing the two magnets to approach, that is to say, forces of repulsion emerge promoting the separation between them.

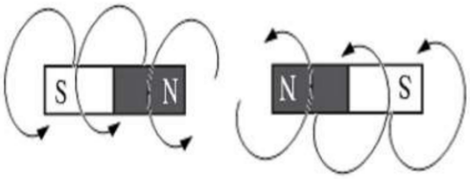

Fig. 14 - Equal polarities of two magnets repel each other

4. Concepts of flux and reluctance of the magnetic circuit

If we feed a coil with a continuous voltage, it generates a current (of free electrons) that creates a circular movement of electrons. If we insert a piece of iron inside it, the electrons circulating in the coil interact with the iron electrons "meshing" their movements and create a joint circulatory movement that is usually associated with the concept of magnetic flux. It should be noted that at the ends of the iron core the air electrons which are "meshed" with the iron electrons apparently exert a braking effect causing the movement of the iron electrons to rotate in their circular orbitals at a slower speed than the electrons that circulate in the windings of the coil. That is, as is commonly said, the magnetic circuit is composed of two parts being one in iron and another in air with their respective magnetic reluctance.

If the iron core has a closed longitudinal shape, the said locking effect does not exist and the velocity of the iron electrons accompany the velocity of the electrons of the electric current in the coil reaching a higher velocity which is usually referred to as an increase in magnetic flux. In this situation the magnetic circuit is composed only of iron having high magnetic permeability.

5. Creation of Induced Electromotive Force

If a core of ferromagnetic material traverses two coils we can recreate the same effects that are present in a transformer. If one of the coils is fed with direct current, a circular movement of the electrons is created in its orbitals. In the second coil the electrons also have circular motion by entrainment through the "gear" with the iron core electrons; however, in this situation, no potential difference is formed between its terminals since the electron density is constant along the conductor of the second coil, although the orbits of its electrons have a circular motion. If the voltage in the first coil is variable, this will consequently create a variable current corresponding to the movement of electrons with accelerations and decelerations.

These electrons that circulate in the first coil with variable velocities in their circular movements will transmit to the electrons of the ferromagnetic nucleus these movements. On the other hand, the electrons of the second coil will also rotate in their orbitals driven by the impacts of the core electrons, with acceleration and deceleration forces being exerted on them in order to also vary their speed. A particle suffers accelerations or decelerations when forces are exerted on it. These forces exerted on the electrons of the second coil are capable of deflecting them from their orbitals by dragging them to one end of the conductor which ends up being left with excess electrons, thereby creating a potential difference between the two ends of the coil. This potential difference is usually called "induced electromotive force" and is represented by Faraday's law. In short, we can say that an alternating voltage that feeds a coil coupled to another in the same magnetic circuit produces at the second coil a voltage through the effect of a magnetic "gear".

In a given coil, from the application of a voltage variation, results a corresponding variation in the electric current. It turns out that this current variation is delayed in relation to the voltage variation applied to the coil. This is due to the fact that the current of the coil, ie the movement of the electrons, is "meshed" with the movement of the electrons of the magnetic core which gives it a delay of response, due to the inertia that must be overcome to change the speed of millions of electrons that are synchronized with the electrons of the electric current in the coil.

6. Mechanical power remote transmission

A variable magnetic field applied to a coil (“A” of Fig. 15) electrically connected to another coil (“a” of Fig. 15), produces in the last coil (“a”) a magnetic field synchronized with the first one (“A”). As a complete setup, consider a magnet (“x” of Fig. 15) to rotate inside three coils (“A”, “B” and “C”, 120 degree phase shifted) that are electrically connected to three other coils (“a”, “b” and “c”, 120 degree phase shifted) in the center of which there is a compass needle.

The compass needle will rotate in parallel with the magnet because the two magnetic fields are "meshed" by the movement of the electrons in the coils and in the transmission conductors. It should be noted that the compass needle, “y”, can be replaced by a magnet, given that it has the same magnetic characteristics, obtaining the equivalent of a "synchronous motor" whose rotor rotates in synchronism with the generator rotor.

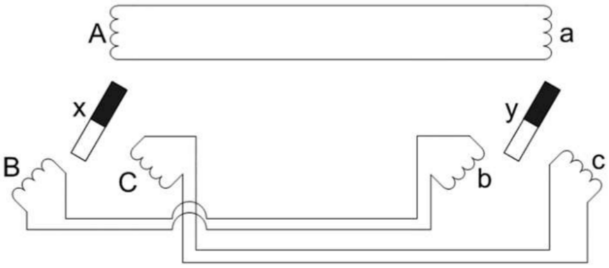

Fig. 15 - The needle of the compass, y, rotates synchronously with movement of the magnet, x

What has just been shown is nothing more than a small-scale representation of what happens in the electricity grid of a country where the mechanical energy of the primary sources is converted into electricity (electron movement) and is subsequently transformed into mechanical energy by the motors or in others types of energy. In this way it can be concluded that the mechanical energy available in a given place is transported by "gear" of the electrons to other geographic locations.

7. Conclusion

Starting from the understanding of a magnetic field created by a current of electrons when it crosses a coil, the concept of North and South magnetic poles was approached; as the permanent magnets have magnetic properties similar to the association of magnetism with the circular movement of the electrons, it was possible to understand why two dipoles arise when a magnet is split in half and also the existence of forces of attraction between different poles and repulsion between equal poles.

The concepts of reluctance, magnetic flux and induced electromotive force creation were explained. The phenomena of energy transmission between two coils through the magnetic field were exposed and it was also shown how it is possible to transmit mechanical energy through the electric current, mechanically driving the shaft of a generator and receiving back the mechanical energy in the shaft of an electrically connected motor.

In terms of conclusion, we dealt with a phenomena with which we live daily, but whose explanation has been supported by laws of classical physics that can model them through their effects, although without explaining the electrons behavior in a simple and transparent way as they exist in nature.

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