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To the theory of a flat coil

Annotation

A requirement for the design of a flat coil is formulated and a method is proposed for calculating a coil that satisfies this requirement - let's call it ideal. The stated requirement is not implemented in existing coils and therefore the distance between the coils in power transmission systems is only centimeters. The author has developed the design of an ideal coil and proposes to consider this article as a grant proposal or private investment.

Contents

1. Introduction

Currently, wireless power transmission (WPT) over short distances (measured in centimeters) is widely used. The scope of the method is growing rapidly - charging electric vehicles and consumer electronic devices, biomedical implants, etc. [2].

The hardware implementation starts by converting DC to high frequency AC. The alternating current excites the wire coil in the transmitter, which induces a magnetic field. When the receiver coil is in close proximity to a magnetic field, the field can excite an alternating current in the receiver coil. The electronic circuitry in the receiver converts the AC back to DC, which is converted into usable power.

So, the main way to implement this method is to transfer energy between two flat coils. The idea of a flat coil belongs to N. Tesla. But there is still no regular method for calculating such a circuit as a WPT - the diameter of the coils, the distance between them, the transmitted power and the design of the coil. In [1], this issue is considered in detail on the basis of an analysis of the proposed calculation methods and experimental data in WPT systems. The main attention is paid to the comparison of two ways of winding coils - simple winding of a single-layer coil and winding of bifilar winding. The authors conclude that bifilar winding is twice as efficient as conventional winding. There is no explanation for this fact.

Below we propose an explanation of this fact and a conclusion about the possible design of flat coils to increase the range and power of energy transfer.

2. Energy flow

It is customary to say that the energy between the coils is transferred by a magnetic field and call such energy transfer inductive power transfer, magnetic resonance coupling and, in general, non-radiative transfer, opposing such transfer to electromagnetic radiation [1, 2]. This is justified by the small distance. Following this ideology, we must generally abandon the search for ways to increase the range of energy transfer between the coils.

But in electrodynamics, there is only a flow of electromagnetic energy for energy transfer. The magnetic field that is transmitted between the coils is an electromagnetic field, because. an alternating magnetic field cannot exist without an electric field. Therefore, further we will consider the flow of electromagnetic energy between the coils.

Note that the flow of electromagnetic energy can be transferred along with the electric current through the wires, together with the magnetic flux through the magnetic circuit and independently of other flows, for example, in an electromagnetic wave propagating in a vacuum.

Wireless transmission of electromagnetic energy together with magnetic flux (which is currently done using flat coils) is in principle limited, since the magnetic circuit has a very limited length. It may be objected that the existence of a magnetic flux from the Sun contradicts this assertion. The answer is that the magnetic flux from the Sun is an electromagnetic energy flux in which the magnetic component is more easily detected than the electrical component.

Therefore, below we will consider only how a flat coil can be made to form a flow of electromagnetic energy, propagating over considerable distances without a magnetic flux. The results obtained do not reject all achievements in the design of flat coils for magnetic flux transmission. And those coils that we will consider also transmit magnetic flux. But we will leave these properties of our coils aside.

The existence of an electromagnetic wave and energy flow inside the solenoid seems to be an obvious fact. Such an energy flow was not considered, apparently, only because no explanation was found for it within the framework of the existing solution of Maxwell's equations.

However, back in 1886-1890, E. Thomson and his followers demonstrated experiments with AC solenoids, from which it followed that such solenoids radiate an energy flow that performs mechanical work [3, 4]. For example, in fig. 1 from [3] shows that the copper ring rotates in the field of the solenoid, and in fig. 2 of [4] the copper ring deviates from the solenoid. It is this energy of the solenoid that does the work of the solenoid, which is considered to be the work of only magnetic forces.

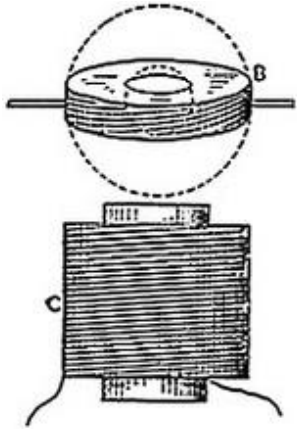

Fig. 1.

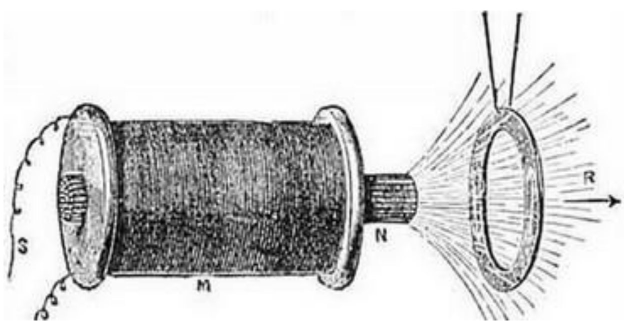

Fig. 2.

It is also necessary to take into account the fact (following from the law of conservation of energy) that the transmitting coil can form only the flow that can be converted by the receiving coil into consumer energy, i.e. for the same circuit, there is an idle energy flow and a consumer energy flow.

A flat coil, just like a conventional solenoid in a symmetrical medium, creates a symmetrical magnetic field, since it is powered by a symmetrical sinusoidal electric current. However, when a power receiver appears, the energy flow becomes asymmetric - there is a large energy flow from the center of the coil and a weak oppositely directed energy flow outside the coil. We will consider this fact in more detail below.

3. Transfer of energy from the wire

Whatever the design of the energy converter, the initial energy flow comes from the generator to the wire, which is the main element of any converter. A coil is wound from the wire, in which a flow of energy is formed. But this energy can enter the coil only from the wire and not from the end of the wire, since this end is outside the coil. Therefore, there must be a mechanism for transferring energy through the surface of the wire.

In [5], this mechanism is considered. The electric field of the wire does not change abruptly when crossing the wire boundary. Obviously, it gradually decreases from the boundary value to zero. However, the change function is unknown even for high-voltage power lines, where knowledge of this function is important for solving technological and environmental problems.

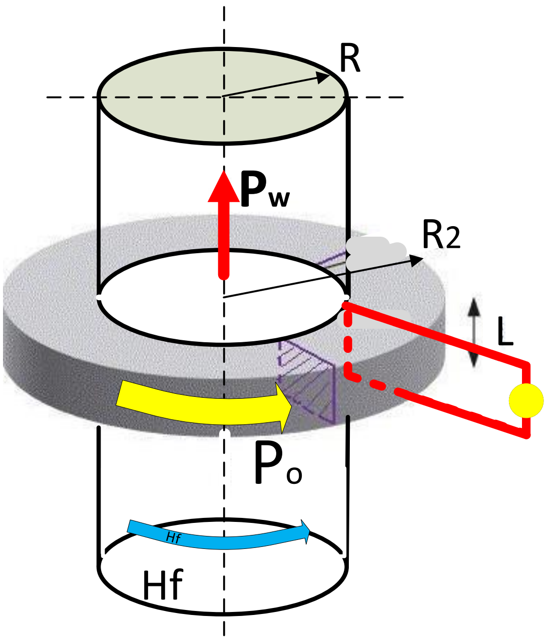

Fig. 3.

The power allocated by this field depends on the size of the external field. On the other hand, this power is equal to the power consumed by this field. Thus, the size of the external field is determined by the power of the consumer of this field. Such a consumer can be, for example, a transformer in which this wire is one of its windings - see fig. 3. Power Pw is transmitted through the wire. The power Po consumed by the light bulb is transferred to the iron ring. The circular flow of this power in the ring is a continuation of the circular power flow in the wire. This power appears only in the volume of this ring and only when the light is on (we neglect the idle power). The transfer of the energy flow from the wire to the ring occurs due to the fact that magnetic strength Hf appears at the boundary of the wire with the ring. This intensity, on the one hand, is a consequence of the existence of an electromagnetic field in the wire, and on the other hand, it is the causative agent of an electromagnetic field in the ring, because the appearance of at least one of the 6 intensities creates an electromagnetic field, as a consequence of solving Maxwell's equations [5].

Another option for transferring energy from a wire is shown in Fig. 4. Shown here is a piece of ring wire carrying the Pw capability. Part of this power is transferred to the vicinity of the wire as a continuation of the annular power flow in the wire (shown in yellow). In this case, the power flow inside the ring Po is directed upwards, where the consumer of this power is located. Outside the ring, the power flow Pxx is directed downward, but its value Pxx<<Po, since there is no power consumer in this direction. Also, as in the previous case, the transfer of the energy flow from the wire to the ring occurs due to the fact that magnetic intensity appears on the border of the wire with the ring, as a result of the existence of an electromagnetic field in the wire, and as an exciter of the electromagnetic field in the vicinity of the wire as a result of solving the Maxwell equations [5].

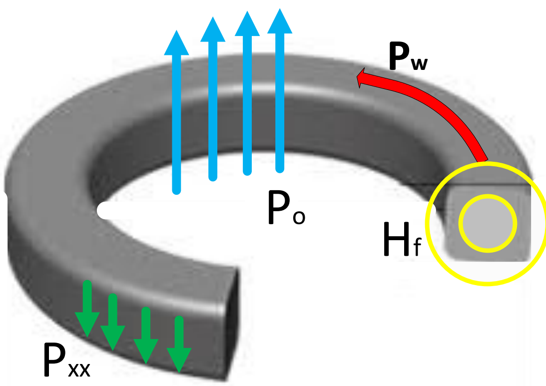

Fig. 4.

Let's consider one more illustration to what has been said, taken from [6] - see fig. 5. The author considers a magnetically conductive torus with a bifilar winding under alternating voltage. According to the existing theory, there is no magnetic field outside this coil. But in the "yellow circuit", according to the law of electromagnetic induction, an emf should be induced induction. The author asks the question: "How does the circuit know that the magnetic flux changes within the circuit?" The author is looking for an answer to this question in solving Maxwell's equations. It turns out that the magnetic induction outside the coil is 10^-16 of the induction inside the coil. Obviously, such an induction cannot create an emf inside the contour. We must admit that the wire of the coil "on its own" creates an emf inside the circuit and transfers energy to it.

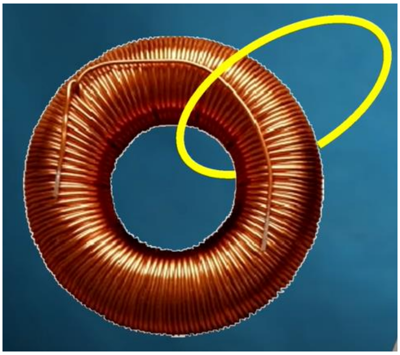

Fig. 5.

The wire can be a long antenna. In this case, the power consumer is the medium that absorbs the radiation power, and technical radiation receivers. In any case, the energy carrier must be a flow of electromagnetic energy. If this is not a longitudinal flow of energy through the end of the wire, then this is the flow of energy through the side surface of the wire. However, the electric field of the wire (as shown in [5]) is such that there is a longitudinal energy flow (power transmitted through the wire) and a circumferential energy flow, but there is no radial energy flow. Therefore, we must look for an explanation for all cases of wireless transmission of energy, as transmission through the surface of a wire. This is how any transfer of energy begins.

Energy is not created by wire configuration. In any case, the field in the vicinity of the wire is excited by the circumferential magnetic tension Hφ. This tension creates an electromagnetic field, one of the tensions of which is this tension. Thus, in any case, the field created by the wire can be calculated as the sum of the fields created by the elements of the wire. This method greatly simplifies the calculation of the electromagnetic field of a flat coil, which we will discuss in more detail below.

A field can only arise if a flow of electromagnetic energy can arise in this field, and the latter can only arise if there is a consumer of this energy. In our case, the power of the energy consumer from the wire with which the coil is wound is equal to the power coming from the generator to the wire, because it is all spent on radiation. It also simplifies flat coil calculation.

4. Conventional and bifilar winding

On fig. 6 shows on the right a conventional winding and on the left a bifilar winding of a flat coil. The directions of the currents in the coils are indicated by black arrows. The colored arrows indicate the vectors of magnetic induction, which are physically directed along the tangents to the circle enclosing the coil section. At the indicated diameter, they are directed perpendicular to the plane of the drawing, but here we have depicted them on the plane of the drawing so as not to clutter up the drawing. The blue and green arrows refer to the intensity vectors of each coil, and the red arrows depict the total magnetic intensity vector in a given gap between coils. It can be seen that the total vectors of the conventional winding are practically equal to zero, and the total vectors of the bifilar winding show a large value. Almost everything is not so bad for a conventional winding and not so good for a bifilar winding, because the magnitude and direction of the currents at a given moment depends on the ratio of the phases of the currents in adjacent turns. And this ratio depends on the length of the wire between the compared points, the frequency of the current and the transmitted power. However, experiments show that the bifilar winding is better [1].

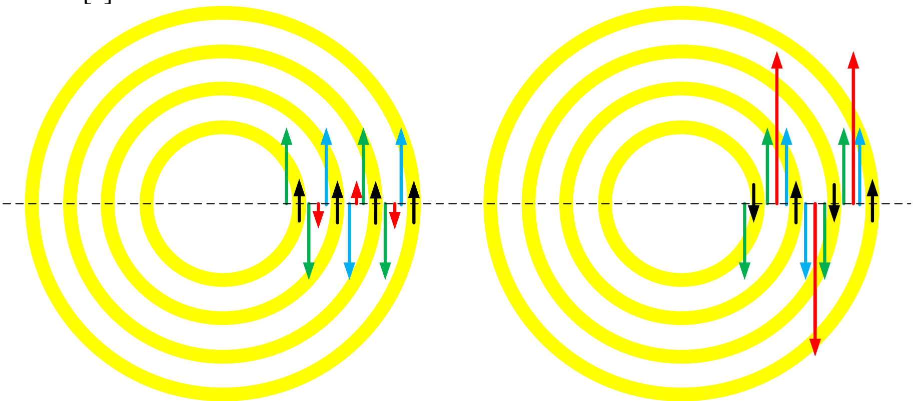

Fig. 6.

The total magnetic field emitted by the transmitting coil enters the receiving coil and excites currents that are oppositely directed in adjacent turns. Figuratively speaking, this magnetic field behaves as if it were directed into a bifilar winding. It remains only to be surprised how the receiving coil, made with a conventional winding, copes with the task.

So, the bifilar winding is certainly better, and in the future we will consider only it. In this case, we will consider the ideal case when the currents in adjacent turns are equal in magnitude and differ in phase by exactly 180 degrees. How should such a winding be made? We leave this question for the end.

From here and from the previous analysis it follows that in a conventional winding, adjacent rings with currents that coincide in phase create oppositely directed energy flows, and in a winding where currents in adjacent rings are opposite in phase, all rings create a unidirectional energy flow. This means that only such a winding is operational.

So, between the turns of the coil, an energy flow is created, directed perpendicular to the plane of the coil. These flows create a tubular cylindrical energy flow. Such tubular energy flows occur in all interturn gaps of the winding. In this case, a multilayer cylindrical energy flow rises from the surface of the coil and perpendicular to it. Obviously, it will be directed strictly perpendicular to the surface of the coil, if the conductors of the coil will have a flat side surface located perpendicular to the plane of the coil. Otherwise, this flow will acquire a conical shape and will diverge. On fig. 7 shows this energy flow. The rings of a flat coil are shown in red - the transmitting coil is at the bottom, the receiving coil is at the top. These coils are assumed to be ideal. In this case, a flow of energy directed upwards is created in half of the gaps of the transmitting coil. On fig. 7 shows in blue three positions of this wave, which reaches the receiving coil and excites a current in it (due to the reversibility of electrodynamic processes). In the other half of the gaps of the transmitting coil, a downward flow of energy is created - shown in green. It has a small value, because is the idle flow.

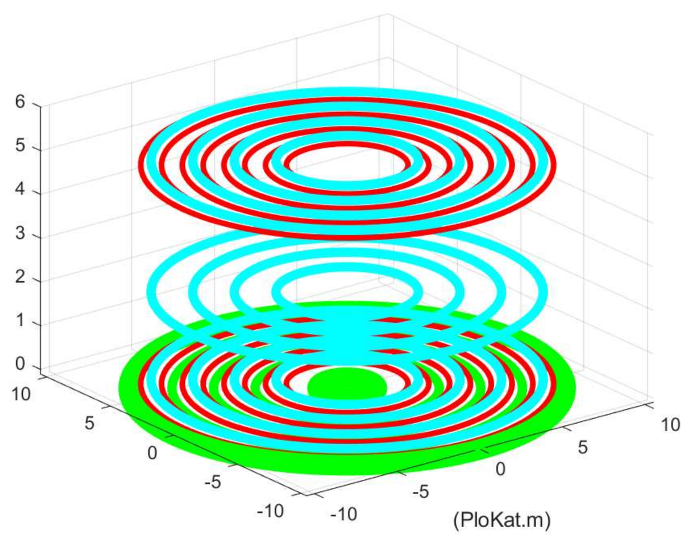

Fig. 7.

On fig. 8 shows a section of a cylindrical field. Here, the red circles indicate the sections of the wires, and the height of the vertical lines is proportional to the energy flux density on a circle of a given radius. Blue lines are the boundaries of the main field, green lines are the boundaries of the idle field.

A flow of electromagnetic energy propagates between the coils, and the magnetic flux closes around each turn of the coil and does not participate in the transfer of energy. Closing the magnetic flux between the coils can only be done using a magnetic circuit - this proves that there is no inductive power transfer between the coils, but only the transfer of electromagnetic energy by an electromagnetic wave.

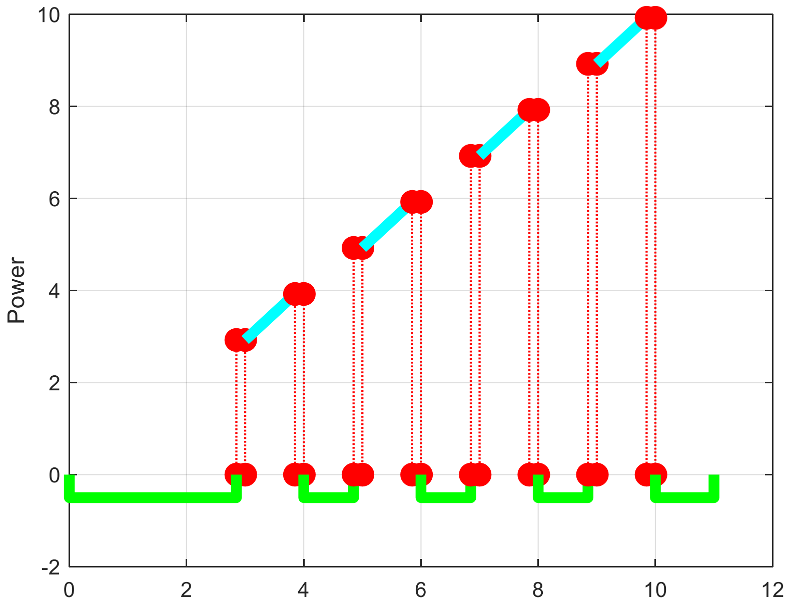

Fig. 8.

5. Conclusion

So, flat coils, in which

1) the side surfaces of the conductors are flat and
2) the currents in adjacent turns are equal in magnitude and differ in phase by exactly 180 degrees,

exchange a tubular multilayer cylindrical energy flow, the length of which is theoretically unlimited. The mathematical substantiation of the above follows from [5].

Item 2) cannot be strictly followed. In existing coils, it is performed randomly, i.e. disgusting, and therefore the distance between the coils is only centimeters.

Flat coils are widely used in new designs. For example, the WIPO patent database contains more than 150 flat-coil patents. In any case, they must be able to calculate. The proposed method is suitable for calculating an ideal coil - one that does not yet exist.

The program allows you to find the maximum expectations from a particular design. The beta version of the program can be purchased - see the invitation. The requested fee may be symbolic, but along with it, your email will be indicated in the receipt from PayPal, to which the program will be sent.

The formulated requirement is not implemented in the existing coils and therefore the distance between the coils is centimeters. The theoretical search for a successful solution is similar to the dances of savages around a straw plane - it doesn't take off, at least cry! I say this without gloating: I danced myself. It is necessary to do another winding, which I know. Please consider this article as an application for a grant or private investment.

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