The Fourth Electromagnetic Induction

Abstract

Different variants of electromagnetic induction are considered. The type of induction caused by changes of electromagnetic induction flow is separated. The dependence of this induction on the flow density of electromagnetic energy emf and on the parameters of the wire is explored. We are discussing the mechanism of occurrence of energy flow, which enters the wire and compensates the heat loss.

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1. Introduction

There is the following known law of electromagnetic induction

$$e = \frac{\partial \Phi}{\partial t}, \tag{1}$$

where Φ is the magnetic flow, e - emf. It is known also [1], that this electromagnetic magnetic induction – the appearance of emf in the conductor, may appear as a consequence of the following two laws:

$$F = q(v \times B), \tag{2}$$

$$\nabla \times E = -\frac{\partial B}{\partial t}. \tag{3}$$

In accordance to this fact two types of electromagnetic induction can be determined –

the first type - case (3), when emf in the conductor appears as a consequence of the magnetic flow change, - electromagnetic *induction caused by the electromagnetic flow change;*

the second type - case (2), when emf in the conductor appears under the influence of the Lorentz magnetic force due to the mutual displacement of the wire and the magnetic field, without changes in the magnetic flow, - *electromagnetic induction caused by the Lorentz force.*

There is also a known <u>third type</u> of electromagnetic induction, which appears in a unipolar Faraday generator – *unipolar electromagnetic induction.* In this generator the motor rotates a permanent magnet, and on the radius of the magnet appears emf, which is determined according to the formula of the form

$$e = \omega B L^2 / 2, \tag{4}$$

where

B - is the induction of the permanent magnet,

L - the length of magnet's radius,

ω - the angular velocity of rotation.

This formula was obtained by different methods: in [2] using the relativity theory, and in [3] based of the law of momentum conservation.

There is also a widely known fact, that the current is inducted in a conductor located in the flow of electromagnetic wave energy flow. Let us give *the electromagnetic induction caused by the change of electromagnetic energy flow* the name of <u>the fourth type</u> of electromagnetic induction. Further we shall determine the emf of this induction depending on the flow density.

In [4] the following fact is proved: if the body is located in a uniform flow of electromagnetic energy

$$S = E \times H, \tag{5}$$

then the following force acts on it (hereinafter the SI system is being used)

$$F = V\left(\frac{\partial}{\partial t}\left(\frac{S\varepsilon\mu}{c^2}\right) + \frac{S\sqrt{\varepsilon\mu}}{c}\right), \tag{6}$$

where

V - the volume of the body in which the electromagnetic field interacts with the charges and currents,

ε - the relative permittivity of the body,

μ - the relative magnetic permeability of the body,

c - The speed of light in vacuum.

In the electromagnetic energy flow an electron may be found. We can assume that this flow inside the electron's body is always uniform (due to its small size). Then the electron will be subjected to the force (6).

2. The Own Energy Flow

It is known that the power of the heat loss in the wire equal to the flux of the Poynting vector through the surface of the wire, and the density of the flow is determined by the electrical and magnetic intensity generated on the surface of the wire by the current in the wire.

Let us consider now the part of the wire in which an alternative current is flowing with a certain density j. Then the current and inintensity in the wire are

$$J = \frac{\pi d^2}{4} j, \tag{9}$$

$$E = j\rho, \tag{10}$$

$$H = J/(\pi d) = 0.25dj, \tag{11}$$

and the density of electromagnetic flow entering the wire from all the sides (we shall call this flow "*the own flow*") is

$$S = EH = 0.25d\rho j^2. \tag{12}$$

Here

d - the diameter of the wire,

ρ - the resistivity of the wire.

The flow of electromagnetic energy entering a wire of length L, is

$$S_L = S \cdot \pi dL. \tag{13}$$

or

$$S_L = 0.25\pi L d^2 \rho j^2. \tag{14}$$

The thermal power dissipated in the wire of volume

$$V = 0.25\pi L d^2 \tag{15}$$

is determined in the same way. Consequently, the entering electromagnetic flow allows the current to overcome the resistance to motion and to perform the work that turns into heat.

This well-known conclusion veils the natural question: how can the current attract the flow if the current occurs due to the flow? It is natural to assume that the flow creates emf which "moves the current." Further this emf will be defined.

Substituting (12) into (6), we shall find the force

$$F = 0.25d\rho V\left(\frac{\partial}{\partial t}\left(\frac{j^2\varepsilon\mu}{c^2}\right) + \frac{j^2\sqrt{\varepsilon\mu}}{c}\right) \tag{16}$$

This force acts on all the charges (electrons) in the wire, is directed to the current (i.e., it doesn't act on the wire as a whole). It is this force that allows the current to overcome the resistance to motion and performs the work that turns into heat.

The force (16) is determined for a known current density. But the current appears only in a close circuit. Consequently, before closing the circuit in the wire must exist emf produced by this force. Since the emf

$$e = \rho j\ , \tag{17}$$

then from (6) and (32) can be found emf at a certain energy flux density (and unknown intensities E and H in this flux).

In particular, for a constant flow from (6) we find

$$F = VS\sqrt{\varepsilon\mu}/c, \tag{18}$$

and from (16) we find

$$F = 0.25 d\rho V j^2 \sqrt{\varepsilon\mu}/c \tag{19}$$

Consequently,

$$j^2 = \frac{4Fc}{d\rho V\sqrt{\varepsilon\mu}} = \frac{4S}{d\rho}. \tag{20}$$

and, taking into account (17),

$$e^2 = 4S\rho/d\ . \tag{21}$$

For a sinusoidal flow

$$S = S_o \sin^2(\omega t) \tag{22}$$

from (6) we find

$$\begin{aligned} F &= V\left(\frac{\partial}{\partial t}\left(\frac{S_o\varepsilon\mu\cdot\sin^2(\omega t)}{c^2}\right) + \frac{S_o\cdot\sin^2(\omega t)\sqrt{\varepsilon\mu}}{c}\right) = \\ &= \frac{S_o V\sqrt{\varepsilon\mu}}{c}\left(\frac{\omega}{c}\sqrt{\varepsilon\mu}\cdot\sin(2\omega t) + \sin^2(\omega t)\right) \end{aligned} \tag{23}$$

With sufficiently low frequencies

$$\left(\omega << c/\sqrt{\varepsilon\mu}\right) \tag{24}$$

from (23, 16) can be taken, respectively,

$$F = \frac{VS_o\cdot\sin^2(\omega t)\sqrt{\varepsilon\mu}}{c}, \tag{25}$$

$$F = 0.25 d\rho V\frac{j^2\sqrt{\varepsilon\mu}}{c}. \tag{26}$$

Consequently,

$$j^2 = \frac{4Fc}{d\rho V\sqrt{\varepsilon\mu}} = \frac{4S_o\sin^2(\omega t)}{d\rho} \tag{27}$$

and, taking into account (17),

$$e = \sin(\omega t)\sqrt{\frac{4\rho S_o}{d}}\ . \tag{28}$$

This exactly is the *fourth electromagnetic induction*. As follows from (21, 28), the electromagnetic energy flow creates emf in the wire regardless of whether it is closed or open.

3. The External Energy Flow

Apparently, the own flow is concentrating around the cable gradually. Therefore there is an area where a foreign wire, not connected with the generator, may occur.so we shall consider the case when the wire is located in an area of a foreign, *external* flow of electromagnetic energy, i.e. a flow created at the absence of current in the given wire (open wire).

Let us assume that the external flow of electric energy permeates the wire along the diameter (and does not enter it from all the sides, as it was in the previous case). Let the density of this external flow be equal to (22). In this case (6) for sufficiently low frequencies takes the form (25), and the current excited by external flow, as follows from (27), takes the form

$$j = 2\sin(\omega t)\sqrt{\frac{S_o}{d\rho}} \tag{29}$$

Given that

$$S_o = E_o H_o = E_o^2 \sqrt{\frac{\varepsilon_o \varepsilon}{\mu_o \mu}}, \tag{30}$$

from (29) we find:

$$j = 2\sin(\omega t) E_o \sqrt{\frac{1}{d\rho}\sqrt{\frac{\varepsilon_o \varepsilon}{\mu_o \mu}}} = \frac{2\sin(\omega t) E_o}{\sqrt{d\rho}} \sqrt[4]{\frac{\varepsilon_o \varepsilon}{\mu_o \mu}}. \tag{31}$$

This is the current induced by the flow of energy in the wire, permeated by the flow of energy S_o. This energy flow in the air is determined as

$$S_o = E'_o H'_o = E'^2_o \sqrt{\frac{\varepsilon_o}{\mu_o}}, \tag{32}$$

where E'_o, H'_o – are the intensity of external field where the wire is located. As the flow density does not change at its transition from the air into the wire, so from (32, 30) we find:

$$E_o^2 \sqrt{\frac{\varepsilon_o}{\mu_o}} = E'^2_o \sqrt{\frac{\varepsilon_o \varepsilon}{\mu_o \mu}}, \tag{33}$$

or

$$E_o = E_o' \sqrt[4]{\frac{\varepsilon}{\mu}}. \tag{34}$$

Combining (31) and (34), we get:

$$j = \frac{2\sin(\omega t)E_o'}{\sqrt{d\rho}} \sqrt[4]{\frac{\varepsilon_o}{\mu_o}} \sqrt{\frac{\varepsilon}{\mu}} \tag{35}$$

Let us find the emf arising in the wire,

$$e = j\rho. \tag{36}$$

Combining (35) and (36), we find:

$$e = 2\sin(\omega t)E' \sqrt{\frac{\rho}{d}} \sqrt[4]{\frac{\varepsilon_o}{\mu_o}} \sqrt{\frac{\varepsilon}{\mu}} \tag{37}$$

Given that $\sqrt[4]{\varepsilon_o / \mu_o} = 19.4$, we get

$$e = 40\sin(\omega t)E' \sqrt{\frac{\varepsilon\rho}{\mu d}} \tag{38}$$

Thus, in the wire located in the external flow (32), emf (38) is generated.

Now let us close the wire. If the wire loop will look like two parallel lines (connected by short jumpers), then in these segments opposing emf will arise and there will be no current. It can therefore be argued that in a closed wire placed in the stream (31), the current does not appear. However, if a part of a closed wire is shielded, then under the influence of an *external* electromagnetic energy flow in it appears a current induced by emf. (38). The same effect should be observed also about a DC transmission line. It can be verified experimentally.

4. Whence Appears the Energy Flow?

In the above discussion there remained an unresolved question - how its own flow is involved into the cable before the current appears? The idea of wandering stream in space does not seem convincing [1]. Furthermore, as the cable detects whose flow flies around? Maybe it's the flow of a "foreign" generator? At the same time, there is another question. A long line radiates an energy flow, and at the same time the cables of this line absorb the energy flow to compensate the heat loss. How these two opposite processes may be combined?

It seems that there can be a following explanation. Every element of the cable radiated a flow of electromagnetic energy. A part of this flow is a radiation flow, and another part permeates the following element of the cable. This flow in this element creates a force acting on the charges, i.e. the determined above emf. This force creates the current. Thus,

the current in the following element appears as a result of the flow of electromagnetic energy, created by the current of the previous element.

This idea is consistent with the known fact that there is a lightning leader, moving at a speed of several hundred kilometers per second.

Recall, finally, the coaxial cable. Let us assume that at the central cable direct current flows. This cable is insulated from the external energy flow. Whence then comes the flow of energy that compensates for heat loss in the wires? It is clear that this flow can only come from the other elements of the cable, which confirms our hypothesis. (Note that the flow of energy generated by an element of the current, CAN NOT act on the current element, just as the field of the charge can not act on this charge.)

References

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