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Inconsistency Solution of Maxwell's Equations

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Annotation

A new solution of Maxwell equations for a vacuum, for wire with constant and alternating current, for the capacitor, for the sphere, etc. is presented. First it must be noted that the proof of the solution's uniqueness is based on the Law of energy conservation which is not observed (for instantaneous values) in the known solution. The solution offered:

- Complies with the energy conservation law in each moment of time, i.e. sets constant density of electromagnetic energy flux;
- Reveals phase shifting between electrical and magnetic intensities;
- Explains existence of energy flux along the wire that is equal to the power consumed.

A detailed proof is given for interested readers.

Experimental proofs of the theory are considered.

Explanation is proposed for the experiments, which have not yet been explained.

The work offers some technical applications of the solution obtained.

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Chapter 0. Preface

Contents

1. Introduction

Maxwell's system of equations is one of the greatest discoveries of the human mind. At the same time, the known solutions of this system of equations have a number of disadvantages. Suffice it to say that these solutions do not satisfy the law of conservation of energy (see Appendix 5). Such solutions allow some authors to doubt the reliability of the Maxwell equations themselves. We emphasize, however, that **these dubious results follow only from a known decision**. But the solution of Maxwell's equations can be different (partial differential equations, as a rule, have several solutions). And it is necessary to find a solution that does not contradict the physical laws and empirically established facts.

The author has found a new solution to the Maxwell system of equations, free from the indicated disadvantages. This solution is found for the Maxwell equations, written in the coordinate form, and cannot be obtained in vector form from Maxwell's equations, written in vector form. This, apparently, was the reason that the proposed solution has not yet been received.

Based on the new solution of Maxwell's equations, the spiral structure of electromagnetic waves and stationary electromagnetic fields was theoretically predicted and experimentally confirmed, and it was also shown that spiral structures exist in all waves and technical devices without exception. The spiral nature of the structures is expressed in the fact that coordinate-wise electric and magnetic intensities of waves and field vary with coordinates and time (for waves) in terms of sinusoidal functions.

Below, the following theoretical predictions are justified by the fact that these functions are such that

- does not contradict the law of conservation of energy at each moment in time (and not on average), i.e. establishes the constancy of the flux density of electromagnetic energy in time,
- reveals a phase shift between electrical and magnetic intensities not only in technical devices but also in waves,
- explains the existence of a flow of energy along and inside (and not outside) the wire, equal to the power consumption.
- explains the light curl, i.e. the appearance of the orbital angular momentum at which the flow of energy not only flies forward, but turns around the axis of motion.

Below, theoretical predictions are confirmed by experimental observations and explanations of experiments that have not yet been substantiated. Among them

- existence of energy transfer devices due to the appearance of emf, unexplained by electromagnetic induction,
- measurements of the energy stored in the dielectric of a capacitor released from the plates,
- measurements of energy stored in a closed magnetic circuit,
- Milroy engine
- single wire power transmission,
- restoration of magnet energy,
- plasma crystal,
- existence of an emf with unexplained by electromagnetic induction,
- moment of impulse in magnet,
- charge of a capacitor by a longitudinal magnetic field,
- charge of a capacitor by a circular magnetic field,
- emf in a wire in a non-uniform longitudinal magnetic field,
- emf in a wire in a circular magnetic field,
- emf in a wire located in a transverse magnetic field,
- magnetic field in a charged capacitor,
- non-electromagnetic induction (as a consequence of the magnetomotive force),

• longitudinal magnetic tension in the cavity of a tubular conductor,
• energy flow, as an electromotive force,
• the nature of the potential energy of the capacitor,
• nonequivalence of the solenoid and magnet,
• Barnett effect (Chapter 5h),
• Aspden effect (Chapter 5h),
• reversibility of unipolar induction,
• the existence of a static electromagnetic field,
• the existence of longitudinal magnetic tension in the wire,
• the existence of unclosed lines of magnetic intensity,
• DC power transformers (Chapter 7a).

"To date, whatsoever effect that would request a modification of Maxwell's equations escaped detection" [36]. Nevertheless, recently criticism of validity of Maxwell equations is heard from all sides. Have a look at the Fig.1 that shows a wave being a known solution of Maxwell's equations. The confidence of critics is created first of all by the violation of the Law of energy conservation. And certainly "*the density of electromagnetic energy flow (the module of Umov-Pointing vector) pulsates harmonically. Doesn't it violate the Law of energy conservation?*" [1]. Certainly, it is violated, **if** the electromagnetic wave satisfies the **known solution** of Maxwell equations. But there is no other solution: "*The proof of solution's uniqueness in general is as follows. If there are two different solutions, then their difference due to the system's linearity, will also be a solution, but for zero charges and currents and for zero initial conditions. Hence, using the expression for electromagnetic field energy we must conclude that the difference between solutions is equal to zero, which means that the solutions are identical. Thus the uniqueness of Maxwell equations solution is proved*" [2]. So, <u>the uniqueness of solution is being proved on the base of using the law which is violated in this solution.</u>

Another result following from the existing solution of Maxwell equations is phase synchronism of electrical and magnetic components of intensities in an electromagnetic wave. This is contrary to the idea of constant transformation of electrical and magnetic components of energy in an electromagnetic wave. In [1[, for example, this fact is called "one of the vices of the classical electrodynamics".

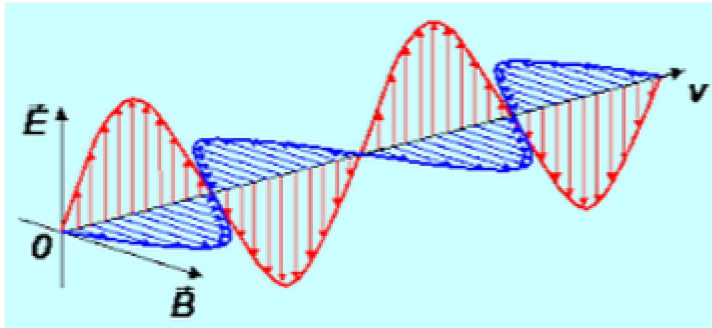


Рис. 1.

Such results following from the known solution of Maxwell equations allow doubting the authenticity of Maxwell equations. However, we must stress that these results follow **only from the found solution**. But this solution, as has been stated above, can be different (in their partial derivatives, equations generally have several solutions).

For convenience of the reader Annex 4 states the method of obtaining of a known solution. Further we shall deduct **another solution** of Maxwell equation, in which the density of electromagnetic energy flow remains constant in time, and electrical and magnetic components of intensities in the electromagnetic wave are shifted in in phase.

In addition, consider an electromagnetic wave in wire. With an assumed negligibly low voltage, Maxwell's equations for this wave literally coincide with those for the wave in vacuum. Yet, electrical engineering eludes any known solution and employs the one that connects an intensity of the circular magnetic field with the current in the wire (for brevity, it will be referred to as "electrical engineering solution"). This solution, too, satisfies the Maxwell's equations. However, firstly, it is one more solution of those equations (which invalidates the theorem of the only solution known). Secondly, and the most important, electrical engineering solution does not explain the famous experimental fact.

The case in point is skin-effect. Solution to explain skin-effect should contain a non-linear radius-to-displacement current (flowing along the wire) dependence. According to Maxwell's equations, such dependence should fit with radial and circular electrical and magnetic intensities that have non-linear dependence from the radius. Electrical engineering solution offers none of these. Explanation of skin-effect bases on the Maxwell's equations, yet it does not follow from electrical engineering solution. It allows the statement that electrical engineering solution does not explain the famous experimental fact.

At last, the existing solution denies the existence of so called twisted light [65].

2. On Energy Flux in Wire

Now, refer to energy flux in wire. The existing idea of energy transfer through the wires is that the energy in a certain way is spreading outside the wire [13]: *"… so our "crazy" theory says that the electrons are getting their energy to generate heat because of the energy flowing into the wire from the field outside. Intuition would seem to tell us that the electrons get their energy from being pushed along the wire, so the energy should be flowing down (or up) along the wire. But the theory says that the electrons are really being pushed by an electric field, which has come from some charges very far away, and that the electrons get their energy for generating heat from these fields. The energy somehow flows from the distant charges into a wide area of space and then inward to the wire."*

Such theory contradicts the Law of energy conservation. Indeed, the energy flow, travelling in the space must lose some part of the energy. But this fact was found neither experimentally, nor theoretically. But, most important, this theory contradicts the following experiment. Let us assume that through the central wire of coaxial cable runs constant current. This wire is isolated from the external energy flow. Then whence the energy flow compensating the heat losses in the wire comes? With the exception of loss in wire, the flux should penetrate into a load, e.g. winding of electrical motors covered with steel shrouds of the stator. This matter is omitted in the discussions of the existing theory.

So, the existing theory claims that the incoming (perpendicularly to the wire) electromagnetic flow permits the current to overcome the resistance to movement and performs work that turns into heat. This known conclusion veils the natural question: how can the current attract the flow, if the current appears due to the flow? It is natural to assume that the flow creates a certain emf which "moves the current". Meanwhile, energy flux of the electromagnetic wave exists in the wave itself and does not use space exterior towards the wave.

Solution of Maxwell's equations should model a structure of the electromagnetic wave with electromagnetic flux energy presenting in it.

The intuition Feynman speaks of has been well founded. The author proves it further while restricted himself to Maxwell's equations.

3. Requirements for Consistent Solution of Maxwell's Equations

Thus, the solution of Maxwell's equations must:

- describe wave in vacuum and wave in wire;
- comply with the energy conservation law in each moment of time, i.e. set constant density of electromagnetic energy flux;
- reveal phase shifting between electrical and magnetic intensities;
- explain existence of energy flux along the wire that is equal to power consumed.

What follows is an appropriate derivation of Maxwell's equations.

4. Variants of Maxwell's Equations

Further, we separate different special cases (alternatives) of Maxwell's equations system numbered for convenience of presentation.

Variant 1.

Maxwell's equations in the general case in the GHS system are of the form [3]:

$$\mathrm{rot}(E)+\frac{\mu}{c}\frac{\partial H}{\partial t}=0, \tag{1}$$

$$\mathrm{rot}(H)-\frac{\varepsilon}{c}\frac{\partial E}{\partial t}-\frac{4\pi}{c}I=0, \tag{2}$$

$$\mathrm{div}(E)=0, \tag{3}$$

$$\mathrm{div}(H)=0, \tag{4}$$

$$I=\sigma E, \tag{5}$$

where

I, H, E - conduction current, magnetic and electric intensities respectively,

ε, μ, σ - dielectric constant, magnetic permeability, conductivity wire of medium.

Variant 2.

For the vacuum must be taken $\varepsilon=1$, $\mu=1$, $\sigma=0$. When the system of equations (1-5) takes the form:

$$\mathrm{rot}(E)+\frac{1}{c}\frac{\partial H}{\partial t}=0, \tag{6}$$

$$\mathrm{rot}(H)-\frac{1}{c}\frac{\partial E}{\partial t}=0, \tag{7}$$

$$\mathrm{div}(E)=0, \tag{8}$$

$$\mathrm{div}(H)=0. \tag{9}$$

The solution to this system is offered in the **Chapter 1.**

Variant 3.

Consider the case 1 in the complex presentation:

$$\mathrm{rot}(E)+i\omega\frac{\mu}{c}H=0, \tag{10}$$

$$\mathrm{rot}(H)-i\omega\frac{\varepsilon}{c}E-\frac{4\pi}{c}(\mathrm{real}(I)+i\cdot\mathrm{imag}(I))=0, \tag{11}$$

$$\mathrm{div}(E)=0, \tag{12}$$

$$\mathrm{div}(H)=0, \tag{13}$$

$$\mathrm{real}(I)=\sigma\cdot\mathrm{abs}(E). \tag{14}$$

It should be noted that instead of showing the whole current, (14) shows only its real component, i.e. conductivity current. Imaginary component formed by a displacement current does not depend on electrical charges.

The solution to this system is offered in the **Chapter 4.**

Variant 4.

For the wire with *sinusoidal current* I flowing out of an external source, $\mathrm{real}(I)$ may at times be excluded from equations (11-14). It is possible for a low-resistance wire and for a dielectric wire (for more details, refer to Chapter 2). As this takes place, the system (11-14) takes the form of

$$\mathrm{rot}(E)+\frac{\mu}{c}\frac{\partial H}{\partial t}=0, \tag{15}$$

$$\mathrm{rot}(H)-\frac{\varepsilon}{c}\frac{\partial E}{\partial t}-\frac{4\pi}{c}I=0, \tag{16}$$

$$\mathrm{div}(E)=0, \tag{17}$$

$$\mathrm{div}(H)=0. \tag{18}$$

It is significant that current I is not a conductivity current even when it flows along the conductor.

The solution for this system will be considered in the **Chapter 2.**

Variant 5.

For a constant current wire, system in alternative 1 simplifies due to lack of time derivative and takes the form of:

$$\mathrm{rot}(E)=0, \tag{21}$$

$$\mathrm{rot}(H)-\frac{4\pi}{c}I=0, \tag{22}$$

$$\mathrm{div}(E)=0, \tag{24}$$

$$\mathrm{div}(H) = 0, \tag{25}$$

$$I = \sigma E \tag{26}$$

or

Variant 6.

$$\mathrm{rot}(I) = 0, \tag{27}$$

$$\mathrm{rot}(H) - \frac{4\pi}{c} I = 0, \tag{28}$$

$$\mathrm{div}(I) = 0, \tag{29}$$

$$\mathrm{div}(H) = 0. \tag{30}$$

The solution for this system will be considered in the **Chapter 5.**

We will be searching a monochromatic solution of the systems mentioned. A transition to polychromatic solution can be accomplished via Fourier transformation.

Appendix 0. Cartesian Coordinates

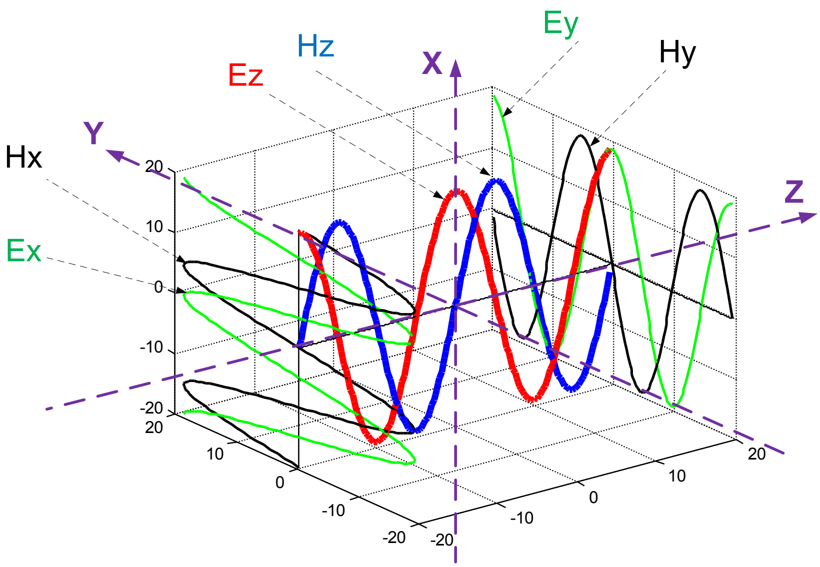
As it is known to [4], in Cartesian coordinates *x, y, z* scalar divergence of H vector, vector gradient of scalar function $a(x, y, z)$, vector rotor of *H* vector, accordingly, take the form of

$$\mathrm{div}(H) = \left(\frac{\partial H_x}{\partial x} + \frac{\partial H_y}{\partial y} + \frac{\partial H_z}{\partial z} \right),$$

$$\mathrm{grad}(a) = \left[\frac{\partial a}{\partial x}, \frac{\partial a}{\partial y}, \frac{\partial a}{\partial z} \right],$$

$$\mathrm{rot}(H) = \left(\left(\frac{\partial H_z}{\partial y} - \frac{\partial H_y}{\partial z} \right), \left(\frac{\partial H_x}{\partial z} - \frac{\partial H_z}{\partial x} \right), \left(\frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y} \right) \right).$$

Electric and magnetic intensities in Cartesian coordinates, obtained as a result of this decision, are shown are shown in the following figure.



Appendix 1. Cylindrical Coordinates

As it is known to [4], in cylindrical coordinates r, φ, z scalar divergence of H vector, vector gradient of scalar function $a(r, \varphi, z)$, vector rotor of H vector, accordingly, take the form of

$$\operatorname{div}(H)=\left(\frac{H_r}{r}+\frac{\partial H_r}{\partial r}+\frac{1}{r}\cdot\frac{\partial H_\varphi}{\partial \varphi}+\frac{\partial H_z}{\partial z}\right), \tag{a}$$

$$\operatorname{grad}_r(a)=\frac{\partial a}{\partial r},\quad \operatorname{grad}_\varphi(a)=\frac{1}{r}\cdot\frac{\partial a}{\partial \varphi},\quad \operatorname{grad}_z(a)=\frac{\partial a}{\partial z}, \tag{b}$$

$$\operatorname{rot}_r(H)=\left(\frac{1}{r}\cdot\frac{\partial H_z}{\partial \varphi}-\frac{\partial H_\varphi}{\partial z}\right), \tag{c}$$

$$\operatorname{rot}_\varphi(H)=\left(\frac{\partial H_r}{\partial z}-\frac{\partial H_z}{\partial r}\right), \tag{d}$$

$$\operatorname{rot}_z(H)=\left(\frac{H_\varphi}{r}+\frac{\partial H_\varphi}{\partial r}-\frac{1}{r}\cdot\frac{\partial H_r}{\partial \varphi}\right). \tag{e}$$

Apppendix 2. Spherical Coordinates

Fig. 1 shows a system of spherical coordinates ρ, θ, φ, and Table 1 contains expressions for rotor and divergence of vector **E** in these coordinates [4].

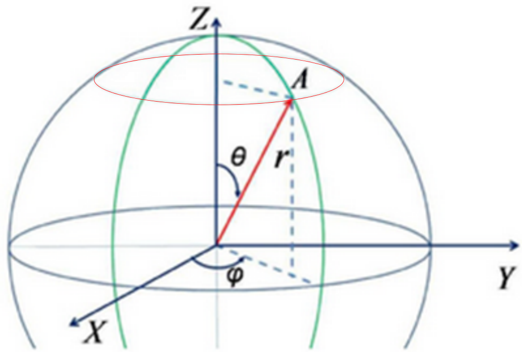


Fig. 1.

Table 1.

1	**2**	**3**
1	$\mathrm{rot}_\rho(E)$	$\frac{E_\varphi}{\rho \mathrm{tg}(\theta)} + \frac{\partial E_\varphi}{\rho \partial \theta} - \frac{\partial E_\theta}{\rho \sin(\theta) \partial \varphi}$
2	$\mathrm{rot}_\theta(E)$	$\frac{\partial E_\rho}{\rho \sin(\theta) \partial \varphi} - \frac{E_\varphi}{\rho} - \frac{\partial E_\varphi}{\partial \rho}$
3	$\mathrm{rot}_\varphi(E)$	$\frac{E_\theta}{\rho} + \frac{\partial E_\theta}{\partial \rho} - \frac{\partial E_\rho}{\rho \partial \varphi}$
4	$\mathrm{div}(E)$	$\frac{E_\rho}{\rho} + \frac{\partial E_\rho}{\partial \rho} + \frac{E_\theta}{\rho \mathrm{tg}(\theta)} + \frac{\partial E_\theta}{\rho \partial \theta} + \frac{\partial E_\varphi}{\rho \sin(\theta) \partial \varphi}$

Appendix 3. Some Correlations Between GHS and SI Systems

Further, formulas appear in GHS system, yet, for illustration, some examples are shown in SI system. This is why, for reader's convenience, Table 1 contains correlations between some measurement units of these systems.

Table 1.

Name	**GHS**	**SI**
electric current	1 GHS	$3{,}33 \cdot 10^{-10}$ A
voltage	1 GHS	$3 \cdot 10^{2}$ V
power, energy flux density	1 GHS	10^{-7} Wt
energy flux density per unit length of wire	1 GHS	10^{-5} Wt/m
electric current density	1 GHS	$3.33 \cdot 10^{-6}$ A/m^2

		$3.33\cdot10^{-12}$ A/mm^2
electric field intensity	1 GHS	$3\cdot10^{4}$ V/m
magnetic field intensity	1 GHS	80 A/m
magnetic induction	1 GHS	10^{-4}T
absolute dielectric permittivity	1 GHS	$8.85\cdot10^{-12}$ F/m
absolute magnetic permeability	1 GHS	$1.26\cdot10^{-8}$ H/m
capacitance	1 GHS	$1.1\cdot10^{-12}$ F
inductance	1 GHS	10^{-9} H
electrical resistance	1 GHS	$9\cdot10^{11}$ Om
electrical conductivity	1 GHS	$1.1\cdot10^{-12}$ sm
specific electrical resistance	1 GHS	$9\cdot10^{9}$ Om·m
specific electrical conductivity	1 GHS	$1.1\cdot10^{-10}$ sm/m

Appendix 4. Known solution of Maxwell's equations for electromagnetic fields in vacuum

Let us consider a system of Maxwell's equations for vacuum stated before in Section 4:

$$\mathrm{rot}(E) = -\frac{1}{c}\frac{\partial H}{\partial t}, \tag{1}$$

$$\mathrm{rot}(H) = \frac{1}{c}\frac{\partial E}{\partial t}, \tag{2}$$

$$\mathrm{div}(E) = 0, \tag{3}$$

$$\mathrm{div}(H) = 0. \tag{4}$$

Taking a curl from each part of the equation (1), we obtain:

$$\mathrm{rot}(\mathrm{rot}(E)) = \mathrm{rot}\left(-\frac{1}{c}\frac{\partial H}{\partial t}\right) \tag{5}$$

or

$$\mathrm{rot}(\mathrm{rot}(E)) = -\frac{1}{c}\cdot\frac{\partial}{\partial t}(\mathrm{rot}(H)). \tag{6}$$

Having combined equations (2, 6), we find out that

$$\mathrm{rot}(\mathrm{rot}(E)) = -\frac{1}{c^2}\cdot\frac{\partial^2}{\partial t^2}(E). \tag{6a}$$

It is stated [4, p.131] that

$$\mathrm{rot}(\mathrm{rot}(E)) = \mathrm{grad}(\mathrm{div}(E)) - \Delta E. \tag{7}$$

where orthogonal coordinates show that

$$\Delta E = \frac{\partial^2 E}{\partial x^2} + \frac{\partial^2 E}{\partial y^2} + \frac{\partial^2 E}{\partial z^2}. \tag{8}$$

From (3, 7) we find that

$$\mathrm{rot}(\mathrm{rot}(E)) = -\Delta E. \tag{9}$$

Having combined equations (6a, 8, 9), we find out that

$$\frac{1}{c^2} \cdot \frac{\partial^2 E}{\partial t^2} = \frac{\partial^2 E}{\partial x^2} + \frac{\partial^2 E}{\partial y^2} + \frac{\partial^2 E}{\partial z^2}. \tag{10}$$

This equation has a complex solution in orthogonal coordinates of the following kind:

$$E(t,x,y,z) = |E| e_p e^{(k_x x + k_y y + k_z z - \omega t + \varphi_o)}, \tag{11}$$

which can be verified by direct substitutions. For this purpose, the first and second derivatives of (10) are pre-calculated. Constants $(|E|,\ e_p,\ k_x,\ k_y,\ k_z,\ \omega,\ \varphi_o)$ have a certain physical significance (which will be not discussed here).

The obtained solution is complex. It is known that an actual part of a complex solution is also a solution. Consequently, the following kind of solution can be taken instead (11):

$$E(t,x,y,z) = |E| e_p \cos(k_x x + k_y y + k_z z - \omega t + \varphi_o), \tag{12}$$

Similarly we obtain a solution of the following kind:

$$H(t,x,y,z) = |H| h_p \cos(k_x x + k_y y + k_z z - \omega t + \varphi_o). \tag{13}$$

It should be stated that energy is calculated as an integral

$$\begin{aligned} W &= \int_t \left(\frac{\varepsilon E^2}{2} + \frac{\mu H^2}{2} \right) dt = \frac{1}{2} \int_t \begin{pmatrix} \varepsilon (|E| e_p \cos(\ldots \omega t))^2 + \\ \mu (|E| e_p \cos(\ldots \omega t))^2 \end{pmatrix} dt \\ &= \frac{1}{2} \left(\varepsilon (|E| e_p)^2 + \mu (|E| e_p)^2 \right) \int_t (\cos^2(\ldots \omega t)) dt = \\ &= \frac{1}{8\omega} \left(\varepsilon (|E| e_p)^2 + \mu (|E| e_p)^2 \right) \Big|_0^t \sin(\ldots 2\omega t) \end{aligned}, \tag{14}$$

From (12, 13, 14) it can be clearly stated that:

1. the energy transforms in time, which contradicts the low of energy conservation
2. vorticities E and H are cophased, which contradicts electrical engineering.

Appendix 5. On the conservation of energy in the electromagnetic wave

Here we consider in detail the issue of energy conservation in an electromagnetic wave. The following reasoning must be given here, despite their simplicity, since in further conclusions, they are of fundamental importance.

1. Running electromagnetic wave

In a traveling electromagnetic wave, the moduli of magnetic induction and electric field strength at each point in space are related by the relation

$$B = E\sqrt{\varepsilon\mu}\big/c, \tag{1a}$$

where is the speed of light in a vacuum $c = 1\big/\sqrt{\varepsilon_o\mu_o}$. Bulk density of electrical energy

$$w_e = \frac{\varepsilon\varepsilon_o E^2}{2}. \tag{1в}$$

Bulk density of magnetic energy

$$w_m = \frac{B^2}{2\mu\mu_o} \tag{2}$$

We substitute (1a) into (2) and obtain (1c). Consequently

$$w_e = w_m \tag{3}$$

Thus, in the traveling electromagnetic wave, mutual transformations of the electric and magnetic energy occur. Bulk density of electromagnetic energy

$$w = w_e + w_m = \frac{\varepsilon\varepsilon_o E^2}{2} + \frac{B^2}{2\mu\mu_o} \tag{4}$$

The sinusoidal traveling electromagnetic wave in the simplest case is described by the formulas

$$E = E_o \mathrm{Cos}(\omega t\text{-}kz), \tag{5}$$

$$B = B_o \mathrm{Cos}(\omega t\text{-}kz), \tag{6}$$

where E_o, B_o are the amplitudes of oscillations of the intensity of the electric and magnetic fields, respectively.

Substituting (5, 6) into (4), we obtain

$$w = \left(\frac{\varepsilon\varepsilon_o E_o^2}{2} + \frac{B_o^2}{2\mu\mu_o} \right) \mathrm{Cos}^2(\omega t\text{-}kz) \tag{7}$$

From (7) it follows that at any point and **in any volume** the electromagnetic energy varies in time from zero to a certain maximum. This is clearly **contrary** to the law of conservation of energy.

2. Standing electromagnetic wave

The standing sinusoidal electromagnetic wave is described by the formulas

$$E = E_o \mathrm{Sin}(kz)\mathrm{Sin}(\omega t), \tag{8}$$

$$B = B_o \mathrm{Cos}(kz)\mathrm{Cos}(\omega t). \tag{9}$$

In this wave, the intensity at all points changes in time with the same frequency and in one phase, and the amplitude in it varies according to the harmonic law depending on the z coordinate.

From formulas (8) and (9) it can be seen that the vibrations of E and B are shifted in phase by a quarter of the period. This means that when the electric field strength reaches a maximum, the B values are zero.

The energy flux density of electromagnetic waves is determined by the Poynting vector. Since at the nodes the values of E or B are equal to zero, the flow at these points is zero. The nodes for E coincide with the antinodes for B and vice versa. This means that through the nodes and antinodes there is no flow of electromagnetic energy. However, since E and B at other points change over time, it can be concluded that over time, energy moves between neighboring nodes and antinodes. When this happens, the energy of the electric field is converted into the energy of a magnetic field and vice versa. The total energy that is enclosed between two adjacent nodes and the antinodes remains constant.

Consider this question in more detail. From (4) and (8, 9) it follows that

$$w = w_e + w_m = \left\{ \begin{array}{l} \dfrac{\varepsilon\varepsilon_o E_o^2}{2} \mathrm{Sin}^2(kz)\mathrm{Sin}^2(\omega t) \\ + \dfrac{B_o^2}{2\mu\mu_o} \mathrm{Cos}^2(kz)\mathrm{Cos}^2(\omega t) \end{array} \right\} \tag{10}$$

Find the energy enclosed between two neighboring nodes and antinodes:

$$w_1 = \int_{z=0}^{z=\frac{\pi}{2k}} \left\{ \begin{array}{l} \frac{\varepsilon\varepsilon_o E_o^2}{2} \mathrm{Sin}^2(kz)\mathrm{Sin}^2(\omega t) \\ + \frac{B_o^2}{2\mu\mu_o} \mathrm{Cos}^2(kz)\mathrm{Cos}^2(\omega t) \end{array} \right\} dz$$

or

$$w_1 = \left\{ \begin{array}{l} \mathrm{Sin}^2(\omega t) \cdot \int_{z=0}^{z=\frac{\pi}{2k}} \left\{ \frac{\varepsilon\varepsilon_o E_o^2}{2} \mathrm{Sin}^2(kz) \right\} dz \\ + \mathrm{Cos}^2(\omega t) \cdot \int_{z=0}^{z=\frac{\pi}{2k}} \left\{ \frac{B_o^2}{2\mu\mu_o} \mathrm{Cos}^2(kz) \right\} dz \end{array} \right\}.$$

This energy does not change in time, because

$$a_1 = \int_{z=0}^{z=\frac{\pi}{2k}} \left\{ \frac{\varepsilon\varepsilon_o E_o^2}{2} \mathrm{Sin}^2(kz) \right\} dz = \int_{z=0}^{z=\frac{\pi}{2k}} \left\{ \frac{B_o^2}{2\mu\mu_o} \mathrm{Cos}^2(kz) \right\} dz, \tag{11}$$

that after taking integrals follows from formula (3). Wherein

$$w_1 = a_1. \tag{12}$$

Similar relations can be obtained for the other three quarter-periods of function (12). Thus, the standing wave retains its electromagnetic energy (which it received during the formation of two traveling waves).

<u>To maintain the ideal standing wave does not require the flow of external energy.</u>

Chapter 1. The Second Solution of Maxwell's Equations for vacuum

Contents

1. Introduction

In Chapter "Introduction" inconsistency of well-known solution of Maxwell's equations was demonstrated. A new solution Maxwell's equations for vacuum is proposed below [5].

2. Solution of Maxwell's Equations

First we shall consider the solution of Maxwell equation for vacuum, which is shown in Chapter "Introduction" as variant 1, and takes the following form

$$\mathrm{rot}(E)+\frac{\mu}{c}\frac{\partial H}{\partial t}=0, \tag{a}$$

$$\mathrm{rot}(H)-\frac{\varepsilon}{c}\frac{\partial E}{\partial t}=0, \tag{b}$$

$$\mathrm{div}(E)=0, \tag{c}$$

$$\mathrm{div}(H)=0. \tag{d}$$

In cylindrical coordinates system $r,\ \varphi,\ z$ these equations look as follows:

$$\frac{E_r}{r}+\frac{\partial E_r}{\partial r}+\frac{1}{r}\cdot\frac{\partial E_\varphi}{\partial \varphi}+\frac{\partial E_z}{\partial z}=0, \tag{1}$$

$$\frac{1}{r}\cdot\frac{\partial E_z}{\partial \varphi}-\frac{\partial E_\varphi}{\partial z}=M_r, \tag{2}$$

$$\frac{\partial E_r}{\partial z} - \frac{\partial E_z}{\partial r} = M_\varphi, \tag{3}$$

$$\frac{E_\varphi}{r} + \frac{\partial E_\varphi}{\partial r} - \frac{1}{r}\cdot\frac{\partial E_r}{\partial \varphi} = M_z, \tag{4}$$

$$\frac{H_r}{r} + \frac{\partial H_r}{\partial r} + \frac{1}{r}\cdot\frac{\partial H_\varphi}{\partial \varphi} + \frac{\partial H_z}{\partial z} = 0, \tag{5}$$

$$\frac{1}{r}\cdot\frac{\partial H_z}{\partial \varphi} - \frac{\partial H_\varphi}{\partial z} = J_r, \tag{6}$$

$$\frac{\partial H_r}{\partial z} - \frac{\partial H_z}{\partial r} = J_\varphi, \tag{7}$$

$$\frac{H_\varphi}{r} + \frac{\partial H_\varphi}{\partial r} - \frac{1}{r}\cdot\frac{\partial H_r}{\partial \varphi} = J_z, \tag{8}$$

$$J = \frac{\varepsilon}{c}\frac{\partial E}{\partial t}, \tag{9}$$

$$M = -\frac{\mu}{c}\frac{\partial H}{\partial t}. \tag{10}$$

For the sake of brevity further we shall use the following notations:

$$co = \cos(\alpha\varphi + \chi z + \omega t), \tag{11}$$

$$si = \sin(\alpha\varphi + \chi z + \omega t), \tag{12}$$

where α, χ, ω – are certain constants. Let us present the unknown functions in the following form:

$$J_r. = j_r(r)co, \tag{13}$$

$$J_\varphi. = j_\varphi(r)si, \tag{14}$$

$$J_z. = j_z(r)si, \tag{15}$$

$$H_r. = h_r(r)co, \tag{16}$$

$$H_\varphi. = h_\varphi(r)si, \tag{17}$$

$$H_z. = h_z(r)si, \tag{18}$$

$$E_r. = e_r(r)si, \tag{19}$$

$$E_\varphi. = e_\varphi(r)co, \tag{20}$$

$$E_z. = e_z(r)co, \tag{21}$$

$$M_r. = m_r(r)co, \tag{21a}$$

$$M_\varphi. = m_\varphi(r)si, \tag{22}$$

$$M_z. = m_z(r)si, \tag{23}$$

where $j(r),\ h(r),\ e(r),\ m(r)$ - certain function of the coordinate r.

By direct substitution we can verify that the functions (13-23) transform the equations system (1-10) with three arguments $r,\ \varphi,\ z$ into equations system with one argument r and unknown functions $j(r),\ h(r),\ e(r),\ m(r)$.

In Appendix 1 it is shown that for such a system there **exists** a solution of the following form (in Appendix 1 see (24, 27, 18, 31, 33, 34, 32) respectively):

$$h_z(r) = 0,\ e_z(r) = 0, \tag{24}$$

$$e_r(r) = e_\varphi(r) = \frac{A}{2} r^{(\alpha-1)}, \tag{25}$$

$$h_\varphi(r) = \sqrt{\frac{\varepsilon}{\mu}} e_r(r), \tag{26}$$

$$h_r(r) = -\sqrt{\frac{\varepsilon}{\mu}} e_\varphi(r), \tag{27}$$

$$\chi = \pm \omega \sqrt{\mu\varepsilon} / c, \tag{28}$$

where $A, \varepsilon, \mu, c, \alpha, \chi, \omega$ – constants.

Thus we have got a monochromatic solution of the equation system (1-10). A transition to polychromatic solution can be achieved with the aid of Fourier transform.

If it exists in cylindrical coordinate system, then it exists in any other coordinate system. It means that we have got a common solution of Maxwell equations in vacuum.

3. Intensities

We consider (2.25):

$$e_r = e_\varphi = 0.5A \cdot r^{\alpha-1}, \tag{1}$$

where A is some constant. From (1) it follows that

$$\left(e_r^2 + e_\varphi^2\right) = \frac{A^2}{4} \cdot r^{2(\alpha-1)}. \tag{2}$$

Fig. 1 shows, for example, the graphics functions (1, 2) for $A = -1,\ \alpha = 0.8$.

Fig. 2 shows the vectors of intensities originating from the point $A(r, \varphi)$. Let us remind that projections $h_\varphi(r) = \sqrt{\frac{\varepsilon}{\mu}} e_r(r)$ and

$h_r(r) = -\sqrt{\frac{\varepsilon}{\mu}} e_\varphi(r)$, - see (2.26, 2.27). The directions of vectors $e_r(r)$ and $e_\varphi(r)$ are chosen as: $e_r(r) > 0, e_\varphi(r) < 0$. Note that the **vectors** E, H **are always orthogonal**.

In order to demonstrate phase shift between the wave components let's consider the functions (2.11, 2.12) and (2.16-2.21). It can be seen, that **at each point with coordinates** r, φ, z **intensities** H, E **are shifted in phase by a quarter-period** - see Fig. 0.

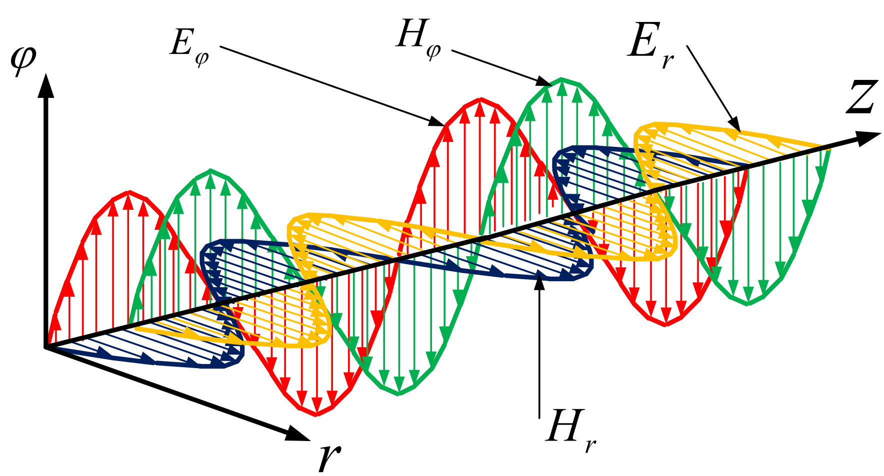


Fig. 0.

Density of energy

$$W = \frac{1}{8\pi}\left(\varepsilon H^2 + \mu E^2\right) \tag{2}$$

Taking into account (2.17, 2.18, 2.20, 2.21, 2.26, 2.27), we find:

$$W = \frac{1}{8\pi}\left(\varepsilon\left((e_r si)^2 + (e_\varphi co)^2\right) + \mu\left((h_r co)^2 + (h_\varphi si)^2\right)\right) =$$

$$= \frac{1}{8\pi}\left(\varepsilon\left((e_r si)^2 + (e_\varphi co)^2\right) + \mu\frac{\varepsilon}{\mu}\left((e_r co)^2 + (e_r si)^2\right)\right)$$

or

$$W(r) = \frac{\varepsilon}{4\pi}\left(e_r(r)\right)^2 \tag{3}$$

- see also Fig. 1. From (3, 3.2) we find:

$$W(r) = \frac{A^2\varepsilon}{16\pi} r^{2(\alpha - 1)} \tag{3a}$$

Thus, **electromagnetic wave energy density is constant in time and equal in all points of the cylinder of given radius**.

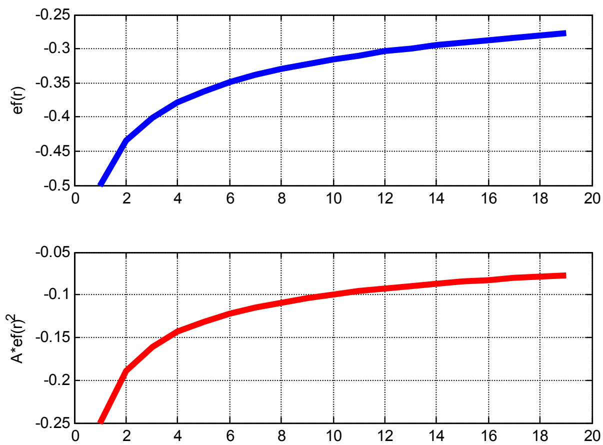


Fig.1. SecondSolMax.m

Let R be the radius of the circular wave front. Then the **energy of the electromagnetic wave, per unit wavelength**,

$$W = \frac{A\varepsilon}{4} \int_{r=0}^{R} \left(r^{2(\alpha-1)} \right) dr = \frac{A\varepsilon}{4} \frac{R^{(2\alpha-1)}}{(2\alpha-1)}. \tag{3в}$$

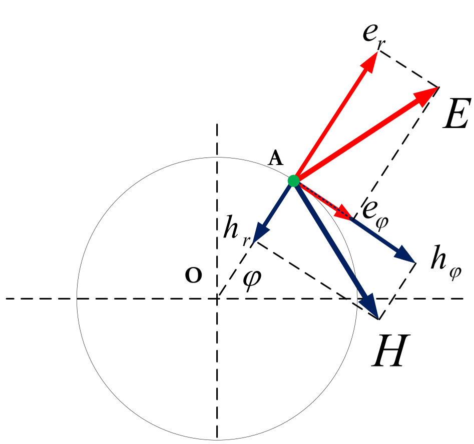


Fig. 2.

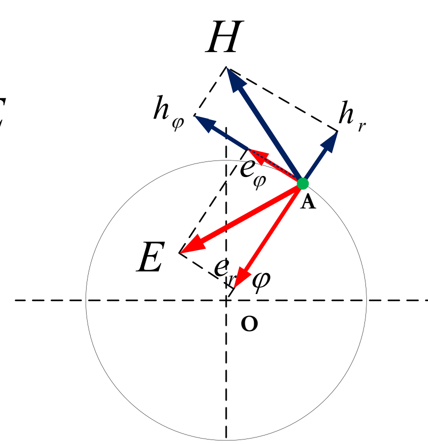


Fig. 3.

The solution exists also for changed signs of the functions (2.11, 2.12). This case is shown on Fig 3. Fig. 2 and Fig. 3 illustrate the fact that **there are two possible type of electromagnetic wave circular polarization.**

Let's consider the functions (2.11, 2.12) and (2.28). Then, we can find

$$co = \cos(\alpha\varphi + \sqrt{\varepsilon\mu}\frac{\omega}{c}z + \omega t), \qquad si = \sin(\alpha\varphi + \sqrt{\varepsilon\mu}\frac{\omega}{c}z + \omega t). \quad (4)$$

Let's consider a point moving along a cylinder of constant radius r, at which the value of intensity depends on time as follows:

$$H_{r.} = h_r(r)\cos(\omega t) \qquad (5)$$

Comparing this equation with (2.16) and taking (4) into account, we can notice that equation (5) is the same as (2.16), if at any moment of time

$$\alpha\varphi + \sqrt{\varepsilon\mu}\frac{\omega}{c}z = 0 \qquad (6)$$

or

$$\varphi = -\frac{\omega\sqrt{\varepsilon\mu}}{\alpha \cdot c}z. \qquad (7)$$

Thus, at the cylinder of constant radius r a path of this point exists, which is described by equations (4, 7), where all the intensities vary harmonically. On the other hand, this path is a helix. Thus, the line, along which the point moves in such a way, that its intensity $H_{r.}$ varies in a sinusoidal manner, is a helix. The same conclusion can be repeated for other intensities (2.17-2.21). Thus,

> **the path of the point, which moves along a cylinder of given radius in such a manner, that each intensity varies harmonically with time, is described by a helix.**

(A)

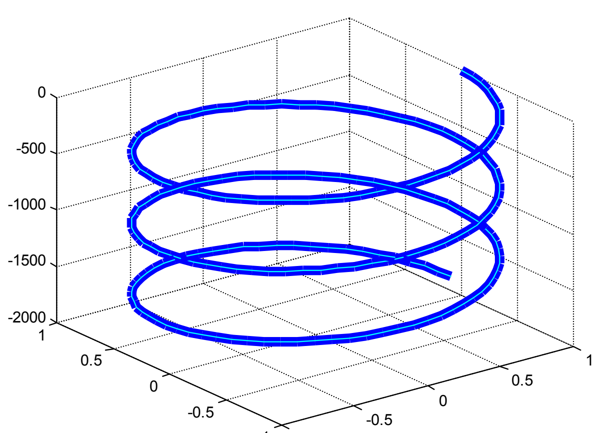


Fig. 4.

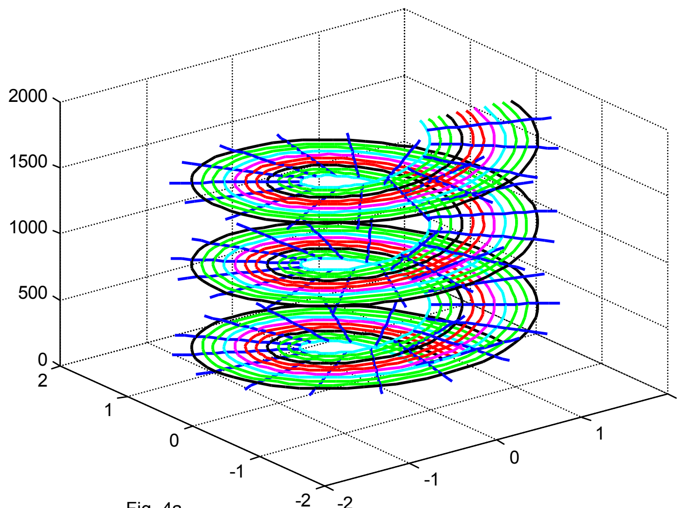


Fig. 4a. (TokPotok33.m)

For example, Fig. 4 shows a helix, for which $r = 1,\ c = 300000,\ \omega = 3000,\ \alpha = -3,\ \varphi = [0 \div 2\pi]$. Fig. 4a shows helices in the same conditions, but for different radii, where $r = [0.5,\ 0.6,\ ...1.0,\ 1.1]$. Straight lines indicate the geometric loci of points with equal φ.

The last means **(A)** that at point T, moving along this helix the vectors of intensities (2.16-2.21) can be written as follows:

$$H_r. = h_r(r)\cos(\omega t),\ H_\varphi. = h_\varphi(r)\sin(\omega t),\ H_z. = h_z(r)\sin(\omega t),$$

$$E_r. = e_r(r)\sin(\omega t),\ E_\varphi. = e_\varphi(r)\cos(\omega t),\ E_z. = e_z(r)\cos(\omega t).$$

It was shown above (see 2.24-2.27), that $h_z(r) = 0$, $e_z(r) = 0$, $e_r(r) = e_\varphi(r) = e_{r\varphi}(r)$, $h_\varphi(r) = \sqrt{\frac{\varepsilon}{\mu}} e_{r\varphi}(r)$, $h_r(r) = -\sqrt{\frac{\varepsilon}{\mu}} e_{r\varphi}(r)$. Therefore, at each point there are only vectors

$$H_r. = -\sqrt{\frac{\varepsilon}{\mu}} e_{r\varphi}(r) cos(\omega t),\ H_\varphi. = \sqrt{\frac{\varepsilon}{\mu}} e_{r\varphi}(r) sin(\omega t),$$

$$E_r. = e_{r\varphi}(r)\sin(\omega t), \quad E_\varphi. = e_{r\varphi}(r)\cos(\omega t).$$

In this case resultant vectors $\mathrm{H}_{r\varphi} = \mathrm{H}_r + \mathrm{H}_\varphi$ and $\mathrm{E}_{r\varphi} = \mathrm{E}_r + \mathrm{E}_\varphi$ lay in plane r, φ, and their modules are $|H_{r\varphi}| = \sqrt{\frac{\varepsilon}{\mu}} e_{r\varphi}(r)$ and $|E_{r\varphi}| = e_{r\varphi}(r)$.

Fig. 4b shows all these vectors. It can be seen, that when the point T moves along the helix, resultant vectors $H_{r\varphi}$ and $E_{r\varphi}$ rotate in plane r, φ. Their moduli are constant and equal one to the other. These vectors $H_{r\varphi}$ and $E_{r\varphi}$ are always orthogonal.

So, **harmonic wave is propagating along the helix**, and in this case at each point T, which moves along this helix, projections of vectors of magnetic and electric intensities:

- exist only in the plane which is perpendicular to the helix axis, i.e. there only two projections of these vectors exist,
- vary in a sinusoidal manner,
- are shifted in phase by a quarter-period.

Resultant vectors:

- rotate in these plane,
- have constant moduli,
- are orthogonal to each other.

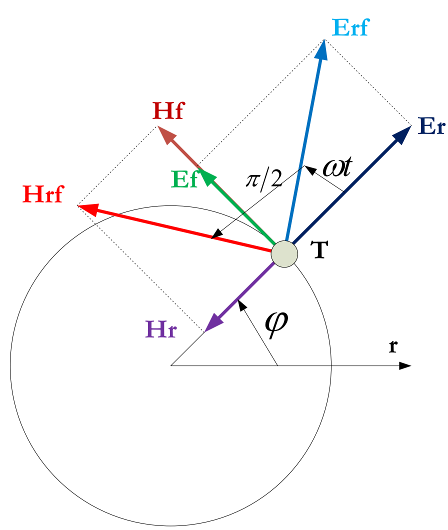


Fig. 4b.

4. Energy Flows

The density of electromagnetic flow is Pointing vector

$$S = \eta E \times H\ , \qquad (1)$$

where

$$\eta = c/4\pi\ . \qquad (2)$$

In the SI system $\eta = 1$ and the last formula (1) takes the form:

$$S = E \times H \,, \tag{3}$$

In cylindrical coordinates $r,\ \varphi,\ z$ the density flow of electromagnetic energy has three components $S_r,\ S_\varphi,\ S_z$, directed along вдоль the axis accordingly. They are determined by the formula

$$S = \begin{bmatrix} S_r \\ S_\varphi \\ S_z \end{bmatrix} = \eta(E \times H) = \eta \begin{bmatrix} E_\varphi H_z - E_z H_\varphi \\ E_z H_r - E_r H_z \\ E_r H_\varphi - E_\varphi H_r \end{bmatrix}. \tag{4}$$

Thus, the flux density of electromagnetic energy propagating along the radius, along the circumference, along the axis oz is determined, respectively, by the formulas of the following form:

$$\frac{e_r}{r} + \dot{e}_r - \frac{e_r}{r}\alpha - \chi e_z = 0 \,, \tag{1}$$

$$\frac{e_r}{r} + \dot{e}_r - \frac{e_r}{r}\alpha + \frac{\mu\omega}{c}h_z = 0 \,, \tag{4}$$

$$-\frac{e_z}{r}\alpha + e_r\chi - \frac{\mu\omega}{c}h_r = 0 \,, \tag{2}$$

$$e_r\chi - \dot{e}_z - \frac{\mu\omega}{c}h_r = 0 \,, \tag{3}$$

$$\frac{h_r}{r} + \dot{h}_r - \frac{h_r}{r}\alpha + \chi h_z = 0 \,, \tag{5}$$

$$-\frac{h_r}{r} - \dot{h}_r + \frac{h_r}{r}\alpha + \frac{\varepsilon\omega}{c}e_z = 0 \,, \tag{8}$$

$$\frac{h_z}{r}\alpha + h_r\chi - \frac{\varepsilon\omega}{c}e_r = 0 \,, \tag{6}$$

$$-h_r\chi - \dot{h}_z + \frac{\varepsilon\omega}{c}e_r = 0 \,. \tag{7}$$

The flow passing through a given section of a cylindrical wave at a given time,

$$\bar{S} = \begin{bmatrix} \bar{S}_r \\ \bar{S}_\varphi \\ \bar{S}_z \end{bmatrix} = \iint_{r,\varphi} \left(\begin{bmatrix} S_r \\ S_\varphi \\ S_z \end{bmatrix} dr \cdot d\varphi \right) \tag{6}$$

It is shown above that $h_z(r) = 0$, $e_z(r) = 0$. Therefore, $S_r = 0,\ S_\varphi = 0,$ i.e. the <u>energy flux propagates only along the axis oz</u> and is equal to

$$\bar{S} = \bar{S}_z = \eta \iint_{r,\varphi} \left(\left(e_r h_\varphi si^2 - e_\varphi h_r co^2 \right) dr \cdot d\varphi \right) \tag{7}$$

Lack of radial energy flux indicates that area of wave existence is <u>**NOT** growing</u>. Existence of laser provides evidence of this fact. The divergence of a laser beam is the subject of numerous studies [132], but these studies are related (as far as the author knows) to a multimode beam and it is tacitly implied that a small divergence is the result of mode interaction. However, it is difficult to imagine the mechanism of such interaction. The proposed solution shows that each mode does not expand and, therefore, the sum of the modes does not expand.

We'll find s_z. From (2.26, 2.27, 2.25), we obtain:

$$e_r h_\varphi = \sqrt{\frac{\varepsilon}{\mu}} e_r^2, \tag{8}$$

$$e_\varphi h_r = -\sqrt{\frac{\varepsilon}{\mu}} e_\varphi^2, \tag{9}$$

$$e_r = e_\varphi. \tag{10}$$

In this way,

$$S_z = \eta e_r^2 \sqrt{\frac{\varepsilon}{\mu}} = \frac{c}{4\pi} e_r^2 \sqrt{\frac{\varepsilon}{\mu}} \tag{11}$$

or, taking into account (2, 2.25),

$$S_z = \frac{A^2}{16\pi} \sqrt{\frac{\varepsilon}{\mu}} c r^{2(\alpha - 1)} \tag{12}$$

Consequently, the <u>**energy flux of the electromagnetic wave is constant in time.**</u>

It follows that the energy flux passing through the cross-sectional area is independent of t, φ, z. This value does not vary with time, and this <u>complies with the Law of energy conservation.</u>

5. Speed of energy movement

First of all, we find the propagation speed of a monochromatic electromagnetic wave. Obviously, this speed is equal to the derivative $\frac{dz}{dt}$ of the function $z(t)$ given implicitly in the form (2.16-2.21). Consider, for example, the function (2.16). We have:

$$\frac{d(H_r)}{dz} = h_r \frac{d}{dz}\left(\cos(\alpha\varphi + \chi z + \omega t)\right) = -si \cdot h_r \chi ,$$

$$\frac{d(H_r)}{dt} = h_r \frac{d}{dt}\left(\cos(\alpha\varphi + \chi z + \omega t)\right) = -si \cdot h_r \omega .$$

Then the propagation speed of a monochromatic electromagnetic wave

$$v_m = \frac{dz}{dt} = -\frac{d(H_r)}{dt} \Big/ \frac{d(H_r)}{dz} = -\frac{\omega}{\chi} .$$

Taking (2.28) into account, we obtain

$$v_m = \frac{dz}{dt} = -\frac{d(H_r)}{dt} \Big/ \frac{d(H_r)}{dz} = -\frac{\omega}{\chi} . \tag{1a}$$

Учитывая (2.28), получаем

$$v_m = -\omega \Big/ \left(\pm \omega\sqrt{\mu\varepsilon}/c\right) = \mp \frac{c}{\sqrt{\mu\varepsilon}} . \tag{1b}$$

Consequently, the propagation speed of a monochromatic electromagnetic wave is equal to the speed of light.

Umov's concept [81] is generally accepted, according to which the energy flux density s is a product of the energy density w and the speed of energy movement v_e:

$$s = w \cdot v_e . \tag{2}$$

Из (4.11, 3.3) получаем:

$$v_e = \frac{S_z}{W} = \left(\frac{c}{4\pi} e_r^2 \sqrt{\frac{\varepsilon}{\mu}}\right) \Big/ \left(\frac{\varepsilon}{4\pi} e_r^2\right) = \frac{c}{\sqrt{\varepsilon\mu}} \tag{3}$$

The speed of movement of electromagnetic energy v_e is not always equal to the speed of light. For example, in a standing wave $v_e = 0$, and generally in a wave that is the sum of two monochromatic electromagnetic waves of the same frequency propagating in opposite directions, the energy transfer is weakened and $v_e < c$.

Note that, based on the known solution and formula (18), we can not find the speed v_e. Indeed, in the SI system we find:

$$v_e = \frac{S}{W} = \mathrm{EH}\Bigg/\left(\frac{\varepsilon E^2}{2} + \frac{H^2}{2\mu}\right) = 2\mu\Bigg/\left(\varepsilon\mu\frac{E}{H} + \frac{H}{E}\right).$$

If $\frac{\varepsilon E^2}{2} = \frac{H^2}{2\mu}$, then $\frac{H}{E} = \sqrt{\mu\varepsilon}$. Then for a vacuum

$$v_e = 2\mu\Bigg/\left(\varepsilon\mu\frac{1}{\sqrt{\varepsilon\mu}} + \sqrt{\varepsilon\mu}\right) = \sqrt{\frac{\mu}{\varepsilon}} \approx 376,$$

which is **not true**. In general, the solution obtained here can not be found in vector form.

6. Momentum and moment of momentum

It is known that the flow of energy is associated with other characteristics of the wave dependency of the following form [21, 25, 63] (in the SI system):

$$|f| = W. \tag{1}$$

$$S = W \cdot c, \tag{2}$$

$$p = W/c,\ p = S/c^2, \tag{3}$$

$$f = p \cdot c,\ f = S/c, \tag{4}$$

$$m = p \cdot r, \tag{5}$$

where

W - energy density (scalar), kg m$^{-1}\cdot$s^{-2},
S - energy flux density (vector), kg$\cdot$s^{-3},
p - momentum density (vector), kg$\cdot$m$^{-2}\cdot$s^{-1},
f - momentum flux density (vector), kg$\cdot$m$^{-1}\cdot$s^{-2},
m - density momentum at this point about an axis spaced from the given point by a distance r (vector), kg$\cdot$s^{-2},
V - volume of the electromagnetic field (scalar), m^3.

It follows from the above that in the electromagnetic wave there exist energy flows, which directed along a radius, along a circle, along a axis. Consequently, in the electromagnetic wave there exists momentum, which directed along a radius, along a circle, along a axis. Also there exists momentum, which directed along a radius, along a circle, along a axis.

Let's consider the angular momentum about the axis z. According to (3) we can find this momentum as follows:

$$L_z = p_z r = s_z r/c^2. \tag{6}$$

This is orbital angular momentum, which can be detected in so called twisted light. Further on, we bring you a reduced quotation from [64]. *The fact that the light wave carries not only energy and momentum, but also angular momentum was known a century ago. At first, of course, angular momentum was associated only with polarization of light. … But time went by. Lasers were created, scientists had learnt to control the light emitted by lasers, and a theory describing its electromagnetic field was developing. And at a certain time it was realized that these two properties — direction of the light beam and its twisted characteristic — do not contradict to each other. … Certain methods of generation and detection of the twisted light were proposed. Three years after ... practical researchers confirmed that a specially prepared mode of the laser beam, which have also been known before, is actually occurred to be the twisted light. … After that, like an avalanche, researches rushed to investigate the phenomenon of the twisted light. … Along with fundamental researching, various practical applications of the twisted light started to be developed…"*

However, it should be noted that existence of the twisted light does **not** follow from the existing solution of Maxwell's equations. But it naturally follows from the proposed solution — see (6). In Fig. 7a (taken from [64]) *"the picture with the twisted light doesn't show the electric field, but the wavefront* (the middle picture shows non-twisted light, and the upper and lower ones — the light twisted to one or another side). *It is not flat; in this case the wave phase changes not only along the beam, but also with shifting in cross-sectional plane… As the energy flow of the light wave is usually directed perpendicular to the wavefront, it occurs, that in the twisted light energy and momentum not only fly ahead, but also spin around the axis of movement."* This particular fact was confirmed above — see Fig. 3.4a for comparison.

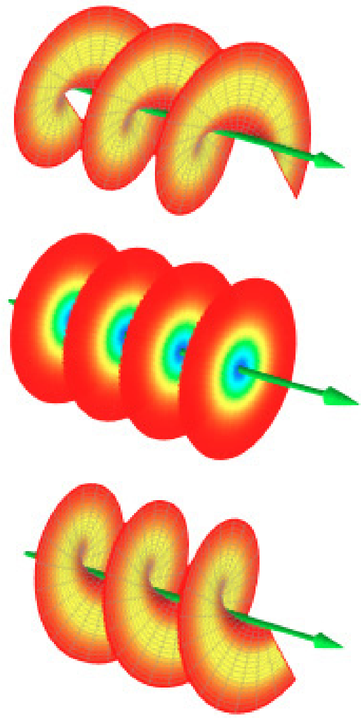


Fig. 7a.

7. Discussion

The Fig. 8 shows the intensities in Cartesian coordinates. The resulting solution describes a wave. The main distinctions from the known solution are as follows:

1. Instantaneous (and not average by certain period) energy flow **does not** change with time, which complies with the Law of energy conservation.
2. The energy flow has a positive value
3. The energy flow extends along the wave.
4. Magnetic and electrical intensities on one of the coordinate axes r, φ, z phase-shifted by a quarter of period.
5. The solution for magnetic and electrical intensities is a real value.
6. The solution exists at constant speed of wave propagation.
7. The existence region of the wave **does not** expand, as evidenced by the existence of laser.

8. The vectors of electrical and magnetic intensities are orthogonal.
9. There are two possible types of electromagnetic wave circular polarization.
10. The path of the point, which moves along a cylinder of given radius in such a manner, that each intensity value varies harmonically with time, is a helix.

Appendix 1

Let us consider the solution of equations (2.1-2.10) in the form of (2.13-2.23). Further the derivatives of r will be designated by strokes. We write the equations (2.1-2.10) in view of (2.11, 2.12) in the form

$$\frac{e_r(r)}{r} + e_r'(r) - \frac{e_\varphi(r)}{r}\alpha - \chi \cdot e_z(r) = 0\,, \tag{1}$$

$$-\frac{1}{r} \cdot e_z(r)\alpha + e_\varphi(r)\chi = m_r(r), \tag{2}$$

$$e_r(r)\chi - e_z'(r) = m_\varphi(r), \tag{3}$$

$$\frac{e_\varphi(r)}{r} + e_\varphi'(r) - \frac{e_r(r)}{r} \cdot \alpha = m_z(r), \tag{4}$$

$$\frac{h_r(r)}{r} + h_r'(r) + \frac{h_\varphi(r)}{r}\alpha + \chi \cdot h_z(r) = 0\,, \tag{5}$$

$$\frac{1}{r} \cdot h_z(r)\alpha - h_\varphi(r)\chi = j_r(r), \tag{6}$$

$$-h_r(r)\chi - h_z'(r) = j_\varphi(r), \tag{7}$$

$$\frac{h_\varphi(r)}{r} + h_\varphi'(r) + \frac{h_r(r)}{r} \cdot \alpha - j_z(r) = 0, \tag{8}$$

$$j_r = \frac{\varepsilon\omega}{c} e_r\,, \quad j_\varphi = -\frac{\varepsilon\omega}{c} e_\varphi\,, \quad j_z = -\frac{\varepsilon\omega}{c} e_z\,, \tag{9}$$

$$m_r = \frac{\mu\omega}{c} h_r\,, \quad m_\varphi = -\frac{\mu\omega}{c} h_\varphi\,, \quad m_z = -\frac{\mu\omega}{c} h_z\,, \tag{10}$$

We consider travelling wave in vacuum. In this case $e_z(r) = 0$, as there is no external energy source.

Along with that, according to (9) we obtain $j_z(r) = 0$. Then, the initial system (1, 5-8) will be as follows:

$$\frac{e_r(r)}{r} + e_r'(r) - \frac{e_\varphi(r)}{r}\alpha = 0\,, \tag{17}$$

$$\frac{h_r(r)}{r} + h'_r(r) + \frac{h_\varphi(r)}{r}\alpha + \chi \cdot h_z(r) = 0\,, \tag{18}$$

$$\frac{1}{r} \cdot h_z(r)\alpha - h_\varphi(r)\chi = j_r(r), \tag{19}$$

$$-h_r(r)\chi - h'_z(r) = j_\varphi(r), \tag{20}$$

$$\frac{h_\varphi(r)}{r} + h'_\varphi(r) + \frac{h_r(r)}{r} \cdot \alpha = 0, \tag{21}$$

Substituting (9) in (17), we get:

$$\frac{j_r(r)}{r} + j'_r(r) + \frac{j_\varphi(r)}{r}\alpha = 0\,, \tag{22}$$

Substituting (19, 20) in (22), we get:

$$\frac{1}{r^2} \cdot h_z(r)\alpha - \frac{1}{r} \cdot h_\varphi(r)\chi + \frac{1}{r} \cdot h'_z(r)\alpha - h'_\varphi(r)\chi + \left(-h_r(r)\chi - h'_z(r)\right)\frac{\alpha}{r} = 0$$

or

$$\frac{1}{r^2} \cdot h_z(r)\alpha - \frac{1}{r} \cdot h_\varphi(r)\chi - h'_\varphi(r)\chi - h_r(r)\frac{\chi\alpha}{r} = 0 \tag{23}$$

In this case, for calculation of three intensities we obtain three equations (19, 21, 23). Then, we exclude $h'_\varphi(r)$ from (21, 23):

$$\frac{1}{r^2} \cdot h_z(r)\alpha - \frac{1}{r} \cdot h_\varphi(r)\chi + \left(\frac{1}{r} \cdot h_\varphi(r) + h_r(r)\frac{\alpha}{r}\right)\chi - h_r(r)\frac{\chi\alpha}{r} = 0$$

or $\frac{-1}{r^2} \cdot h_z(r)\alpha = 0$ or $h_z(r) = 0$. Thus, in a $e_z(r) = 0$ condition $h_z(r) = 0$ to be respected. This implies

<u>Lemma 1.</u> The equation system (1, 5-9) for $e_z(r) \neq 0$ is compatible only if $h_z(r) = 0$.

If $e_z(r) = 0$ and $h_z(r) = 0$, then equations (1, 5-9) will be as follows – equations (1, 5, 8) can be simplified, and equations (6, 7) taking (9) into account, can be substituted for the following equations (1.3, 1.4):

$$\frac{e_r(r)}{r} + e'_r(r) - \frac{e_\varphi(r)}{r}\alpha = 0\,, \tag{1.1}$$

$$\frac{h_r(r)}{r} + h'_r(r) + \frac{h_\varphi(r)}{r}\alpha = 0\,, \tag{1.2}$$

$$\frac{c\chi}{\varepsilon\omega} h_\varphi(r) = e_r(r), \tag{1.3}$$

$$-\frac{c\chi}{\varepsilon\omega} h_r(r) = e_\varphi(r)\,, \tag{1.4}$$

$$\frac{h_\varphi(r)}{r}+h'_\varphi(r)+\frac{h_r(r)}{r}\cdot\alpha=0. \qquad (1.5)$$

In a similar way we can prove

Lemma 2. If $e_z(r)=0$, system of equations (1-5, 10) has a solution only in that case, when $h_z(r)=0$.

In this case, similar to equations (24, 28), we can obtain equations

$$\frac{e_r(r)}{r}+e'_r(r)-\frac{e_\varphi(r)}{r}\alpha=0, \qquad (2.1)$$

$$e_\varphi(r)\chi=-\frac{\mu\omega}{c}h_r(r), \qquad (2.2)$$

$$e_r(r)\chi=\frac{\mu\omega}{c}h_\varphi(r), \qquad (2.3)$$

$$\frac{e_\varphi(r)}{r}+e'_\varphi(r)-\frac{e_r(r)}{r}\cdot\alpha=0, \qquad (2.4)$$

$$\frac{h_r(r)}{r}+h'_r(r)+\frac{h_\varphi(r)}{r}\alpha=0. \qquad (2.5)$$

From Lemmas 1 and 2 follows

Lemma 3. System of equations (1-10) has a solution only if

$$h_z(r)=0,\ e_z(r)=0. \qquad (3.1)$$

Therefore, initial system of equations (1-10) can be written in the form of equations shown in lemmas 1 and 2. We combined them for readers' convenience.

$$\frac{e_r(r)}{r}+e'_r(r)-\frac{e_\varphi(r)}{r}\alpha=0, \qquad (24)$$

$$e_\varphi(r)\chi=-\frac{\mu\omega}{c}h_r(r), \qquad (25)$$

$$e_r(r)\chi=\frac{\mu\omega}{c}h_\varphi(r), \qquad (26)$$

$$\frac{e_\varphi(r)}{r}+e'_\varphi(r)-\frac{e_r(r)}{r}\cdot\alpha=0, \qquad (27)$$

$$\frac{h_r(r)}{r}+h'_r(r)+\frac{h_\varphi(r)}{r}\alpha=0, \qquad (28)$$

$$h_\varphi(r)\chi=\frac{\varepsilon\omega}{c}e_r(r), \qquad (29)$$

$$-h_r(r)\chi=\frac{\varepsilon\omega}{c}e_\varphi(r), \qquad (30)$$

$$\frac{h_\varphi(r)}{r} + h'_\varphi(r) + \frac{h_r(r)}{r} \cdot \alpha = 0. \tag{31}$$

We multiply equations (26, 29). Then we get:

$$-e_r(r)h_\varphi(r)\chi^2 = -\mu\varepsilon\left(\frac{\omega}{c}\right)^2 e_r(r)h_\varphi(r)$$

or

$$\chi = \pm\omega\sqrt{\mu\varepsilon}/c. \tag{32}$$

Substituting (32) in (26, 29), we get:

$$h_\varphi(r) = \sqrt{\frac{\varepsilon}{\mu}} e_r(r) \quad . \tag{33}$$

Thus, with condition (32) equation (26, 29) are equivalent to a single equation (33). A similar equation follows from (25, 30):

$$h_r(r) = -\sqrt{\frac{\varepsilon}{\mu}} e_\varphi(r), \tag{34}$$

So, the system of equations (24-31) is equivalent to the system of equations (24, 27, 28, 31-34).

Next is the solution of equations (24, 27).

We first consider the equation of the form

$$\frac{ay}{x} + y' = 0, \tag{34a}$$

The solution to this equation is:

$$y = x^{-a} \text{ or } y = 0. \tag{34b}$$

Add up equations (24) and (27):

$$(e_r + e_\varphi)' + \frac{(e_r + e_\varphi)}{r}(1-\alpha) = 0, \tag{35}$$

Subtract equation (27) from (24):

$$(e_r - e_\varphi)' + \frac{(e_r - e_\varphi)}{r}(1+\alpha) = 0, \tag{36}$$

In accordance with (34a, 34b) from (35) we find:

$$(e_r + e_\varphi) = Ar^{-(1-\alpha)} \text{ or } (e_r + e_\varphi) = 0. \tag{37}$$

In accordance with (34a, 34b) from (36) we find:

$$(e_r - e_\varphi) = Cr^{-(1+\alpha)} \text{ or } (e_r - e_\varphi) = 0. \tag{38}$$

Adding and subtracting equations (38) from (37), we find 4 solutions:

$$e_r = e_\varphi = \frac{A}{2} r^{-(1-\alpha)}, \tag{39}$$

$$e_r = -e_\varphi = \frac{C}{2} r^{-(1+\alpha)}, \tag{40}$$

$$\begin{cases} e_r(r) = \dfrac{1}{2}\left(Ar^{-(1-\alpha)} + Cr^{-(1+\alpha)}\right) \\ e_\varphi(r) = \dfrac{1}{2}\left(Ar^{-(1-\alpha)} - Cr^{-(1+\alpha)}\right) \end{cases} \tag{41}$$

$$e_r = e_\varphi = 0\,. \tag{42}$$

In the future, we consider the solution (39). Thus, the initial system of equations (1-10) has a solution of the following form:

$$h_z(r) = 0\,,\ e_z(r) = 0\,, \tag{3.1}$$

$$\chi = \omega\sqrt{\mu\varepsilon}/c\,, \tag{32}$$

$$e_r = e_\varphi = 0.5\mathrm{A}r^{(\alpha-1)}, \tag{39}$$

$$h_\varphi(r) = \sqrt{\frac{\varepsilon}{\mu}} e_r(r), \tag{33}$$

$$h_r(r) = -\sqrt{\frac{\varepsilon}{\mu}} e_\varphi(r)\,. \tag{34}$$

Chapter 1a Plane wave

Consider again the system of Maxwell equations for vacuum in cylindrical coordinates, which is given in Chapter 1 and has the following form (1.2.1-1.2.10). In a flat wave, by definition, the intensities does not depend on φ. In this case, equations (1-8) take the form :

$$\frac{E_r}{r}+\frac{\partial E_r}{\partial r}+\frac{\partial E_z}{\partial z}=0, \tag{1}$$

$$-\frac{\partial E_\varphi}{\partial z}=-\frac{\mu\,\partial}{c\partial r}H_r, \tag{2}$$

$$\frac{\partial E_r}{\partial z}-\frac{\partial E_z}{\partial r}=-\frac{\mu\,\partial}{c\partial r}H_\varphi, \tag{3}$$

$$\frac{E_\varphi}{r}+\frac{\partial E_\varphi}{\partial r}=-\frac{\mu\,\partial}{c\partial r}H_z, \tag{4}$$

$$\frac{H_r}{r}+\frac{\partial H_r}{\partial r}+\frac{\partial H_z}{\partial z}=0, \tag{5}$$

$$-\frac{\partial H_\varphi}{\partial z}=\frac{\varepsilon\,\partial}{c\partial r}E_r, \tag{6}$$

$$\frac{\partial H_r}{\partial z}-\frac{\partial H_z}{\partial r}=\frac{\varepsilon\,\partial}{c\partial r}E_\varphi, \tag{7}$$

$$\frac{H_\varphi}{r}+\frac{\partial H_\varphi}{\partial r}=\frac{\varepsilon\,\partial}{c\partial r}E_z. \tag{8}$$

The solution of this system of equations for a monochromatic wave, as before, has the form (1.2.11, 1.2.12, 1.2.16-1.2.21, 1.2.24-1.2.28). But in this case

$$\propto=0. \tag{9}$$

In this case, instead of (1.2.11, 1.2.12, 1.2.25), you should write accordingly:

$$co=cos(\chi z+\omega t), \tag{11}$$

$$si=sin(\chi z+\omega t), \tag{12}$$

$$e_r(r)=e_\varphi(r)=\frac{A}{2r}. \tag{25}$$

Thus, the front of a plane wave is a flat circle, the intensities on which hyperbolically decrease depending on radius. Such a **plane wave can exist physically** (which contradicts the existing ideas)

Chapter 2. Solution of Maxwell's Equations for Electromagnetic Wave in the Dielectric Circuit of Alternating Current

Contents

1. Introduction

An electromagnetic field in vacuum is considered in chapter 1. The evident solution obtained there is extended to a non-conducting dielectric medium with certain dielectric and magnetic permeability ε and μ, respectively. Therefore, the electromagnetic field does also exist in a capacitor as well. However, a considerable difference of the capacitor is that its field has a non-zero electrical intensity along on of the coordinates induced by an external source. The electromagnetic field in vacuum was examined on the basis of an assumption that an external source was absent.

The same can be said about an alternating current dielectric circuit. The system of Maxwell equations is applied to such a circuit. It is shown that an electromagnetic wave is also formed in this circuit. An important difference between this wave and the wave in vacuum is that the former has a longitudinal electrical intensity induced by an external power source.

Below are considered the Maxwell equations of the following form written in the GHS system (as in chapter 1, but with ε and μ which are not equal to 1 and taking into account displacement currents):

$$\mathrm{rot}(E)+\frac{\mu}{c}\frac{\partial H}{\partial t}=0, \tag{1}$$

$$rot(H)-\frac{\varepsilon\partial E}{c\partial t}-\frac{4\pi}{c}J=0, \tag{2}$$

$$\mathrm{div}(E)=0, \tag{3}$$

$$\mathrm{div}(H)=0, \tag{4}$$

where H, E are the magnetic intensity and the electrical intensity, respectively, J - displacement currents.

2. Maxwell Equations Solution

Let us consider solution to the Maxwell equations (1.1-1.4) [37]. In the cylindrical coordinate system r, φ, z, these equations take the form:

$$\frac{E_r}{r}+\frac{\partial E_r}{\partial r}+\frac{1}{r}\cdot\frac{\partial E_\varphi}{\partial \varphi}+\frac{\partial E_z}{\partial z}=0, \tag{1}$$

$$\frac{1}{r}\cdot\frac{\partial E_z}{\partial \varphi}-\frac{\partial E_\varphi}{\partial z}=v\frac{dH_r}{dt}, \tag{2}$$

$$\frac{\partial E_r}{\partial z}-\frac{\partial E_z}{\partial r}=v\frac{dH_\varphi}{dt}, \tag{3}$$

$$\frac{E_\varphi}{r}+\frac{\partial E_\varphi}{\partial r}-\frac{1}{r}\cdot\frac{\partial E_r}{\partial \varphi}=v\frac{dH_z}{dt}, \tag{4}$$

$$\frac{H_r}{r}+\frac{\partial H_r}{\partial r}+\frac{1}{r}\cdot\frac{\partial H_\varphi}{\partial \varphi}+\frac{\partial H_z}{\partial z}=0, \tag{5}$$

$$\frac{1}{r}\cdot\frac{\partial H_z}{\partial \varphi}-\frac{\partial H_\varphi}{\partial z}=q\frac{dE_r}{dt}+g\cdot J_r \tag{6}$$

$$\frac{\partial H_r}{\partial z}-\frac{\partial H_z}{\partial r}=q\frac{dE_\varphi}{dt},+g\cdot J_\varphi \tag{7}$$

$$\frac{H_\varphi}{r}+\frac{\partial H_\varphi}{\partial r}-\frac{1}{r}\cdot\frac{\partial H_r}{\partial \varphi}=q\frac{dE_z}{dt}+g\cdot J_z \tag{8}$$

where

$$v=-\mu/c, \tag{9}$$

$$q=\varepsilon/c, \tag{10}$$

$$g=4\pi/c, \tag{10a}$$

E_r, E_φ, E_z are the electrical intensity components,

H_r, H_φ, H_z are the magnetic intensity components.

A solution should be found for non-zero intensity component H_z.

To write the equations in a concise form, the following designations are used below:

$$co = \cos(\alpha\varphi + \chi z + \omega t), \tag{11}$$

$$si = \sin(\alpha\varphi + \chi z + \omega t), \tag{12}$$

where α, χ, ω are constants. Let us write the unknown functions in the following form:

$$H_r. = h_r(r)co, \tag{13}$$

$$H_\varphi. = h_\varphi(r)si, \tag{14}$$

$$H_z. = h_z(r)si, \tag{15}$$

$$E_r. = e_r(r)si, \tag{16}$$

$$E_\varphi. = e_\varphi(r)co, \tag{17}$$

$$E_z. = e_z(r)co, \tag{18}$$

$$J_r = j_r co, \tag{18a}$$

$$J_\varphi = j_\varphi si, \tag{18b}$$

$$J_z = j_z si. \tag{18c}$$

where $h(r)$, $e(r)$, $j(r)$ are function of the coordinate r.

Direct substitution enables us to ascertain that functions (13-18) convert the system of equations (1-8) with four arguments r, φ, z, t in a system of equations with one argument r and unknown functions $h(r)$, $e(r)$, $j(r)$. This system of equations has the following form:

$$\frac{e_r(r)}{r} + e_r'(r) - \frac{e_\varphi(r)}{r}\alpha - \chi \cdot e_z(r) = 0, \tag{21}$$

$$-\frac{1}{r} \cdot e_z(r)\alpha + e_\varphi(r)\chi - \frac{\mu\omega}{c} h_r = 0, \tag{22}$$

$$e_r(r)\chi - e_z'(r) + \frac{\mu\omega}{c} h_\varphi = 0, \tag{23}$$

$$\frac{e_\varphi(r)}{r} + e_\varphi'(r) - \frac{e_r(r)}{r} \cdot \alpha + \frac{\mu\omega}{c} h_z = 0, \tag{24}$$

$$\frac{h_r(r)}{r} + h_r'(r) + \frac{h_\varphi(r)}{r}\alpha + \chi \cdot h_z(r) = 0, \tag{25}$$

$$\frac{1}{r}h_z(r) \propto - h_\varphi(r) - \frac{\varepsilon\omega}{c}e_r(r) - \frac{4\pi}{c}j_r(r) = 0, \tag{26}$$

$$-h_r(r)\chi - h_z'(r) + \frac{\varepsilon\omega}{c}e_\varphi(r) - \frac{4\pi}{c}j_\varphi(r) = 0, \tag{27}$$

$$\frac{h_\varphi(r)}{r} + h_\varphi'(r) + \frac{-h_r(r)}{r}\propto + \frac{\varepsilon\omega}{c}e_r(r) - \frac{4\pi}{c}j_z(r) = 0. \tag{28}$$

Also, as in Chapter 1, the energy flux densities by coordinates are determined by the formula

$$S = \begin{bmatrix} S_r \\ S_\varphi \\ S_z \end{bmatrix} = \eta(E \times H) = \eta \begin{bmatrix} E_\varphi H_z - E_z H_\varphi \\ E_z H_r - E_r H_z \\ E_r H_\varphi - E_\varphi H_r \end{bmatrix}. \tag{29}$$

or, taking into account previous formulas,

$$S_r = \eta\left(e_\varphi h_z - e_z h_\varphi\right) co \cdot si \tag{30}$$

$$S_\varphi = \eta\left(e_z h_r co^2 - e_r h_z si^2\right) \tag{31}$$

$$S_z = \eta\left(e_r h_\varphi si^2 - e_\varphi h_r co^2\right) \tag{32}$$

It will be shown below that <u>these energy flux densities satisfy the energy conservation law</u>, if

$$h_r = k e_r, \tag{33}$$

$$h_\varphi = -k e_\varphi. \tag{34}$$

$$h_z = -k e_z. \tag{35}$$

It follows from (30, 34, 35) that

$$S_r = \eta\left(-e_\varphi k e_z + k e_z e_\varphi\right) co \cdot si = 0, \tag{36}$$

i.e. there is no radial energy flow and there is a standing wave on the radiuses.

It follows from (31, 33, 15) that

$$S_\varphi = \eta k e_r e_z (co^2 + si^2) = \eta k e_r e_z, \tag{37}$$

i.e. the energy flux density along the circumference at a given radius does not depend on time and other coordinates.

It follows from (32, 33, 34) that

$$S_z = \eta k e_r e_\varphi (si^2 + co^2) = \eta k e_r e_\varphi, \tag{38}$$

i.e. the energy flux density along the vertical for a given radius is independent of time and other coordinates. <u>These statements were the purpose of the assumptions </u>(33-34).

We replace the variables with respect to (33-35) in equations (21-28) and rewrite them without changing the numbering:

$$\frac{e_r}{r} + \dot{e}_r - \frac{e_\varphi}{r}\alpha - \chi e_z = 0, \quad (41)$$

$$-\frac{e_z}{r}\alpha + e_\varphi \chi - \frac{\mu\omega}{c} k e_r = 0, \quad (42)$$

$$-\dot{e}_z + e_r \chi - k\frac{\mu\omega}{c} e_\varphi = 0, \quad (43)$$

$$\frac{e_\varphi}{r} + \dot{e}_\varphi - \frac{e_r}{r}\alpha - k\frac{\mu\omega}{c} e_z = 0, \quad (44)$$

$$k\frac{e_r}{r} + k\dot{e}_r - k\frac{e_\varphi}{r}\alpha - k\chi e_z = 0, \quad (45)$$

$$-k\frac{e_z}{r}\alpha + k e_\varphi \chi - \frac{\varepsilon\omega}{c} e_r - \frac{4\pi}{c} j_r = 0, \quad (46)$$

$$k\dot{e}_z - k e_r \chi + \frac{\varepsilon\omega}{c} e_\varphi - \frac{4\pi}{c} j_\varphi = 0. \quad (47)$$

$$-k\frac{e_\varphi}{r} - k\dot{e}_\varphi + k\frac{e_r}{r}\alpha + \frac{\varepsilon\omega}{c} e_z - \frac{4\pi}{c} j_z = 0, \quad (48)$$

It can be seen that equations (41) and (45) coincide and therefore equation (45) can be removed from the system of equations. The remaining 7 equations (41-44, 46-48) are a system of differential equations with 7 unknowns

$e_r, e_\varphi, e_z, j_r, j_\varphi, j_z, k$.

In Appendix 1 we consider the solution of this system of equations. It shows that all the functions of the stresses and displacement currents can be found from the Maxwell equations system if we determine the parameters $\propto, \chi, \omega$ and the amplitude of the time function

$$E_z = e_z(r)\cos(\propto\varphi + \chi z + \omega t) \quad (49)$$

at the point $r = 0$; i.e. if we determine the quantities $e_z(0) = A, \propto, \chi, \omega$.

The function (29) at the point $(r = 0, \varphi = 0, z = 0)$ has the form

$$E_{zo} = A\cos(\omega t). \quad (50)$$

Thus, the function (50) determines a <u>monochromatic solution</u> of the system of Maxwell equations.

We shall also find the values of the other intensities at the point. $(r = 0, \varphi = 0, z = 0)$. It follows from (1, p1.40) that

$$E_{\varphi o} = \frac{\alpha}{m} A\cos(\omega t). \tag{51}$$

It follows from (1, p1.41) that

$$E_{ro} = \frac{1}{m} A\sin(\omega t). \tag{52}$$

It follows from (15, 35) that

$$H_{zo} = -kA\sin(\omega t). \tag{53}$$

It follows from (2, 14, 34) that

$$H_{\varphi o} = -kA\sin(\omega t). \tag{54}$$

It follows from (3, 13, 33) that

$$H_{ro} = kA\cos(\omega t). \tag{55}$$

2a UHP-theorem

> Regardless of the wire parameters, there is an unambiguous relationship between the electrical voltage U on the wire, the longitudinal magnetic intensity H_z in the wire, and the active power P transmitted through the wire.

It was shown above that all functions of the intensities and currents are determined by the value of the parameters: $A, \propto, \chi, \omega$. The value ω is determined from the outside, and the parameter χ depends on ω:

$$\chi = \frac{\omega}{c}\sqrt{\mu\varepsilon}. \tag{1}$$

Consequently, all functions of intensities and currents are determined by the value of two parameters: $A, \propto$. The value of these two parameters also determines the energy fluxes (2.36–2.37), which depend on the intensities. Therefore, if we set the value of the two quantities from the set

$$E_r, E_\varphi, E_z, H_r, H_\varphi, H_z, S_r, S_\varphi, S_z, \tag{2}$$

then from the given equations, one can find the value of the parameters A, ∝, and then find the value of the other quantities from the set (2).

It is important to emphasize that in a **dielectric circuit there is a longitudinal magnetic intensity**. By virtue of the limited length of this chain, <u>the lines of longitudinal magnetic intensities turn out to be **unclosed**</u>. This is contrary to existing ideas, but is confirmed by experiments - see chapter 4c. Note that non-closed lines do end at not zero intensities values.

Let, for example, in the set (2) the quantities E_z, S_z is defined. This determines the voltage on the wire with a length L

$$U = E_z L \tag{3}$$

and active power transmitted over the wire,

$$P = S_z. \tag{4}$$

Then, with known U, P one can find E_z, S_z, from the given equations one can find the value of the parameters $A, \propto$, and then find the value of the other quantities from the set (2).

Similarly, with the known longitudinal magnetic intensity in the wire H_z and active power (4), it is possible to find the value of the other quantities from the set (2).

From this, in particular, it follows that regardless of the wire parameters, there is an unambiguous dependence

$$U = f(H, P). \tag{5}$$

In chapter 4c, an experiment will be described that proves the validity of this theorem.

3. Invertibility of the solution

By virtue of the symmetry of the solution obtained, there is another solution, where instead of the longitudinal <u>electric</u> intensity function (2.49), the function of the longitudinal <u>magnetic</u> intensity is defined as the value of the amplitude of the time function

$$H_z = h_z(r) sin(\propto \varphi + \chi z + \omega t) \tag{1}$$

at the point $r = 0$; i.e. if we determine the quantities $h_z(0) = A, \propto, \chi, \omega$.

Find the voltage on the wire with a length L from (2.18):

$$U = \int_0^L E_z dz = e_z \int_0^L co \cdot dz \tag{2}$$

Find the magnetomotive force on the wire with a length L from (2.15):

$$F = \int_0^L H_z dz = h_z \int_0^L si \cdot dz = -ke_z \int_0^L si \cdot dz, \tag{3}$$

With a large L we have:

$$\int_0^L co \cdot dz = \int_0^L si \cdot dz = Q \quad . \tag{4}$$

From (2-4) we find:

$$U = e_z Q \quad , \tag{5}$$

$$F = -ke_z Q = -kU \quad . \tag{6}$$

Formula (6) shows the relationship between the external voltage and the external magnetomotive force, which create equal currents in the wire.

4. Polychromatic solution of the system of equations

Obviously, if the function (2.50) determines a monochromatic solution of the system of Maxwell equations, then the function

$$E_{zo} = \sum_b \left(A_b cos\left(\omega_b t\right)\right). \tag{1}$$

determines a polychromatic solution of the system of Maxwell's equations. We denote this function by

$$f(t) = \sum_b \left(A_b cos\left(\omega_b t\right)\right). \tag{2}$$

A reversible polychromatic solution defines a function

$$H_{zo} = \sum_b \left(A_b sin\left(\omega_b t\right)\right). \tag{3}$$

We denote this function by

$$y(t) = \sum_b \left(A_b sin\left(\omega_b t\right)\right) \quad , \tag{4}$$

The coefficients of the functions (2) and (3) coincide.

By analogy with (2.51-2.55), we find the values of the other intensities at the point $(r = 0, \varphi = 0, z = 0)$:

$$E_{\varphi o} = \frac{\alpha}{m} Acos(\omega t), \tag{5}$$

$$E_{ro} = \frac{1}{m} Asin(\omega t), \tag{6}$$

$$H_{zo} = -kAsin(\omega t), \tag{7}$$

$$H_{\varphi o} = -kAsin(\omega t), \tag{8}$$

$$H_{ro} = kAcos(\omega t). \tag{9}$$

Appendix 1.

The solution of the equations (2.41-2.44, 2.46-2.48) is considered:

$$\frac{e_r}{r}+\dot{e}_r-\frac{e_\varphi}{r}\alpha-\chi e_z=0, \tag{21}$$

$$-\frac{e_z}{r}\alpha+e_\varphi\chi-k\frac{\mu\omega}{c}e_r=0, \tag{22}$$

$$-\dot{e}_z+e_r\chi-k\frac{\mu\omega}{c}e_\varphi=0, \tag{23}$$

$$\frac{e_\varphi}{r}+\dot{e}_\varphi-\frac{e_r}{r}\alpha-k\frac{\mu\omega}{c}e_z=0, \tag{24}$$

$$-k\frac{e_z}{r}\alpha+ke_\varphi\chi-\frac{\varepsilon\omega}{c}e_r-\frac{4\pi}{c}j_r=0, \tag{26}$$

$$k\dot{e}_z-ke_r\chi+\frac{\varepsilon\omega}{c}e_\varphi-\frac{4\pi}{c}j_\varphi=0, \tag{27}$$

$$-k\frac{e_\varphi}{r}-k\dot{e}_\varphi+k\frac{e_r}{r}\alpha+\frac{\varepsilon\omega}{c}e_z-\frac{4\pi}{c}j_z=0, \tag{28}$$

In Appendix 2 we give a solution of the system of equations (21-23). It has the following form:

$$\ddot{e}_z+\frac{\dot{e}_z}{r}-e_z\left(\chi^2-(k\mu\omega/c)^2\right)-\frac{e_z}{r^2}\alpha^2=0. \tag{29}$$

In Appendix 3 we give a solution of the system of equations (22-24). It has the following form:

В приложении 3 приведено решение системы уравнений (22-24). Оно имеет следующий вид:

$$\ddot{e}_z+\frac{\dot{e}_z}{r}\left(1+\alpha\left(2\frac{k\mu\omega}{c\chi}-\frac{c\chi}{k\mu\omega}\right)\right)-$$
$$e_z\left(\chi^2-(k\mu\omega/c)^2\right)-\frac{e_z}{r^2}\alpha^2=0. \tag{30}$$

Both these solutions (29) and (30) must coincide because they must be a general solution for the system of equations (21-24). Consequently, must be fulfilled the condition

$$\left(1+\alpha\left(2\frac{k\mu\omega}{c\chi}-\frac{c\chi}{k\mu\omega}\right)\right)=1 \tag{31}$$

or

$$2\frac{k\mu\omega}{c\chi}-\frac{c\chi}{k\mu\omega}=0,$$

where do we find

$$k=\frac{c\chi}{\mu\omega}\sqrt{\frac{1}{2}}. \tag{32}$$

If

$$\chi=\pm\frac{\omega}{c}\sqrt{\mu\varepsilon}, \tag{32a}$$

Then

$$k=\pm\frac{\sqrt{\mu\varepsilon}}{\mu}\sqrt{\frac{1}{2}}=\pm\sqrt{\frac{\varepsilon}{2\mu}}. \tag{33}$$

So, the function e_z is defined by the equations (29, 32):

$$\ddot{e}_z+\frac{\dot{e}_z}{r}-e_z\left(\chi^2-\left(\sqrt{\frac{1}{2}}\frac{c\chi}{\mu\omega}\mu\omega/c\right)^2\right)-\frac{e_z}{r^2}\alpha^2=0$$

or

$$\ddot{e}_z+\frac{\dot{e}_z}{r}-e_z\left(\frac{\chi^2}{2}+\frac{\alpha^2}{r^2}\right)=0. \tag{34}$$

This equation is a modified Bessel equation and its solution e_z is considered in Appendix 4. The function $\dot{e}_z$ is also considered ibid.

For known $e_z, \dot{e}_z, k$ one can find e_r, e_φ by (22, 23). Adding (22, 23), we find:

$$-\frac{e_z}{r}\alpha-\dot{e}_z+\left(e_\varphi+e_r\right)\left(\chi-\frac{k\mu\omega}{c}\right)=0, \tag{35}$$

Subtracting (23) from (22), we find:

$$-\frac{e_z}{r}\alpha+\dot{e}_z+\left(e_\varphi-e_r\right)\left(\chi+\frac{k\mu\omega}{c}\right)=0, \tag{36}$$

Substituting (32) into (35, 36), we obtain:

$$\left(-\frac{e_z}{r}\alpha-\dot{e}_z\right)\Big/m_1+\left(e_\varphi+e_r\right)=0, \tag{37}$$

$$\left(-\frac{e_z}{r}\alpha+\dot{e}_z\right)\Big/m_2+\left(e_\varphi-e_r\right)=0 \quad , \tag{38}$$

where

$$m_1=\chi\left(1-\sqrt{\frac{1}{2}}\right), m_2=\chi\left(1+\sqrt{\frac{1}{2}}\right). \tag{39}$$

From (37, 38) we find:

$$e_\varphi=\frac{1}{2}\left(\frac{e_z}{r}\alpha\left(\frac{1}{m_1}+\frac{1}{m_2}\right)+\dot{e}_z\left(\frac{1}{m_1}-\frac{1}{m_2}\right)\right), \tag{40}$$

$$e_r=\frac{1}{2}\left(\frac{e_z}{r}\alpha\left(\frac{1}{m_1}-\frac{1}{m_2}\right)+\dot{e}_z\left(\frac{1}{m_1}+\frac{1}{m_2}\right)\right). \tag{41}$$

Comparing (26-27) with (22-24), we get:

$$j_r=\frac{c}{4\pi}\left(k^2\frac{\mu\omega}{c}e_r-\frac{\varepsilon\omega}{c}e_r\right), \tag{42}$$

$$j_\varphi=\frac{c}{4\pi}\left(-k^2\frac{\mu\omega}{c}e_\varphi+\frac{\varepsilon\omega}{c}e_\varphi\right), \tag{43}$$

$$j_z=\frac{c}{4\pi}\left(-k^2\frac{\mu\omega}{c}e_z+\frac{\varepsilon\omega}{c}e_z\right). \tag{44}$$

Considering (33), from (42-43) we find:

$$j_r=\frac{c}{4\pi}\left(\frac{\varepsilon}{2\mu}\frac{\mu\omega}{c}e_r-\frac{\varepsilon\omega}{c}e_r\right)=-\frac{\varepsilon\omega}{8\pi}e_r, \tag{45}$$

$$j_\varphi=\frac{c}{4\pi}\left(-\frac{\varepsilon}{2\mu}\frac{\mu\omega}{c}e_\varphi+\frac{\varepsilon\omega}{c}e_\varphi\right)=\frac{\varepsilon\omega}{8\pi}e_\varphi, \tag{46}$$

$$j_z=\frac{c}{4\pi}\left(-\frac{\varepsilon}{2\mu}\frac{\mu\omega}{c}e_z+\frac{\varepsilon\omega}{c}e_z\right)=\frac{\varepsilon\omega}{8\pi}e_z \tag{47}$$

With known e_r, e_φ, e_z, k displacement currents can be found from (26-28):

$$j_r=\frac{c}{4\pi}\left(-k\frac{e_z}{r}\alpha+ke_\varphi\chi-\frac{\varepsilon\omega}{c}e_r\right), \tag{42}$$

$$j_\varphi=\frac{c}{4\pi}\left(k\dot{e}_z-ke_r\chi+\frac{\varepsilon\omega}{c}e_\varphi\right), \tag{43}$$

$$j_z=\frac{c}{4\pi}\left(-k\frac{e_\varphi}{r}-k\dot{e}_\varphi+k\frac{e_r}{r}\alpha+\frac{\varepsilon\omega}{c}e_z\right). \tag{44}$$

Substituting here (40-43), we obtain:

$$j_r = \frac{c}{4\pi}\left(\frac{e_z}{r}k\alpha\left(\frac{\chi}{m}-1\right)-\frac{\varepsilon\omega\cdot}{cm}e_z\right), \qquad (45)$$

To compare the calculations, we find dependence (47) differently. Denote for the electric circuit the length d, the cross-sectional area b, the capacitance C. In the GHS system we have:

$$C = \frac{\varepsilon b}{4\pi d}. \qquad (48)$$

uppose that the current density does not depend on the radius, i.e. $j_z = const$. Next, we have:

$$J_z = j_z b,\ E_z = e_z d,\ E_z = \frac{J_z}{\omega C} \qquad (49)$$

From (48, 49) we have:

$$j_z = \frac{J_z}{b} = \frac{E_z\omega C}{b} = \frac{e_z d\omega C}{b} = \frac{\varepsilon\omega}{4\pi}e_z. \qquad (50)$$

Expressions (47, 50) coincide up to a constant coefficient, as required.

Consider the algorithm for calculating the dielectric circuit of alternating current using the obtained relations:

1. R, α, ω, A are known where A is intensity amplitude e_z.
2. We calculate χ by (app.1.32a):

$$\chi = \frac{\omega}{c}\sqrt{\mu\varepsilon}. \qquad (1)$$

3. We calculate e_z in accordance with Appendix 4
4. We calculate k by (app.1.33):

$$k = \sqrt{\frac{\varepsilon}{2\mu}}. \qquad (2)$$

5. We calculate $m_1,\ m_2$ by (app.1.39).
6. We calculate e_φ, e_r by (app.1.40, app.1.41).
7. We calculate h_r, h_φ, h_z by (2.33-2.35) respectively:

$$h_r = ke_r, \qquad (6)$$

$$h_\varphi = -ke_\varphi. \qquad (7)$$

$$h_z = -ke_z. \qquad (8)$$

8. We calculate j_z по (app.1.50):

$$j_z = \frac{\varepsilon\omega}{4\pi} e_z. \tag{9}$$

9. We calculate the density of the longitudinal energy flux S_z according to (2.38):

$$S_z = \eta k e_r e_\varphi \tag{10}$$

10. We calculate the longitudinal energy flux S_z with (4, 5)

$$\bar{S}_z = \iint_{\varphi,r} (S_z \cdot r \cdot d\varphi \cdot dr) = 2\pi \int_0^R (S_z \cdot r \cdot dr). \tag{13}$$

11. With a known power $P = \bar{S}_z$, transmitted through the dielectric circuit, and the voltage across it (ie, the coefficient A), it is possible to find the coefficient $\propto$.

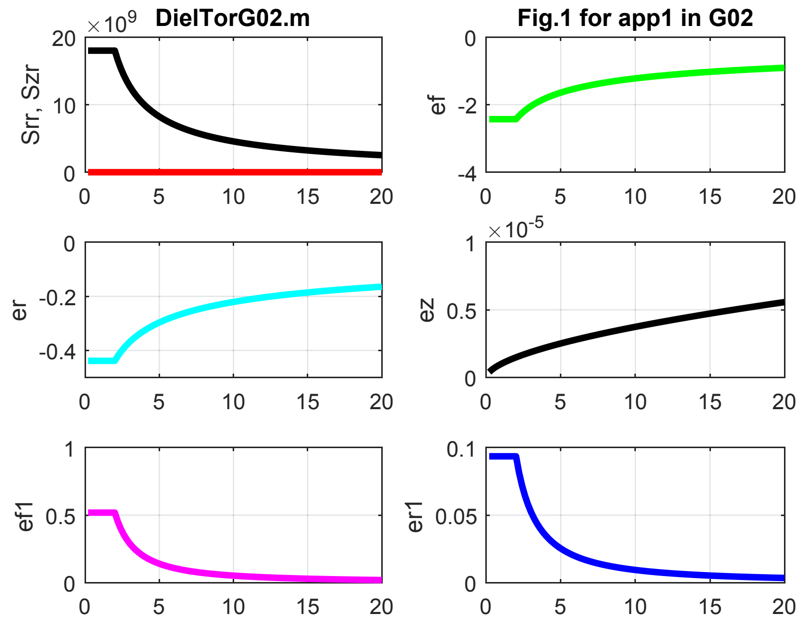
Example 1

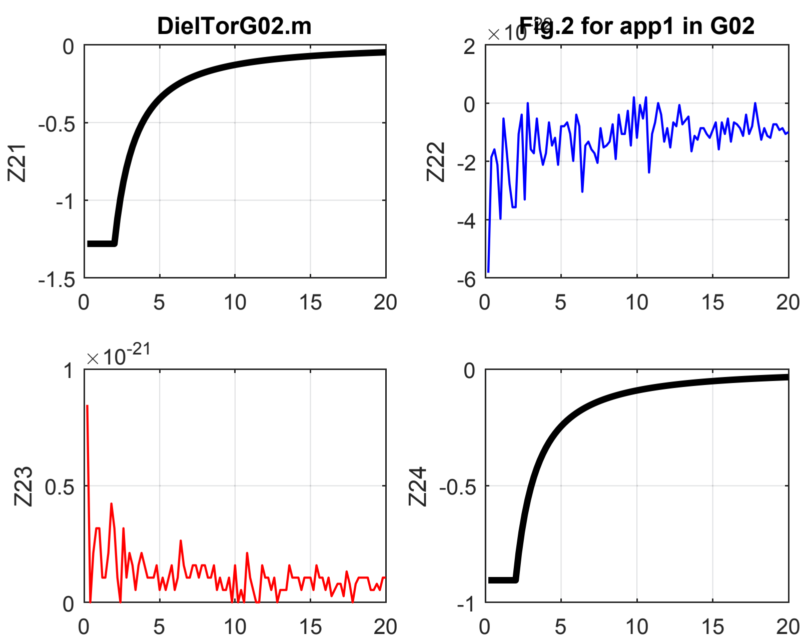
In fig. 1 shows the graphs of the functions $S_z, e_\varphi, e_r, e_z, \dot{e}_r, \dot{e}_z$ for $A = 1 \cdot 10^{-6}, R = 20, \propto = 0.95, \omega = 10^5$ in the GHS system. In this case, the entire flow of energy $\bar{S}_z = 555$ in the SI system.

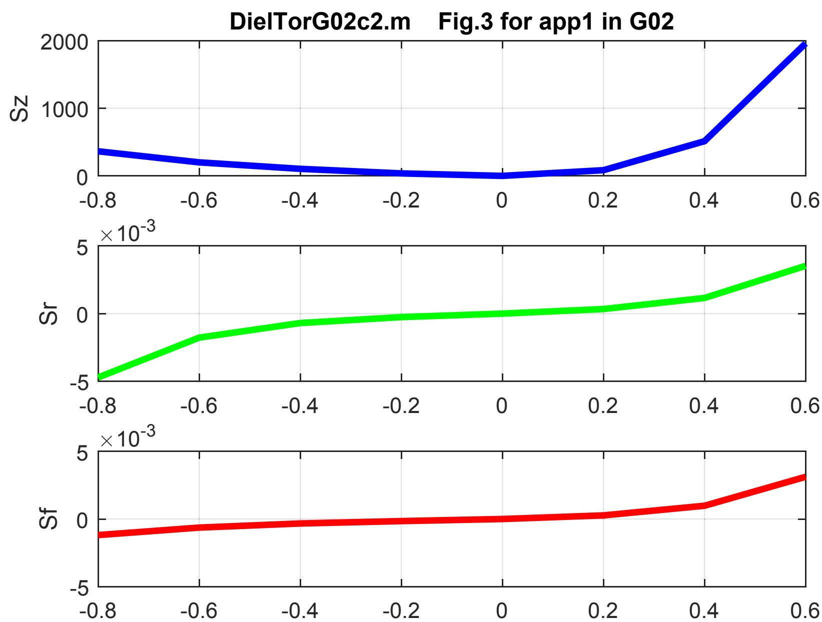
In fig. 2 shows the graphs of errors in solving equations (21_24) under the same conditions.

Example 2.

In fig. 3 shows the graphs of the functions $\bar{S}_z, \bar{S}_r, \bar{S}_f$ (Wt) depending on $\propto$ at $A = 0.3\ V/m, R = 0.2m, \omega = 10^5\ Hz$.


DielTorG02.m
Fig.1 for app1 in G02
Srr, Szr
ef
er
ez
ef1
er1


DielTorG02.m
Fig.2 for app1 in G02
Z21
Z22
Z23
Z24



Appendix 2.

We consider the solution of the system of equations (21, 22, 23) from Appendix 1:

$$\frac{e_r}{r} + \dot{e}_r - \frac{e_\varphi}{r}\alpha - \chi e_z = 0, \tag{21}$$

$$-\frac{e_z}{r}\alpha + e_\varphi \chi - \frac{\mu\omega}{c} k e_r = 0, \tag{22}$$

$$-\dot{e}_z + e_r \chi - k\frac{\mu\omega}{c} e_\varphi = 0. \tag{23}$$

The solution will be considered in detail so that the reader can easily verify it. From (23) we find:

$$e_\varphi = \frac{c}{k\mu\omega}\left(e_r\chi - \dot{e}_z\right), \tag{31}$$

Combining (21, 31), we find:

$$\frac{e_r}{r} + \dot{e}_r - \frac{c}{k\mu\omega r}\alpha\left(e_r\chi - \dot{e}_z\right) - \chi e_z = 0,$$

or

$$\frac{e_r}{r}\left(1-\frac{c\alpha\chi}{k\mu\omega}\right)+\dot{e}_r-\chi e_z+\frac{c\quad\alpha\cdot}{k\mu\omega r}e_z=0\quad, \tag{32}$$

Combining (22, 31), we find:

$$-\frac{e_z}{r}\alpha+\frac{c\chi}{k\mu\omega}\left(e_r\chi-\dot{e}_z\right)-\frac{\mu\omega}{c}ke_r=0\quad,$$

or

$$-\frac{e_z}{r}\alpha-\frac{c\chi}{k\mu\omega}\dot{e}_z+e_r\left(\frac{c\chi^2}{k\mu\omega}-\frac{k\mu\omega}{c}\right)=0\quad,$$

or

$$e_r=\left(\frac{e_z}{r}\alpha+\frac{c\chi}{k\mu\omega}\dot{e}_z\right)\Big/\left(\frac{c\chi^2}{k\mu\omega}-\frac{k\mu\omega}{c}\right). \tag{33}$$

From (33) we find:

$$\dot{e}_r=\left(-\frac{e_z}{r^2}\alpha+\frac{\dot{e}_z}{r}\alpha+\frac{c\chi}{k\mu\omega}\ddot{e}_z\right)\Big/\left(\frac{c\chi^2}{k\mu\omega}-\frac{k\mu\omega}{c}\right)\quad, \tag{34}$$

Combining (32, 33, 34), we find:

$$\frac{1}{r}\left(1-\frac{c\alpha\chi}{k\mu\omega}\right)\left(\frac{e_z}{r}\alpha+\frac{c\chi}{k\mu\omega}\dot{e}_z\right)\Big/\left(\frac{c\chi^2}{k\mu\omega}-\frac{k\mu\omega}{c}\right)+$$

$$\left(-\frac{e_z}{r^2}\alpha+\frac{\dot{e}_z}{r}\alpha+\frac{c\chi}{k\mu\omega}\ddot{e}_z\right)\Big/\left(\frac{c\chi^2}{k\mu\omega}-\frac{k\mu\omega}{c}\right)-\chi e_z+$$

$$\frac{c\quad\alpha\cdot}{k\mu\omega r}e_z=0$$

or

$$\frac{1}{r}\left(1-\frac{c\alpha\chi}{k\mu\omega}\right)\left(\frac{e_z}{r}\alpha+\frac{c\chi}{k\mu\omega}\dot{e}_z\right)+\left(-\frac{e_z}{r^2}\alpha+\frac{\dot{e}_z}{r}\alpha+\frac{c\chi}{k\mu\omega}\ddot{e}_z\right)+$$

$$\left(\frac{c\quad\alpha\cdot}{k\mu\omega r}e_z-\chi e_z\right)\left(\frac{c\chi^2}{k\mu\omega}-\frac{k\mu\omega}{c}\right)=0$$

or

$$\frac{c\chi}{k\mu\omega}\ddot{e}_z+\frac{\dot{e}_z}{r}\left(\left(1-\frac{c\alpha\chi}{k\mu\omega}\right)\frac{c\chi}{k\mu\omega}+\alpha+\frac{c\alpha}{k\mu\omega}\left(\frac{c\chi^2}{k\mu\omega}-\frac{k\mu\omega}{c}\right)\right)-$$

$$e_z\left(\frac{c\chi^2}{k\mu\omega}-\frac{k\mu\omega}{c}\right)\chi+\frac{e_z}{r^2}\left(\left(1-\frac{c\alpha\chi}{k\mu\omega}\right)\alpha-\alpha\right)=0$$

or

$$\frac{c\chi}{k\mu\omega}\ddot{e}_z + \frac{\dot{e}_z}{r}\left(\frac{c\chi}{k\mu\omega} - \alpha\left(\frac{c\chi}{k\mu\omega}\right)^2 + \alpha + \left(\frac{c\alpha}{k\mu\omega}\frac{c\chi^2}{k\mu\omega} - \alpha\right)\right) - e_z\left(\frac{c\chi^2}{k\mu\omega} - \frac{k\mu\omega}{c}\right)\chi - \frac{e_z c\alpha^2\chi}{r^2 k\mu\omega} = 0$$

or

$$\frac{c\chi}{k\mu\omega}\ddot{e}_z + \frac{\dot{e}_z}{r}\frac{c\chi}{k\mu\omega} - e_z\left(\frac{c\chi^2}{k\mu\omega} - \frac{k\mu\omega}{c}\right)\chi - \frac{e_z c\alpha^2\chi}{r^2 k\mu\omega} = 0$$

or

$$c\chi\ddot{e}_z + \frac{\dot{e}_z}{r}c\chi - e_z\left(c\chi^2 - \frac{(k\mu\omega)^2}{c}\right)\chi - \frac{e_z}{r^2}c\alpha^2\chi = 0$$

or

$$\ddot{e}_z + \frac{\dot{e}_z}{r} - e_z\left(\chi^2 - (k\mu\omega/c)^2\right) - \frac{e_z}{r^2}\alpha^2 = 0. \tag{35}$$

Appendix 3.

We consider the solution of the system of equations (22, 23, 24) from Appendix 1:

$$-\frac{e_z}{r}\alpha + e_\varphi\chi - \frac{\mu\omega}{c}ke_r = 0, \tag{22}$$

$$-\dot{e}_z + e_r\chi - k\frac{\mu\omega}{c}e_\varphi = 0, \tag{23}$$

$$\frac{e_\varphi}{r} + \dot{e}_\varphi - \frac{e_r}{r}\alpha - k\frac{\mu\omega}{c}e_z = 0, \tag{24}$$

The solution will be considered in detail so that the reader can easily verify it. From (23) we find:

$$e_r = \frac{1}{\chi}\left(\dot{e}_z + \frac{k\mu\omega}{c}e_\varphi\right) \tag{31}$$

Combining (24, 31), we find:

$$\frac{e_\varphi}{r} + \dot{e}_\varphi - \frac{1}{\chi}\left(\dot{e}_z + \frac{k\mu\omega}{c}e_\varphi\right)\frac{\alpha}{r} - k\frac{\mu\omega}{c}e_z = 0,$$

or

$$\frac{e_\varphi}{r}\left(1 - \frac{k\alpha\mu\omega}{c\chi}\right) + \dot{e}_\varphi - \frac{k\mu\omega}{c}e_z - \frac{1\alpha}{\chi r}\dot{e}_z = 0. \tag{32}$$

Combining (22, 31), we find:

$$-\frac{e_z}{r}\alpha + e_\varphi\chi - \frac{k\mu\omega}{c}\frac{1}{\chi}\left(\dot{e}_z + \frac{k\mu\omega}{c}e_\varphi\right) = 0$$

or

$$-\frac{e_z}{r}\alpha - \frac{k\mu\omega}{c\chi}\dot{e}_z + e_\varphi\left(\chi - \frac{1}{\chi}\left(\frac{k\mu\omega}{c}\right)^2\right) = 0$$

or

$$e_\varphi = \left(\frac{e_z}{r}\alpha + \frac{k\mu\omega}{c\chi}\dot{e}_z\right)\Big/\left(\chi - \frac{1}{\chi}\left(\frac{k\mu\omega}{c}\right)^2\right). \tag{33}$$

From (33) we find:

$$\dot{e}_\varphi = \left(-\frac{e_z}{r^2}\alpha + \frac{\dot{e}_z}{r}\alpha + \frac{k\mu\omega}{c\chi}\ddot{e}_z\right)\Big/\left(\chi - \frac{1}{\chi}\left(\frac{k\mu\omega}{c}\right)^2\right). \tag{34}$$

Combining (32, 33, 34), we find:

$$\frac{1}{r}\left(1 - \frac{k\alpha\mu\omega}{c\chi}\right)\left(\frac{e_z}{r}\alpha + \frac{k\mu\omega}{c\chi}\dot{e}_z\right)\Big/\left(\chi - \frac{1}{\chi}\left(\frac{k\mu\omega}{c}\right)^2\right) + \left(-\frac{e_z}{r^2}\alpha + \frac{\dot{e}_z}{r}\alpha + \frac{k\mu\omega}{c\chi}\ddot{e}_z\right)\Big/\left(\chi - \frac{1}{\chi}\left(\frac{k\mu\omega}{c}\right)^2\right) - \frac{k\mu\omega}{c}e_z - \frac{1}{\chi}\frac{\alpha}{r}\dot{e}_z = 0$$

or

$$\frac{1}{r}\left(1 - \frac{k\alpha\mu\omega}{c\chi}\right)\left(\frac{e_z}{r}\alpha + \frac{k\mu\omega}{c\chi}\dot{e}_z\right) + \left(-\frac{e_z}{r^2}\alpha + \frac{\dot{e}_z}{r}\alpha + \frac{k\mu\omega}{c\chi}\ddot{e}_z\right) - \left(\frac{k\mu\omega}{c}e_z + \frac{1}{\chi}\frac{\alpha}{r}\dot{e}_z\right)\left(\chi - \frac{1}{\chi}\left(\frac{k\mu\omega}{c}\right)^2\right) = 0$$

or

$$\frac{k\mu\omega}{c\chi}\ddot{e}_z + \frac{\dot{e}_z}{r}\left(\left(1 - \frac{k\alpha\mu\omega}{c\chi}\right)\frac{k\mu\omega}{c\chi} + \frac{\alpha}{\chi}\left(\chi - \frac{1}{\chi}\left(\frac{k\mu\omega}{c}\right)^2\right)\right) - \left(\frac{k\mu\omega}{c}e_z\right)\left(\chi - \frac{1}{\chi}\left(\frac{k\mu\omega}{c}\right)^2\right) + \frac{e_z}{r^2}\left(\left(1 - \frac{k\alpha\mu\omega}{c\chi}\right)\alpha - \alpha\right) = 0$$

or

$$\frac{k\mu\omega}{c\chi}\ddot{e}_z + \frac{\dot{e}_z}{r}\left(\frac{k\mu\omega}{c\chi} - \alpha\left(\frac{k\mu\omega}{c\chi}\right)^2 + \alpha - \frac{\alpha}{\chi^2}\left(\frac{k\mu\omega}{c}\right)^2\right) - e_z\left(\chi\frac{k\mu\omega}{c} - \frac{1}{\chi}\left(\frac{k\mu\omega}{c}\right)^3\right) - \frac{e_z}{r^2}\frac{k\alpha^2\mu\omega}{c\chi} = 0$$

or

$$\ddot{e}_z + \frac{\dot{e}_z}{r}\left(1 - 2\alpha\frac{k\mu\omega}{c\chi} + \alpha\frac{c\chi}{k\mu\omega}\right) - e_z\left(\chi^2 - \left(\frac{k\mu\omega}{c}\right)^2\right) - \frac{e_z}{r^2}\alpha^2 = 0$$

or

$$\ddot{e}_z + \frac{\dot{e}_z}{r}\left(1 - \alpha\left(2\frac{k\mu\omega}{c\chi} - \frac{c\chi}{k\mu\omega}\right)\right) - e_z\left(\chi^2 - (k\mu\omega/c)^2\right) - \frac{e_z}{r^2}\alpha^2 = 0. \quad (35)$$

Appendix 4.

We know a modified Bessel equation, which has the following form:

$$\ddot{y} + \frac{\dot{y}}{x} - y\left(1 + \frac{\nu^2}{x^2}\right) = 0, \quad (1)$$

where ν is the order of the equation. With a real argument, it has a real solution. This solution and its derivative can be found by a numerical method.

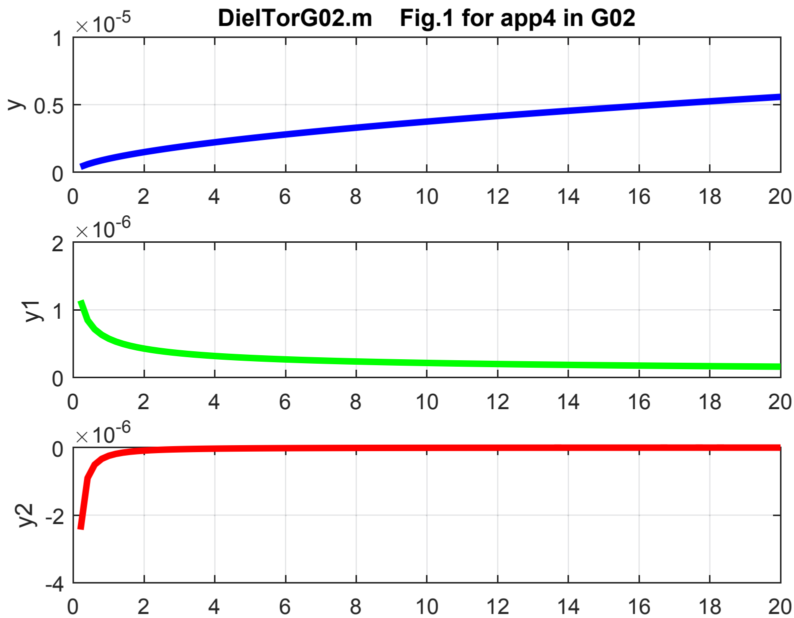
Equation (34)

$$\ddot{e}_z + \frac{\dot{e}_z}{r} - e_z\left(\frac{\chi^2}{2} + \frac{\alpha^2}{r^2}\right) = 0. \quad (2)$$

in Appendix 1 like equation (1) and its solution and its derivative can also be found by a numerical method.

The value of A is the amplitude of the function E_z at the point $r = 0$, varying in time according to (2.18, 2.11):

$E_z = e_z(r)cos(\propto \varphi + \chi z + \omega t)$.



Appendix 5. Another way to solve Maxwell's equations for a vacuum

In Chapter 1, the solution was found under the assumption that there is no longitudinal electric field strength.

Here, in Chapter 2, the existence of a longitudinal electric field was postulated.

In Chapter 1, the solution was found without any assumptions about the characteristics of the energy fluxes along the coordinate axes. It was found that there is only a longitudinal flow of energy.

Here in chapter 2, we assumed that there is only a longitudinal energy flow and a circular energy flow. It was much easier to find a solution.

Now we can assume that there is no longitudinal electric field strength and there is only a longitudinal energy flow. These assumptions correspond to the solution found in Chapter 1. But we will find this solution again, using the method applied here.

In accordance with (2.35), the longitudinal magnetic intensity is also absent. Then the equations (2.41-2.48) are simplified and take the following form:

$$\frac{e_r}{r}+\dot{e}_r-\frac{e_\varphi}{r}\alpha=0 \quad , \tag{41}$$

$$e_\varphi \chi - \frac{\mu\omega}{c} k e_r = 0, \tag{42}$$

$$e_r \chi - k \frac{\mu\omega}{c} e_\varphi = 0, \tag{43}$$

$$\frac{e_\varphi}{r} + \dot{e}_\varphi - \frac{e_r}{r}\alpha = 0, \tag{44}$$

$$k\frac{e_r}{r} + k\dot{e}_r - k\frac{e_\varphi}{r}\alpha = 0, \tag{45}$$

$$k e_\varphi \chi - \frac{\varepsilon\omega}{c} e_r - \frac{4\pi}{c} j_r = 0, \tag{46}$$

$$-k e_r \chi + \frac{\varepsilon\omega}{c} e_\varphi - \frac{4\pi}{c} j_\varphi = 0, \tag{47}$$

$$-k\frac{e_\varphi}{r} - k\dot{e}_\varphi + k\frac{e_r}{r}\alpha = 0. \tag{48}$$

From (43, 42) it follows that

$$e_r = e_\varphi. \tag{50}$$

Under this condition, equations (41-48) are simplified and take the following form:

$$\frac{e_\varphi}{r} + \dot{e}_\varphi - \frac{e_\varphi}{r}\alpha = 0, \tag{51}$$

$$e_\varphi \chi - \frac{\mu\omega}{c} k e_\varphi = 0, \tag{52}$$

$$e_\varphi \chi - k \frac{\mu\omega}{c} e_\varphi = 0, \tag{53}$$

$$\frac{e_\varphi}{r} + \dot{e}_\varphi - \frac{e_\varphi}{r}\alpha = 0, \tag{54}$$

$$k\frac{e_\varphi}{r} + k\dot{e}_\varphi - k\frac{e_\varphi}{r}\alpha = 0, \tag{55}$$

$$k e_\varphi \chi - \frac{\varepsilon\omega}{c} e_\varphi - \frac{4\pi}{c} j_r = 0, \tag{56}$$

$$-k e_\varphi \chi + \frac{\varepsilon\omega}{c} e_\varphi - \frac{4\pi}{c} j_\varphi = 0, \tag{57}$$

$$-k\frac{e_\varphi}{r} - k\dot{e}_\varphi + k\frac{e_\varphi}{r}\alpha = 0. \tag{58}$$

It is easy to notice that in this system of equations it is possible to exclude part of the equations. In this case, the system of equations takes the form:

$$\frac{e_\varphi}{r} + \dot{e}_\varphi - \frac{e_\varphi}{r}\alpha = 0, \tag{51}$$

$$e_\varphi \chi - \frac{\mu\omega}{c} k e_\varphi = 0, \tag{52}$$

$$k e_\varphi \chi - \frac{\varepsilon\omega}{c} e_\varphi - \frac{4\pi}{c} j_r = 0, \tag{56}$$

$$- k e_\varphi \chi + \frac{\varepsilon\omega}{c} e_\varphi - \frac{4\pi}{c} j_\varphi = 0. \tag{57}$$

From (51) we find:

$$e_\varphi = \frac{A}{2} r^{(\alpha - 1)}. \tag{58}$$

From (52) we find:

$$k = \frac{c\chi}{\mu\omega}. \tag{59}$$

From (56, 57) we find:

$$j_r = j_\varphi = \frac{1}{4\pi}\left(c k e_\varphi \chi - \varepsilon\omega e_\varphi\right). \tag{59a}$$

Thereby a solution is found.

Consider the algorithm for calculating the dielectric circuit of alternating current using the obtained relations:

1. R, α, ω, A are known.
2. We calculate χ by (app.1.32a):

$$\chi = \frac{\omega}{c}\sqrt{\mu\varepsilon}. \tag{60}$$

3. We calculate k by (59) with (60) taken into account:

$$k = \frac{c\chi}{\mu\omega} = \sqrt{\frac{\varepsilon}{\mu}}. \tag{60a}$$

4. We calculate e_φ, e_r by (58, 50) respectively:
5. We calculate h_r, h_φ by (2.33, 2.34) respectively:

$$h_r = k e_r, \tag{61}$$

$$h_\varphi = - k e_\varphi. \tag{62}$$

6. We calculate the density of the longitudinal energy flux S_z according to (2.38):

$$S_z = \eta k e_r e_\varphi \tag{63}$$

7. We calculate the longitudinal energy flux S_z with (62, 63)

$$\bar{S}_z = \iint_{\varphi,r} (S_z \cdot r \cdot d\varphi \cdot dr) = -\iint_{\varphi,r} \left(\eta k r e_\varphi^2 d\varphi \cdot dr\right) . \tag{64}$$

Considering (58) and $\eta = \frac{c}{4\pi}$, we find

$$\bar{S}_z = -\frac{cA^2k}{4\pi}\iint_{\varphi,r} \left(r^{(2\propto-1)} d\varphi \cdot dr\right) = -0.5cA^2k\int_0^R \left(r^{(2\propto-1)} dr\right) = -\frac{1}{4\propto}cA^2kR^{2\propto} \tag{65}$$

From here, considering (60a), we find:

$$\bar{S}_z = -\frac{cA^2}{4\propto}\sqrt{\frac{\varepsilon}{\mu}}R^{2\propto} \tag{66}$$

Example 1

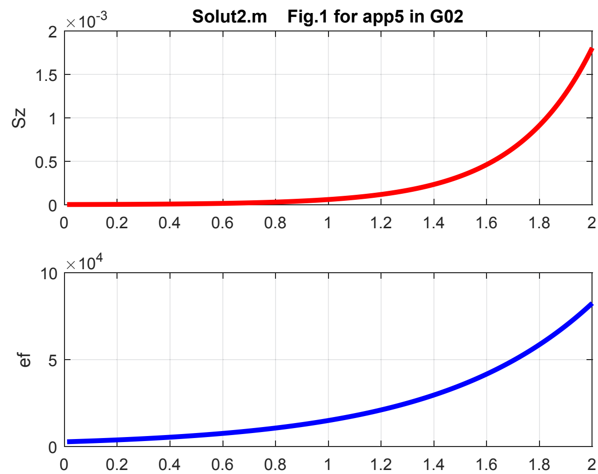
In fig. 1 shows the graphs of the functions $S_z(\propto)$ and $e_\varphi(\propto)$ for $A = 1, \omega = 10^5, R = 11, r = R/2$ in the SI system.

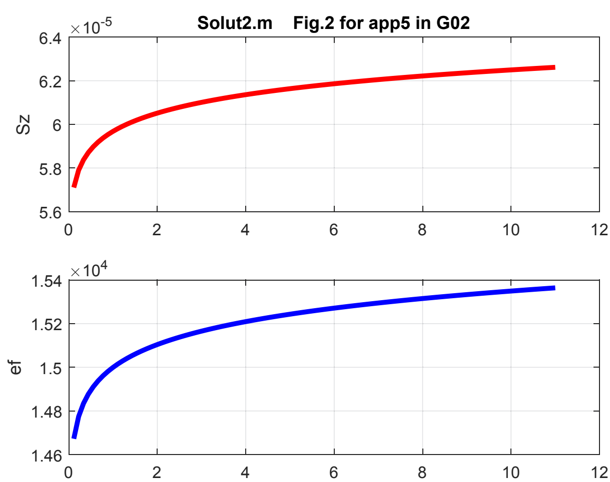
Example 2.

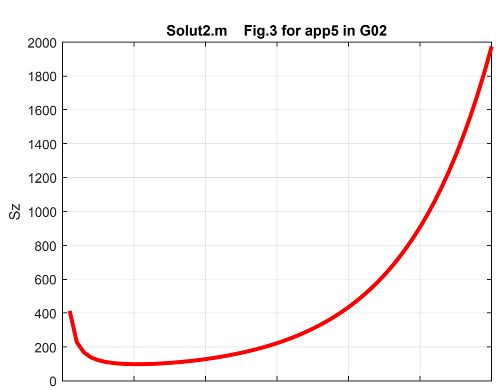
In fig. 2 shows the graphs of the functions $S_z(r)$ and $e_\varphi(r)$ for $A = 1, \omega = 10^5, R = 11, \propto = 1.01$ in the SI system. In this case, the entire flow of energy $\bar{S}_z = 943\ Wt$

Example 3.

In fig. 3 shows the graphs of the functions $\bar{S}_z(\propto)$ for $A = 1, \omega = 10^5, R = 11$ in the SI system.


Solut2.m Fig.1 for app5 in G02
×10^-3
Sz
×10^4
ef


Solut2.m Fig.2 for app5 in G02
×10^-5
Sz
×10^4
ef


Solut2.m Fig.3 for app5 in G02
Sz

Chapter 2a. Solution of Maxwell's equations for capacitor with alternating voltage in cylindrical coordinates

Contents

1. Introduction

In Chapter 2 a new solution of the Maxwell equations is obtained for a monochromatic wave in a dielectric medium with definite ε, μ - dielectric and magnetic permeabilities. The main feature of this solution is that the field has a nonzero longitudinal electric intensities created by an external source. When considering the electromagnetic field in vacuum, the absence of an external source was postulated.

The dielectric of the capacitor, which is under alternating voltage, is also such a medium. Therefore, for him the solution obtained in Chapter 2 can be applied without reservations.

According to the existing concept, in the energy flow through the capacitor only the average (in time) value of the energy flux is conserved [3]. The existing solution is such that it assumes a synchronous change in the electric and magnetic intensities of such a field as a function of the radius on the Bessel function, which has zeros along the axis of the argument, i.e. at certain values of the radius. At these points (more precisely - circles of a given radius), the energy of the radial field turns out to be zero [13]. And then it increases with increasing radius ... This contradicts the law of conservation of energy (which has already been discussed above for a traveling wave). Therefore, we propose a new solution of the Maxwell equations for a capacitor in which the law of conservation of energy is satisfied without exceptions and for each moment of time.

2. Solution of the Maxwell equations

Next we will use the cylindrical coordinates r, φ, z and the solution of the Maxwell equations obtained in Chapter 2. Here we only note the following:

1. There are electrical and magnetic stresses along all the coordinate axes r, φ, z. In particular, there is a longitudinal magnetic intensity H_z proportional to the longitudinal electric field intensity E_z.
2. The magnetic and electrical intensities on each coordinate axis r, φ, z are phase shifted by a quarter of a period.
3. The vectors of electric and magnetic intensities on each axis of coordinates r, φ, z are orthogonal.

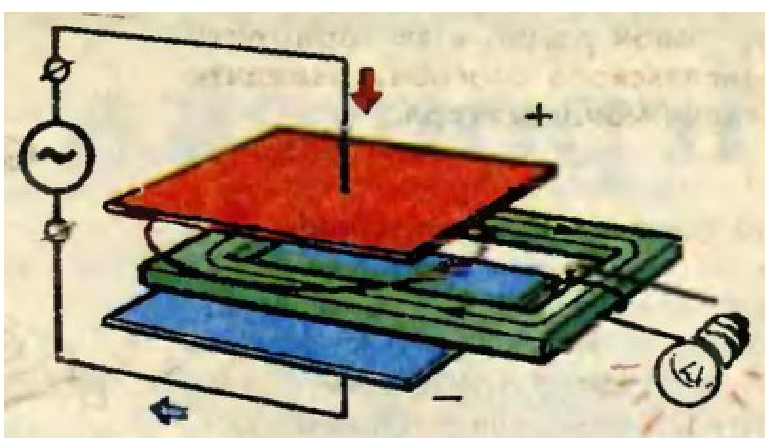


Fig. 1.

It is important to note, in particular, that there exists a longitudinal magnetic intensity H_z, proportional to the longitudinal electric intensity E_z. This fact is known. For example, in Fig. 1 shows a capacitor converter of alternating voltage in an alternating magnetic intensity, which in a magnetic core is converted into an alternating voltage on the winding [117, 1992]. But, as the author of the article cautiously notes, "the work of an externally simple device to this day in its subtleties is not entirely clear."

3. Speed of electromagnetic wave propagation

Obviously, the speed of propagation of an electromagnetic wave is equal to the derivative $\frac{dz}{dt}$ of a function $z(t)$ specified implicitly in the form of functions (2.2.13-2.2.18). Having determined this derivative, we find the speed of propagation of the electromagnetic wave

$$v_m = \frac{dz}{dt} = -\frac{\omega}{\chi}. \qquad (1)$$

In the case under consideration, no restrictions are imposed on the value of χ. Therefore

$$v_m \le c. \qquad (2)$$

Consequently, the <u>propagation velocity of the electromagnetic wave in the capacitor is less than the speed of light.</u>

4. Density of energy

The energy density is

$$W = \frac{1}{8\pi}\left(\varepsilon H^2 + \mu E^2\right) \qquad (1)$$

or, taking into account the previous formulas of Chapter 2,

$$W = \frac{\varepsilon}{8\pi}\left((e_r si)^2 + (e_\varphi co)^2 + (e_z co)^2\right) + \frac{\mu}{8\pi}\left((h_r co)^2 + (h_\varphi si)^2 + (h_z si)^2\right)$$

or, taking into account (2.2.33-2.2.35),

$$W = \frac{1}{8\pi}(\varepsilon + k\mu)\left((e_r si)^2 + (e_\varphi co)^2 + (e_z co)^2\right). \qquad (2)$$

Thus, <u>**the energy density of the electromagnetic wave in the condenser is the same at all points of the cylinder of a given radius.**</u>

5. Energy Flows

The density of the flux of electromagnetic energy by coordinates $r,\ \varphi,\ z$ is found in Chapter 2 - see (2.2.36-2.2.38), respectively. It shows that

- there is no radial energy flow,
- the energy flux density along the circle at a given radius is independent of time and other coordinates,
- the energy flux density along the vertical for a given radius is independent of time and other coordinates.

The energy flow, which propagates along the axis Oz through the cross section of the condenser, is equal to

$$\vec{S}_z = \iint_{r,\varphi} (S_z dr d\varphi) = \iint_{r,\varphi} (\eta k e_r e_\varphi dr d\varphi) = 2\pi\eta k \int_0^R (e_r e_\varphi dr). \tag{1}$$

This flow is active power

$$P = \overline{S_z}\,, \tag{2}$$

transmitted through the capacitor. There is only one parameter, which is not defined in the mathematical model of the wave - it is a parameter χ and power depends on it. More precisely, on the contrary, the power $P = \overline{S_z}$ determines the value of the parameter χ. It follows from (1, 2) we find:

$$k = {}^{\mathrm{P}}\Big/ 2\pi\eta \int_0^R (e_r e_\varphi dr). \tag{3}$$

Further, from (3, 2p1.32) we find:

$$\frac{c\chi}{\mu\omega\sqrt{2}} = {}^{\mathrm{P}}\Big/ 2\pi\eta \int_0^R (e_r e_\varphi dr), \tag{4}$$

$$\chi = \frac{P\mu\omega}{\pi c\eta\sqrt{2}\int_0^R (e_r e_\varphi dr)}. \tag{5}$$

From (5, 3.1) we can find the propagation velocity of an electromagnetic wave:

$$v_m = \frac{\omega}{\chi} = \frac{\pi c\eta\sqrt{2}\int_0^R (e_r e_\varphi dr)}{P\mu}. \tag{7}$$

6. Voltage in the capacitor

It follows from (2.2.18) that

$$E_z = e_z(r)\cos(\propto\varphi + \chi z + \omega t). \tag{1}$$

We assume that the potential on the lower plate is zero for $z = 0$ and for some φ_o, r_o, and the potential on the upper plate for $z = d$ and for the same number φ_o, r_o is numerically equal to the voltage U across the capacitor. Then

$$U = e_z(r_o)\cos(\propto\varphi_o + \chi d + \omega t). \tag{2}$$

At some intermediate value z, the voltage for the same φ_o, r_o will be equal to

$$u(z) = e_z(r_o) cos(\propto \varphi_o + \chi z + \omega t), \tag{3}$$

i.e. the voltage along the capacitor varies in function $\cos(\chi z)$.

7. Reversibility of the capacitor

At a certain external voltage between the plates (i.e. at a given electrical intensity E_z), a magnetic intensity H_z appears in the capacitor - see Chapter 2.3. Above we consider a capacitor in which the external voltage between the plates is determined. Similarly, we can consider a capacitor in which a magnetic intensity H_z is given. In this case (due to the reversibility of the solution of the system of Maxwell's equations - see Chapter 2.3), the electric intensity E_z also appears in the capacitor, i.e. on the capacitor plates there is a voltage. Such a capacitor can be considered as a converter of variable magnetic induction into an alternating electric voltage.

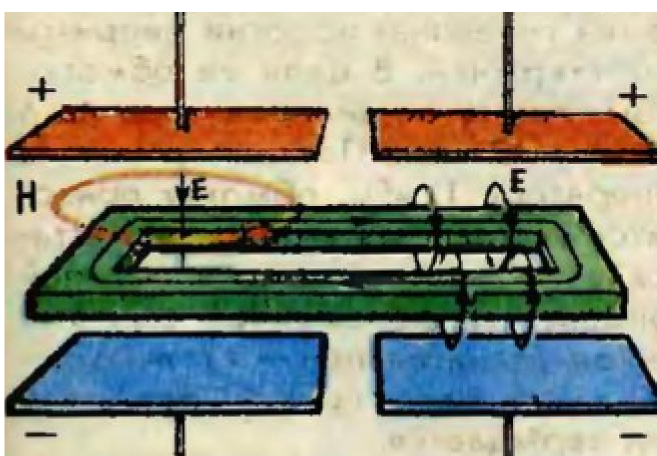


Fig. 1.

The "Mislavsky transformer" invented by a student of the 7th class in 1992 is known, where this conversion of electrical tension into magnetic induction is used explicitly in the body of the condenser - see Fig. 2 [117, 118]. In this transformer, the electrical intensity is transformed into a magnetic intensity (see the left part in Figure 1) and the reverse transformation of the magnetic intensity into electrical intensity (see the right-hand side in Figure 1).

Thus, this experiment illustrates the reversibility of a capacitor.

8. Discussion

The proposed solution of Maxwell's equations for a capacitor under alternating voltage is interpreted as an electromagnetic wave. We note the following features of this wave:

1. There are electrical and magnetic intensities along all the coordinate axes r, φ, z. In particular, there is a longitudinal magnetic intensity H_z proportional to the longitudinal electric intensity E_z.
2. The magnetic and electrical intensities on each coordinate axis r, φ, z are phase shifted by a quarter of a period.
3. The vectors of electric and magnetic intensities on each axis of coordinates r, φ, z are orthogonal.
4. The instantaneous (rather than the average over a certain period) energy flow through the capacitor does **not** change in time, which corresponds to the law of conservation of energy.
5. The energy flow along the axis of the capacitor is equal to the active power transmitted through the capacitor.
6. The speed of propagation of an electromagnetic wave is less than the speed of light
7. This speed decreases with increasing transmission power (in particular, in the absence of power, the velocity is zero and the wave becomes stationary).
8. The longitudinal electric intensities varies according to the modified Bessel function from the radius.
9. All other electric and magnetic intensities also depend on the radius and vary according to the modified Bessel function or its derivative.
10. The wave propagates also along the radii.
11. The energy flux along the radius is absent on any radius. We note that this conclusion contradicts the well-known assertion [13] that there exist radii where the flow exists.
12. There is an electromagnetic momentum proportional to the square of the active power transmitted through the capacitor.
13. The capacitor is reversible in the sense that at a certain external voltage between the plates (i.e. at a given electrical intensity E_z), a

magnetic intensitiy H_z appears in the capacitor, and for a certain external induction between the plates (i.e., at given magnetic intensity H_z) in capacitor there is an electric intensity E_z. <u>This effect can be used in various designs</u>.

Chapter 2d. Solution of Maxwell's Equations for a alternating Voltage Capacitor in Cartesian Coordinates

Contents

1. Introduction

Chapter 2a gives a solution to the Maxwell equations for a capacitor with an alternating voltage in cylindrical coordinates. Here we look at the capacitor in Cartesian coordinates - see fig. 1.

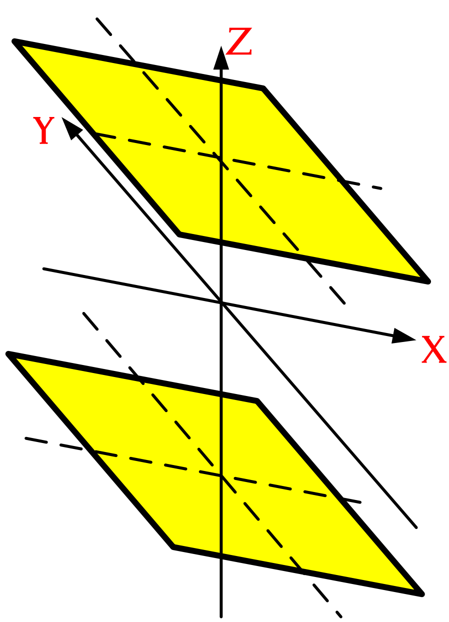


Fig. 1.

2. A partial solution of the system of Maxwell equations

In the Cartesian coordinate system x, y, z and t coordinates, these equations in the SI system are:

1	$\frac{\partial H_z}{\partial y} - \frac{\partial H_y}{\partial z} - \varepsilon \frac{\partial E_x}{\partial t} = J_x$	
2	$\frac{\partial H_x}{\partial z} - \frac{\partial H_z}{\partial x} - \varepsilon \frac{\partial E_y}{\partial t} = J_y$	
3	$\frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y} - \varepsilon \frac{\partial E_z}{\partial t} = J_z$	
4	$\frac{\partial E_z}{\partial y} - \frac{\partial E_y}{\partial z} + \mu \frac{\partial H_x}{\partial t} = 0$	
5	$\frac{\partial E_x}{\partial z} - \frac{\partial E_z}{\partial x} + \mu \frac{\partial H_y}{\partial t} = 0$	(1)
6	$\frac{\partial E_y}{\partial x} - \frac{\partial E_x}{\partial y} + \mu \frac{\partial H_z}{\partial t} = 0$	
7	$\frac{\partial E_x}{\partial x} + \frac{\partial E_y}{\partial y} + \frac{\partial E_z}{\partial z} = 0$	
8	$\frac{\partial H_x}{\partial x} + \frac{\partial H_y}{\partial y} + \frac{\partial H_z}{\partial z} = 0$	

where E_r, E_φ, E_z are electric intensities, H_r, H_φ, H_z are magnetic intensities. The solution must be found with non-zero intensity E_z. In this case, a non-zero intensity H_z appears.

We will seek a solution in the form of the following functions (see also [45], p. 284):

$$H_x = h_x(x)co, \quad (2)$$

$$H_y = h_y(x)si, \quad (3)$$

$$H_z = h_z(x)si, \quad (4)$$

$$E_x = e_x(x)si, \quad (5)$$

$$E_y = e_y(x)co, \quad (6)$$

$$E_z = e_z(x)co, \quad (7)$$

$$J_x = j_x(x)co, \quad (8)$$

$$J_y = j_y(x)si, \quad (9)$$

$$J_z = j_z(x)si. \quad (10)$$

where

$e(x),\ h(x),\ j(x)$ is some functions of coordinate x,

$\propto, \chi, \omega$ is constants,

$$co = cos(\propto y + \chi z + \omega t), \quad (11)$$

$$si = sin(\propto y + \chi z + \omega t). \tag{12}$$

Differentiating (3-8) and substituting the obtained in (1), after reducing by common factors we get:

$$h_z \propto - h_y \chi - e_x \varepsilon\omega = j_x, \tag{13}$$

$$- h_x \chi - \dot{h}_z + e_y \varepsilon\omega = j_y, \tag{14}$$

$$\dot{h}_y + h_x \propto + e_z \varepsilon\omega = j_z, \tag{15}$$

$$- e_z \propto + e_y \chi - h_x \mu\omega = 0, \tag{16}$$

$$e_x \chi - \dot{e}_z + h_y \mu\omega = 0, \tag{17}$$

$$\dot{e}_y - e_x \propto + h_z \mu\omega = 0, \tag{18}$$

$$\dot{e}_x - e_y \propto - e_z \chi = 0, \tag{19}$$

$$\dot{h}_x + h_y \propto + h_z \chi = 0. \tag{20}$$

The density of energy flows by coordinates is determined by the formula

$$S = \begin{bmatrix} S_x \\ S_y \\ S_z \end{bmatrix} = (E \times H) = \begin{bmatrix} E_y H_z - E_z H_y \\ E_z H_x - E_x H_z \\ E_x H_y - E_y H_x \end{bmatrix}. \tag{29}$$

or, taking into account formulas (3-8),

$$S_x = \left(e_y h_z - e_z h_y\right) co \cdot si \tag{30}$$

$$S_y = \left(e_z h_x{}^{co^2} - e_x h_z{}^{si^2}\right) \tag{31}$$

$$S_z = \left(e_x h_y{}^{si^2} - e_y h_x{}^{co^2}\right) \tag{32}$$

Further, it will be shown that <u>these densities of energy flow satisfy the law of energy conservation, if</u>

$$h_x = ke_x, \tag{33}$$

$$h_y = - ke_y. \tag{34}$$

$$h_z = - ke_z. \tag{35}$$

From (30, 34, 35) it follows that

$$S_x = \left(- ke_y e_z + ke_z e_y\right) co \cdot si = 0, \tag{36}$$

i.e. there is no flow of energy along the axis *ox*. From (31, 33, 35) it follows that

$$S_y = \left(ke_z e_x co^2 + ke_x e_z si^2\right) = ke_x e_z, \tag{37}$$

i.e. the energy flux density along the *oy* axis depends only on the coordinate *x*. From (32, 33, 34) it follows that

$$S_z = \left(- ke_x e_y si^2 - ke_y e_x co^2\right) = - ke_x e_y, \tag{38}$$

i.e. the energy flux density along the oz axis depends only on the coordinate x. These statements were the aim of assumptions (33-35).

Perform the change of variables according to (33-35) in equations (16-20) and rewrite them without changing the numbering:

$$-e_z \propto + e_y\chi - ke_x\mu\omega = 0, \tag{16}$$

$$e_x\chi - \dot{e}_z - ke_y\mu\omega = 0, \tag{17}$$

$$\dot{e}_y - e_x \propto - ke_z\mu\omega = 0, \tag{18}$$

$$\dot{e}_x - e_y \propto - e_z\chi = 0, \tag{19}$$

$$\dot{e}_x - e_y \propto - e_z\chi = 0. \tag{20}$$

It can be noted that equations (19) and (20) coincide and therefore equation (20) can be removed from the system of equations. The remaining 4 equations (16-19) are a system of differential equations with 4 unknown functions

$$e_r, e_\varphi, e_z, k. \tag{40}$$

Appendix 1 discusses the solution of this system of equations. Further, with the functions found (40) by (33-35), we find the functions

$$h_x, h_y, h_z. \tag{41}$$

Finally, with known functions (40, 41) by (13-15), we find j_x, j_y, j_z. Thus, the system of equations (13-20) is solved.

3. Complete solution of Maxwell's system of equations.

Obviously, there is a similar solution in which functions (11, 12) depend on x, and not on y, and the functions $e(y)$, $h(y)$, $j(y)$ depend on y, and not on x. Physically there must be both solutions, and the complete solution is equal to the sum of these two solutions. We call the solution obtained in Section 2, an x-solution, and the second is a y-solution.

In the x-solution, there is no energy flow along the axis ox, and in y-solution there is no energy flow along the axis oy. The energy flow along the oz axis exists in both solutions. Therefore, in the complete solution

- the energy flux along the axis ox is equal to the flux in the y-solution,
- energy flow along the axis oy is equal to the flow in the x-solution,
- energy flow along the oz axis is equal to the sum of the flows along the oz axis

In this complete solution, functions (2.11, 2.12) have a positive sign. The solution also exists when the signs of the functions are changed (2.11, 2.12). This means that two types of circular polarization of an electromagnetic wave are possible. This fact is discussed in more detail in Chapter 1 — see fig. 2 and fig. 3.

Application 1

From (2.16) we have:

$$k\mu\omega = \left(e_y\chi - e_z \propto\right)/e_x \quad (50)$$

From (50, 2.17, 2.18) we have:

$$e_x\chi - \dot{e}_z - \frac{e_y}{e_x}\left(e_y\chi - e_z \propto\right) = 0, \quad (51)$$

$$\dot{e}_y - e_x \propto - \frac{e_z}{e_x}\left(e_y\chi - e_z \propto\right) = 0, \quad (52)$$

From (2.19, 51, 52) we have:

$$\dot{e}_x = e_y \propto + e_z\chi, \quad (53)$$

$$\dot{e}_z = e_x\chi - \frac{e_y}{e_x}\left(e_y\chi - e_z \propto\right), \quad (54)$$

$$\dot{e}_y = e_x \propto + \frac{e_z}{e_x}\left(e_y\chi - e_z \propto\right), \quad (55)$$

For example, let for x = 0

$$e_x = e_y = e_z = 1.$$

Then from (2.19, 54, 55), we find, respectively:

$$\dot{e}_x = \propto + \chi, \quad (56)$$

$$\dot{e}_z = \chi - (\chi - \propto) = \propto, \quad (57)$$

$$\dot{e}_y = \propto + (\chi - \propto) = \chi. \quad (58)$$

In fig. 1 (mode = 1) shows the coefficient k and the function $e(x)$ with

$$\propto = 1, \chi = -3.1, \omega = 1, \mu = 1, R = 1.9$$

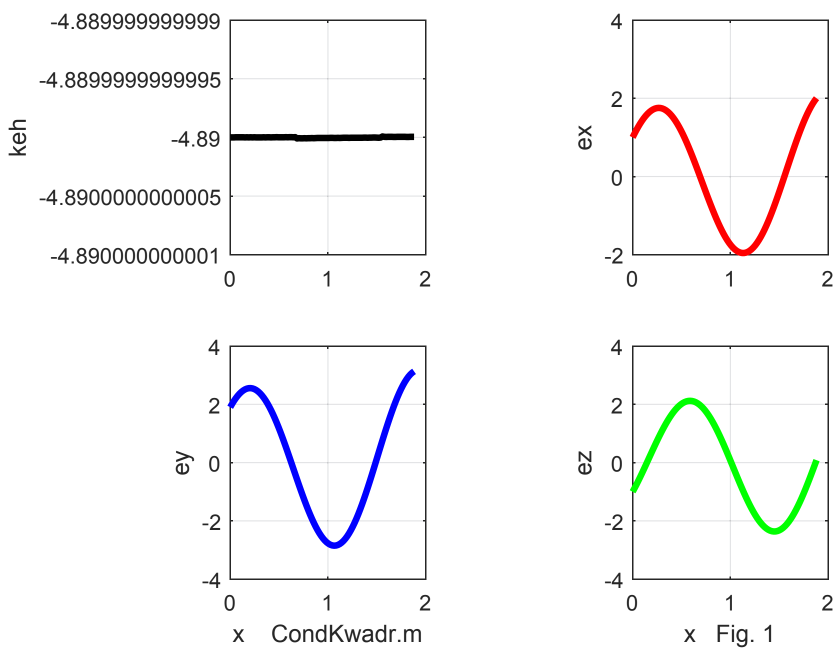
and initial values

$e_x(0) = 1, e_y(0) = 1.9, e_z(0) = -1.$

It can be seen that the coefficient k, calculated from (50), has a constant value.

In fig. 2 shows the coefficient k and the function $j(x)$.

In fig. 3 shows the functions $S_y(x)$ and $S_z(x)$.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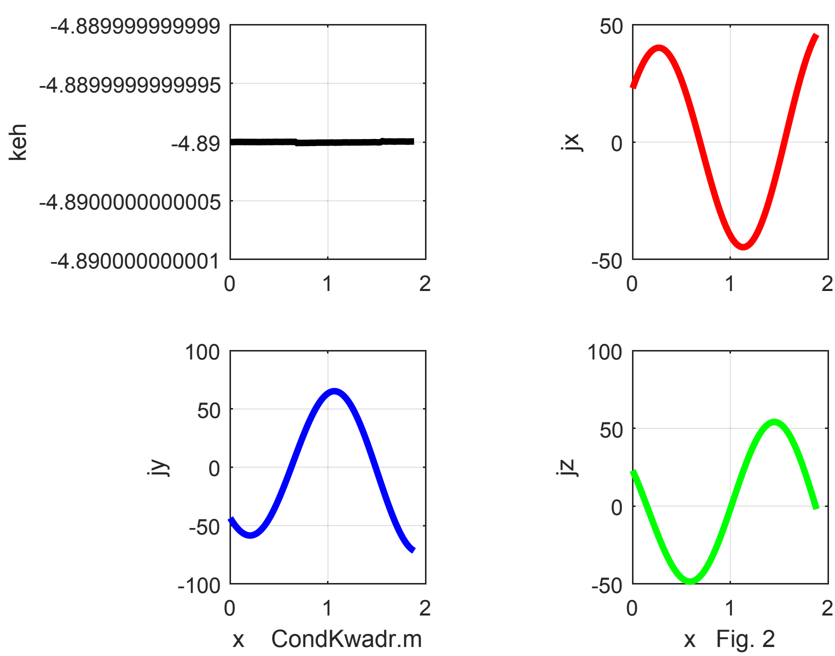
x CondKwadr.m
x Fig. 1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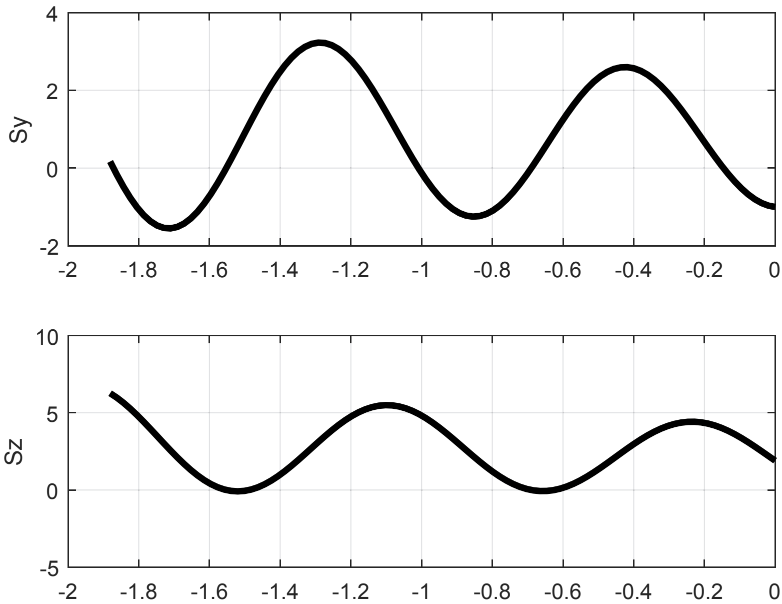
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-0.2
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10
5
0
-5
Sz
-2
-1.8
-1.6
-1.4
-1.2
-1
-0.8
-0.6
-0.4
-0.2
0
x

Fig. 3

Chapter 3. Solution of Maxwell's equations for an alternating current magnetic circuit

Chapter 2 discusses the electromagnetic field in an alternating current dielectric circuit. Similarly, we can consider the electromagnetic field in a magnetic circuit of alternating current. The simplest example of such a circuit is an AC solenoid. However, if in a dielectric circuit there is a longitudinal **electric** intensity created by an external energy source, then in a magnetic circuit there is a longitudinal **magnetic** intensity created by an external energy source and transmitted to the circuit by a solenoid winding.

It also considers the Maxwell equations in the GHS system of the form (2.2.1-2.2.8) and the solution of these equations in the form (2.2.11-2.2.18c), where the functions $h(r)$, $e(r)$, $j(r)$ are defined in Appendix 1 of Chapter 2 for given values of parameters $A, \propto, \chi, \omega$.

Here, as in Chapter 2, electromagnetic energy fluxes with densities (2.2.36-2.2.37) are defined. The flow of electromagnetic energy S_z along the magnetic circuit is equal to the active power P transmitted by the magnetic circuit,

$$P = S_z. \tag{1}$$

In Chapter 2, Section 2a, it is shown that, if we set the value of two quantities from the set

$$E_r, E_\varphi, E_z, H_r, H_\varphi, H_z, S_r, S_\varphi, S_z, \tag{2}$$

then from the obtained solution of Maxwell's equations one can find the value of the parameters $A, \propto$, and then find the value of the remaining quantities from the set (2).

Let for example, the magnetomotive force in a magnetic circuit with a length

$$F = H_z L \tag{3}$$

and transmitted by a magnetic circuit,

$$P = S_z. \tag{4}$$

Then with known F and P it is possible to H_z find S_z and, from the obtained solution of Maxwell's equations, one can find the value of the parameters $A, \propto$, and then find the value of the other quantities from the set (2).

Further conclusions are similar to those obtained in Chapters 1 and 2. Thus, an electromagnetic wave propagates in a magnetic circuit of a sinusoidal current, and the mathematical description of this wave is a solution of Maxwell's equations. At the same time, the intensity and flow of energy spread in such a chain along a helical trajectory.

Such an electromagnetic wave propagates in the magnetic circuit of the transformer. Together with it, the magnetic flux and the flux of electromagnetic energy propagate through a magnetic circuit. It is important to note that the magnitude of the magnetic flux does not change with the load. Consequently, it is the flow of electromagnetic energy that transfers energy from the primary winding to the secondary winding. So, the flow of energy does not depend on the magnetic flux. Here you can see an analogy with the transfer of current through an electrical circuit, where the same current can transfer different energy. This issue is discussed in detail in Chapter 5. It shows that the energy flux at a given current density (in the case under consideration, at a given magnetic flux density) the transmitted power can take on virtually any value depending on the values χ, α of the quantities, i.e. on the density of the screw path of the current (in this case, at a given magnetic flux density). Consequently, the transmitted power is determined by the density of the helical trajectory of electromagnetic energy at a fixed magnitude of the magnetic flux.

Chapter 4b. Solution of Maxwell's equations for tubular wire with alternating current

Chapter 2 dealt with the solution of Maxwell's equations for a wire with the sinusoidal alternating current. Below we look at the solution for the tubular wire. We will seek a solution with a known pipe radius *R* and its small thickness, when

$$r \approx R, \tag{0}$$

and all derivatives with respect to r are equal to zero. Then the system of equations (4a.2.41-4a.2.48) takes the form:

$$\frac{e_r}{r} - \frac{e_\varphi}{r}\alpha - \chi e_z = 0, \tag{1}$$

$$-\frac{e_z}{r}\alpha + e_\varphi \chi - \frac{\mu\omega}{c} k e_r = 0, \tag{2}$$

$$e_r \chi - k\frac{\mu\omega}{c} e_\varphi = 0, \tag{3}$$

$$\frac{e_\varphi}{r} - \frac{e_r}{r}\alpha - k\frac{\mu\omega}{c} e_z = 0, \tag{4}$$

$$k\frac{e_r}{r} - k\frac{e_\varphi}{r}\alpha - k\chi e_z = 0, \tag{5}$$

$$-k\frac{e_z}{r}\alpha + k e_\varphi \chi - \frac{\varepsilon\omega}{c} e_r - \frac{4\pi}{c} j_r = 0, \tag{6}$$

$$-k e_r \chi + \frac{\varepsilon\omega}{c} e_\varphi - \frac{4\pi}{c} j_\varphi = 0, \tag{7}$$

$$-k\frac{e_\varphi}{r} + k\frac{e_r}{r}\alpha + \frac{\varepsilon\omega}{c} e_z - \frac{4\pi}{c} j_z = 0. \tag{8}$$

For further it is important to note that in this solution there is $j_\varphi \neq 0$, i.e. there is a ring current with density

$$J_\varphi = j_\varphi sin(\propto \varphi + \chi z + \omega t). \tag{9}$$

Obviously, such a current creates **in the cavity of the tubular conductor longitudinal magnetic intensity**

$$H_z = h_z sin(\propto \varphi + \chi z + \omega t), \tag{10}$$

where

$$h_z = \frac{j_\varphi}{2(R - a)}, \tag{11}$$

a is the distance from the center of the tube to the observation point H_z. It is important to note that existing representations deny such a phenomenon. Below in chapter 4c, we will give an experimental proof of the existence of this phenomenon.

Chapter 4c. Special transformers

Contents

1. Introduction

In Chapter 2, Section 3, it is shown that current in a wire can arise not only as a result of an applied alternating voltage *U* but as a result of an applied external longitudinal magnetomotive force *F*. For either of these cases, equal currents are generated in the wire if in system SI

$$F = \omega\sqrt{\frac{\varepsilon}{2\mu}}U. \quad (0)$$

In Chapter 2, Section 2a, it is also shown that there is a longitudinal magnetic intensity in the wire with **nonclosed** lines of longitudinal magnetic intensity.

2. Markov’s Transformer

Markov's transformer is known [150, 151] - see fig. 1. Unlike a conventional transformer, this transformer has an elongated magnetic circuit, two primary windings and a secondary winding that is wound over the primary windings. The primary windings are turned on and create opposing magnetic fluxes.

According to the new Markov induction law, the magnetic flux in the conductor can be induced simultaneously in both opposite directions. After several years of experimentation and practical research, Markov was able to prove the validity of his theory, develop a workable transformer based on it, and obtain several international patents for his invention. The advantage of Markov transformers is that they can induce the necessary voltage even from the “worst iron” and can have significantly reduced dimensions.

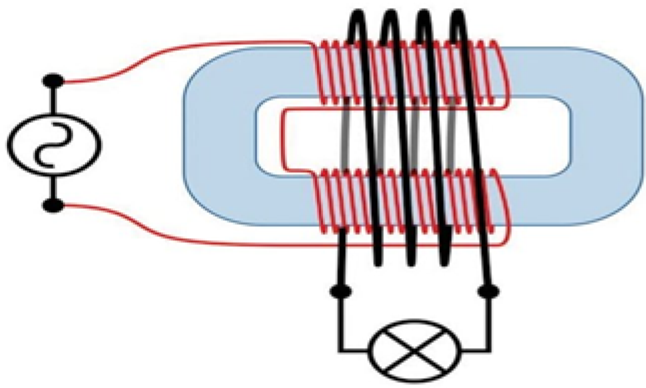


Fig. 1.

According to the existing ideas, the lines of magnetic intensity should be closed. Opposed windings with an equal number of turns in a Markov transformer do not allow the existence of closed lines of magnetic tension. Therefore, they are not at all. This conclusion (I think) forced Markov to create a new theory.

From the above stated the existence of non-closed lines of magnetic intensity is possible. This explains the operation of Markov's transformer.

3. Zatsarinin's Transformer

Known **Zatsarinin's transformer** [120]. This transformer is a solenoid, the axis of which is a rod of any conductive material. If the voltage U_1 is applied to the coil of the solenoid, then the voltage U_2 also appears on the rod. The rod can be connected to the load (for example, a lamp) and then the power P_1 from the voltage source U_1 is transferred to the load, which consumes power $P_1 < P_2$. Other experiments with the Zatsarinin transformer are also known.

This fact - the appearance of voltage in the rod is not a consequence of the law of electromagnetic induction. The magnetic field inside the solenoid does not have a longitudinal component of magnetic intensity, directed perpendicular to the radius. However, in the solenoid there is a longitudinal component of magnetic intensity and, therefore, there is a magnetomotive force F. Zatsarinina's transformer proves the previous theoretical statement: a current can arise as a result of an applied external longitudinal magnetomotive force F.

4. Pozynich's Transformer

Known **coaxial Pozynich's transformer** - CTP [121]. In this transformer, the sheath and center wire are included as transformer windings. There are two possible inclusion schemes.

1. The central wire is the primary winding of the transformer connected to a voltage source; the shell is the secondary winding of the CTP.

2. The sheath is the central wire is the primary winding of the CTP connected to the voltage source; the central wire is the secondary winding of the package transformer.

In this case, the primary winding of the CTP is connected to a voltage source, and the secondary - to the load.

Experiments have shown that in both modes, the transformation ratio was equal to 1.

CTP cannot be identified with Zatsarinin's transformer [120] (although the external manifestations are similar). The circuit of the CTP does not coincide with the diagram of the known coaxial transformer (since the latter is a two-pole cell, and the CTP is a four-pole cell).

As will be shown below, the operation of CTP in mode 2 cannot be explained by the law of electromagnetic induction.

All these features of CTP require explanation.

In **mode 1**, there in the center wire is a current with a density

$$J_{zp} = j_{zp} sin(\propto \varphi + \chi z + \omega t) \tag{1}$$

- see chapter 4a. In accordance with the law of electromagnetic induction, this current creates a magnetic intensity in the shell

$$H_{\varphi o} = \frac{dJ_{zp}}{dt} = \omega j_{zp} cos(\propto \varphi + \chi z + \omega t). \tag{2}$$

This intensity creates (as shown in Chapter 4b) a longitudinal wave in the shell and, in particular, a current

$$J_{zo} = j_{zo} cos(\propto \varphi + \chi z + \omega t). \tag{3}$$

Thus, current (1) is transformed into a current (3).

In **mode 2**, the cable jacket is under alternating voltage, i.e. this shell is a tubular wire. The current of the shell as a whole should not create magnetic intensity in the center of the pipe, since the elementary currents in all cylinder create intensities that, due to symmetry, cancel each other out. However, as the experiment shows, the current through the central wire flows. It can only be caused by magnetic intensity. So, "according to Faraday" there is no magnetic intensity, but "according to Pozynich" there is magnetic intensity. This requires an explanation.

In **mode 2** in the shell, as in a tubular wire, there is a current with a density

$$J_{zo} = j_{zo} sin(\propto \varphi + \chi z + \omega t) \tag{4}$$

- see chapter 4b. At the same time (as shown in chapter 4b) in the cavity of the tubular wire creates a longitudinal magnetic intensity

$$H_{zp} = h_{zp} sin(\propto \varphi + \chi z + \omega t), \tag{5}$$

The central wire is in the area of existence of this intensity. This intensity (5) creates (as shown in chapter 4) in the wire a longitudinal wave and, in particular, the current

$$J_{zp} = j_{zp} cos(\propto \varphi + \chi z + \omega t). \tag{6}$$

Thus, current (4) is transformed into current (6).

This fact (as shown) is not a consequence of the law of electromagnetic induction. In this regard, it should be noted that the Maxwell equations were a generalization of this and some other particular laws. This generalization covers an area of phenomena that is larger than the areas related to each particular law. Therefore, the consequence of Maxwell's equations can describe a phenomenon that is not subject to the law of electromagnetic induction (but cannot contradict this law where it operates).

Consider the mathematical model of CTP in more detail. Maxwell's equations for the center conductor are described in chapter 2. We will denote the solution of these equations as (E_p, H_p, J_p). Maxwell's equations for the shell are described in Chapter 4c. We will denote the solution of these equations as (E_o, H_o, J_o). The sheath and wire are in a common cylindrical area. Therefore, the longitudinal magnetic intensities in the solutions (E_p, H_p, J_p) and (E_o, H_o, J_o) coincide, i.e.

$$H_{pz} = H_{oz} = H_z. \tag{7}$$

Chapter 2 proved the UHP-theorem, which states that **regardless of the wire parameters**, there is a one-to-one relationship between the electrical voltage *U* on the wire, the longitudinal magnetic strength in the wire *H*, and the active power *P* transmitted over the wire,

$$U = f(H, P). \tag{8}$$

In our case, there is a common tension *H* on the shell and the central wire, and the power *P* is transmitted between the shell and the central wire in any switching mode of the CTP. Consequently, the voltage *U* on the shell and the center wire must be the same in any switching mode CTP.

That is what is observed in the experiments.

Thus, CTP is described by 16 equations with 16 unknowns of the form

$$\begin{gathered} E_{pr}, H_{pr}, J_{pr}, E_{p\varphi}, H_{p\varphi}, J_{p\varphi}, J_{pz}, \\ E_{or}, H_{or}, J_{or}, E_{o\varphi}, H_{o\varphi}, J_{o\varphi}, J_{oz}, E_z, H_z. \end{gathered} \tag{9}$$

Such a system of equations has a unique solution. This system is a system of differential equations (since these are the equations for the wire in Chapter 2). Therefore, the solution depends on the initial conditions.

According to the obtained solution (9), the energy flow passing through the CTP can be determined, i.e. power transmitted through the CTP or load power equal to the generator power. Therefore, the initial conditions determine the power of the load.

Physically, of course, everything happens the other way round: the power of the generator determines the initial conditions, and the initial conditions determine the type of solution.

Thus, the existence of listed transformers is another experimental confirmation of the theory developed in this book.

Chapter 5. Solution of Maxwell's Equations for Wire with Constant Current

Contents

1. Introduction

In [7, 9-11] based on the Law of impulse conservation it is shown that constant current in a conductor must have a complex structure. Let us consider first a conductor with constant current. The current J in the wire creates in the body magnetic induction B, which acts on the electrons with charge q_e, moving with average speed v in the direction opposite the current J, with Lorentz force F, making them move to the center of the wire – see Fig. A.

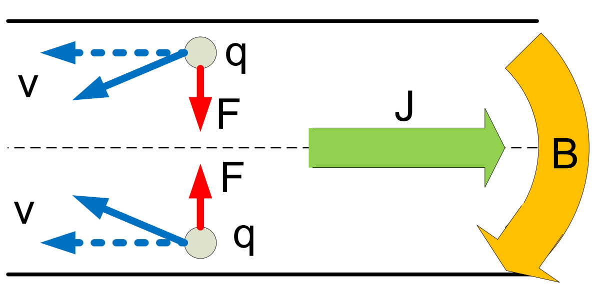


Fig. A.

Due to the known distribution of induction B on the wire's cross section the force F decreases from the wire surface to its center – see

Fig. B, showing the change of F depending on radius r, on which the electron is located.

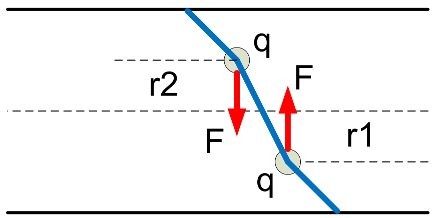


Fig. B.

Thus, it may be assumed that in the wire's body there exist elementary currents I, beginning on the axis and directed by certain angle α to the wire axis – see Fig. C.

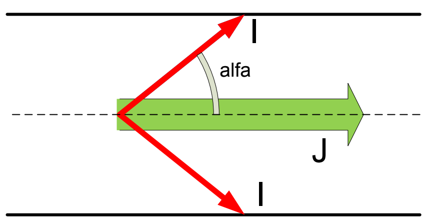


Fig. C.

In [7, 9-11] was also shown that the flow of electromagnetic energy is spreading **inside** the wire. Also the electromagnetic flow

- directed along the wire axis,
- spreads along the wire axis,
- spreads inside the wire,
- compensates the heat losses of the axis component of the current.

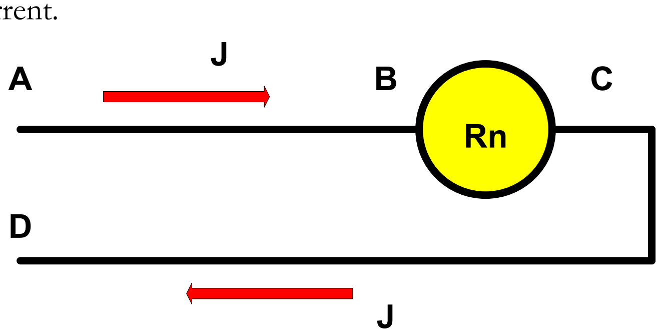


Fig. 1.

In [9-11] a mathematical model of the current and the flow has been. The model was built exclusively on base of Maxwell equations. Only one question remained unclear. The electric current **J** ток and the flow of electromagnetic energy **S** are spreading inside the wire **ABCD** and it is passing through the load **Rn**. In this load a certain amount of strength P is spent. Therefore the energy flow on the segment **AB** should be larger than the energy flow on the segment **CD**. More accurate, **Sab=Scd+P.** But the current strength after passing the load did not change. How must the current structure change so that ehe electromagnetic energy decreased correspondingly? This issue was considered in [7].

Below we shall consider a mathematical model more general than the model (compared to [7, 9-11]) and allowing to clear also this question. This mathematical model is also built solely on the base of Maxwell equations. In [12] describes an experiment which was carried out in 2008. In [17] it is shown that this experiment can be explained on the basis of non-linear structure of constant current in the wire and can serve as an experimental proof of the existence of such a structure.

2. Mathematical Model

Maxwell's equations for direct current wire are shown Chapter "Introduction" - see variant 6:

$$\mathrm{rot}(J) = 0, \tag{a}$$

$$\mathrm{rot}(H) - J - J_o = 0, \tag{b}$$

$$\mathrm{div}(J) = 0, \tag{c}$$

$$\mathrm{div}(H) = 0. \tag{d}$$

In building this model we shall be using the cylindrical coordinates $r, \ \varphi, \ z$ considering

- the main current J_o and intensity $H_{\varphi o}$ produced by it,
- the additional currents $J_r, \ J_\varphi, \ J_z$,
- magnetic intensities $H_r, \ H_\varphi, \ H_z$,
- electrical intensities E,
- electrical resistivity ρ.

Here, in these equations we included a given value of density J_o of the current passing through the wire as a load. We know, that $H_\varphi = J_z r$. As the definition of curl includes derivatives $\partial H / \partial r$ and $\partial H_\varphi / \partial r = J_o$, then equation (b) can be simplified as follows

$$\mathrm{rot}(H) - J = 0. \tag{b1}$$

The solution of equations (a, b1, c, d) is assumed to be zero. However, below we will demonstrate that in the presence of current J_o there shall be non-zero solution of these equations.

$$E = \rho \cdot J. \tag{0}$$

The equations (a-d) for cylindrical coordinates have the following form:

$$\frac{H_r}{r} + \frac{\partial H_r}{\partial r} + \frac{1}{r} \cdot \frac{\partial H_\varphi}{\partial \varphi} + \frac{\partial H_z}{\partial z} = 0, \tag{1}$$

$$\frac{1}{r} \cdot \frac{\partial H_z}{\partial \varphi} - \frac{\partial H_\varphi}{\partial z} = J_r, \tag{2}$$

$$\frac{\partial H_r}{\partial z} - \frac{\partial H_z}{\partial r} = J_\varphi, \tag{3}$$

$$\frac{H_\varphi}{r} + \frac{\partial H_\varphi}{\partial r} - \frac{1}{r} \cdot \frac{\partial H_r}{\partial \varphi} = J_z + J_o, \tag{4}$$

$$\frac{J_r}{r} + \frac{\partial J_r}{\partial r} + \frac{1}{r} \cdot \frac{\partial J_\varphi}{\partial \varphi} + \frac{\partial J_z}{\partial z} = 0, \tag{5}$$

$$\frac{1}{r} \cdot \frac{\partial J_z}{\partial \varphi} - \frac{\partial J_\varphi}{\partial z} = 0, \tag{6}$$

$$\frac{\partial J_r}{\partial z} - \frac{\partial J_z}{\partial r} = 0, \tag{7}$$

$$\frac{J_\varphi}{r} + \frac{\partial J_\varphi}{\partial r} - \frac{1}{r} \cdot \frac{\partial J_r}{\partial \varphi} = 0. \tag{8}$$

The model is based on the following facts:

1. the main electric intensities E_o is directed along the wire axis ,
2. it creates the main electric current J_o – the vertical flow of charges,
3. vertical current J_o forms an annular magnetic field with intensity H_φ and radial magnetic field H_r - see (4),
4. magnetic field H_φ deflects by the Lorentz forces charges vertical flow in the radial direction, creating a radial flow of charges - radial current J_r,
5. magnetic field H_φ deflects by the Lorentz forces the charges of radial flow perpendicularly to the radii, thus creating an vertical current J_z (in addition to current J_o),

6. magnetic field H_r by the aid of the Lorentz forces deflects the charges of vertical flow perpendicularly to the radii, thus creating an annular current J_φ,
7. magnetic field H_r by the aid of the Lorentz forces deflects the charges of annular flow along radii, thus creating vertical current J_z (in addition to current J_o),
8. current J_r forms a vertical magnetic field H_z and annular magnetic field H_φ - see (2),
9. current J_φ form a vertical magnetic field H_z and radial magnetic field H_r - see (3),
10. current J_z form a annular magnetic field H_φ and radial magnetic field H_r - see (6),

Thus, the main electric current J_o creates additional currents J_r, J_φ, J_z and magnetic fields H_r, H_φ, H_z. They should satisfy the Maxwell equations.

In addition, electromagnetic fluxes shall be such that

A. Energy flux in vertical direction was equal to transmitted power,
B. The sum of energy fluxes is to equal to transmitted power plus the power of thermal losses in the wire.

Thus, currents and intensities shall confirm Maxwell's equations and conditions A and B. In order to find a solution we part this problem into two following tasks (that is true, because Maxwell's equations are linear):

a) to find solution of equations (1-8) without current J_o; this solution occurs to be multi-valued;
b) to find additional limitations on initial solution posed by conditions A and B; here we take into account current J_o and intensity $H_{o\varphi}$ produced by it.

First of all, we shall prove that <u>a solution of system (1-8) is exist with **non**-zero currents</u> J_r, J_φ, J_z.

For the sake of brevity further we shall use the following notations:

$$co = -\cos(\alpha\varphi + \chi z), \tag{10}$$

$$si = \sin(\alpha\varphi + \chi z), \tag{11}$$

where $\alpha,\ \chi$ – are certain constants. In the Appendix 1 it is shown that there exists a solution of the following form:

$$J_r = j_r co, \tag{12}$$

$$J_\varphi = j_\varphi si, \tag{13}$$

$$J_z = j_z si, \tag{14}$$

$$H_r = h_r co, \tag{15}$$

$$H_\varphi = h_\varphi si, \tag{16}$$

$$H_z = h_z si, \tag{17}$$

where $j(r),\ h(r)$ - certain function of the coordinate r.

It can be assumed that the average speed of electrical charges doesn't depend on the current direction. In particular, for a fixed radius the way passed by the charge around a circle and the way passed by it along a vertical will be equal. Consequently, for a fixed radius it can be assumed that

$$\Delta\varphi \equiv \Delta z\,. \tag{18}$$

Thus, there on cylinder of constant radius is trajectory of point, which described by the formulas (10, 11, 18). This trajectory is a helix. On the other hand, in accordance with (12-17) on this trajectory all intensities and current densities varies harmonically as a function of φ. Consequently,

> line on a cylinder of constant radius r, at which point moves so that all the intensities and current densities therein varies harmonically depending of φ, is helical line.

Based on this assumption, it is possible to construct a trajectory of motion of the charge in accordance with the functions (10, 11). In fig. 1 shows three helix lines with $\Delta\varphi = \Delta z$ the functions described by (10, 11) current: a thick line with $\alpha = 2,\ \chi = 0.8$, a middle line with $\alpha = 0.5,\ \chi = 2$ and a thin line with $\alpha = 2,\ \chi = 1.6$.

In fig. 1 shows the helixes for the functions J and H defined by (10-17), namely for the total current with the projections J_φ and J_z with $r = const$. These projections are determined by (13, 14), i.e. depend on the function si However, the functions J and H can be defined as follows:

$$J_r = j_r co, \tag{19}$$

$$J_\varphi = j_\varphi si, \tag{20}$$

$$J_z = j_z si, \tag{21}$$

$$H_r = h_r co, \tag{22}$$

$$H_\varphi = h_\varphi si, \tag{23}$$

$$H_z = h_z si. \tag{24}$$

The difference of these functions from functions (10-17) is that the functions co are replaced by the functions si and vice versa.

In fig. 1P shows helix lines

- for functions J and H, defined by (13, 14), as in fig. 1, and dependent on the function si (see the thin line) and
- for functions J and H, defined by (20, 21) and depending on the function si (see the thick line).

It can be seen that functions (12-17) differ from functions (19-24) by different **polarization**. Which one exists physically?

Below we will consider the solution in the form of functions (12-17). Next, an analogy between solutions (12-17) and (19-24) will be shown. Then it will be shown that the complete solution consists of the sum of the solutions for (12-17) and (19-24).

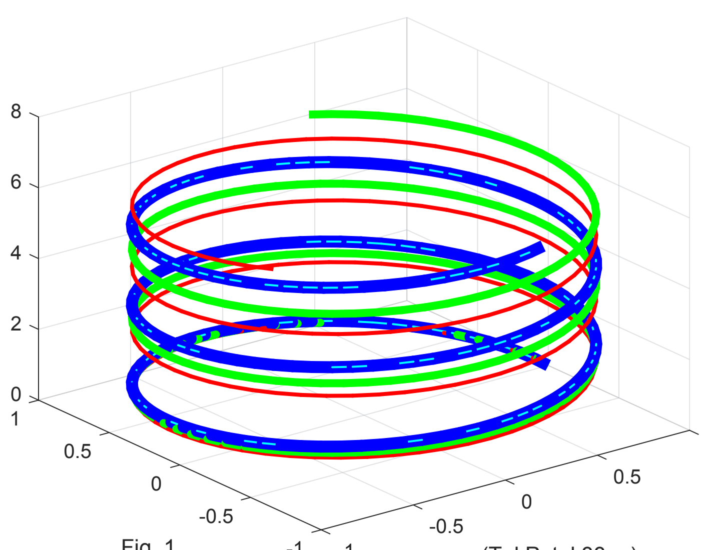


Fig. 1. (TokPotok33.m)

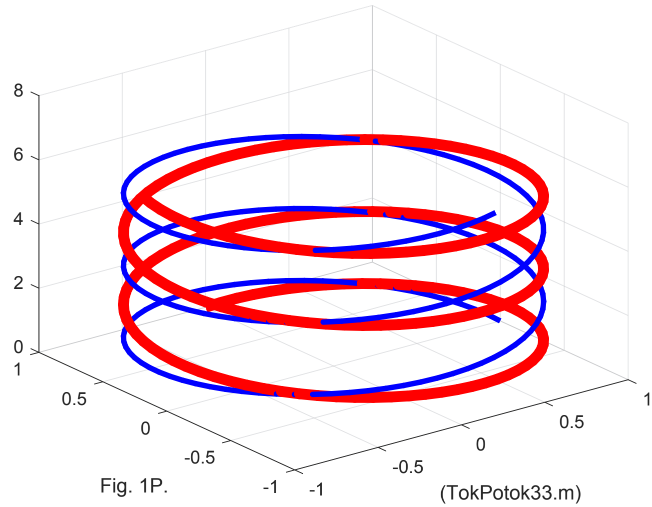


Fig. 1P. (TokPotok33.m)

The very fact of existence around a conductor with a constant current of a magnetic field, having a spiral-like configuration, was established by Oersted in 1820 [127, p. 184]. In fig. 2 shows a photograph of a wire moistened with magnetic fluid (magnified 20 times). One can see the spiral lines formed in the magnetic fluid. This photograph indicates the existence of spiral lines of magnetic intensities.

Fig. 2.

Based on this assumption we can build the trajectory of the charge motion according to the functions (10, 11).

In Appendix 1 it is shown that there exists a definite Bessel function, denoted as $F_\alpha(r)$, on which the functions of the intensities $h(r)$ and current density $j(r)$ depend, viz

$$j_\varphi(r) = F_\alpha(r), \tag{25}$$

$$j_r(r) = \left(j_\varphi(r) + r \cdot j'_\varphi(r)\right)/\alpha, \tag{26}$$

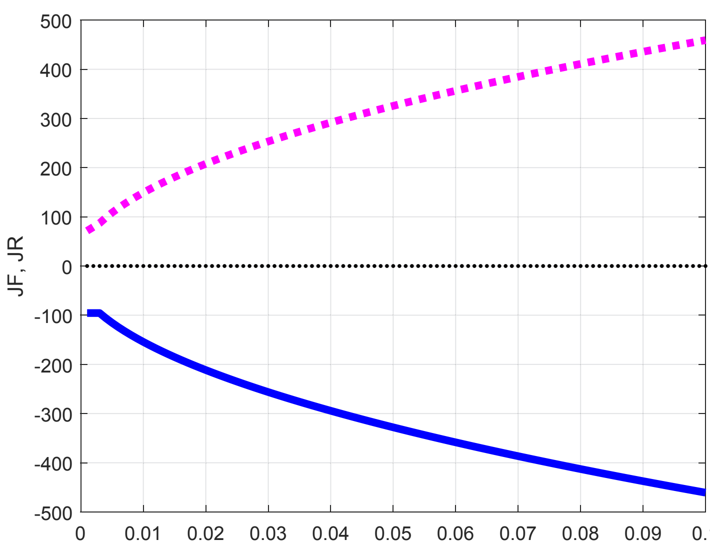
$$j_z(r) = -\frac{\chi}{\alpha} r \cdot j_\varphi(r), \tag{27}$$

$$h_z(r) \equiv 0, \tag{28}$$

$$h_\varphi(r) = \frac{1}{\chi}\left(\frac{h_z(r)}{r}\alpha - j_r(r)\right) \tag{29}$$

$$h_r(r) = j_\varphi(r)/\chi, \tag{30}$$

where the function $\vartheta_z(r)$ is defined in Appendix 4.



(r) Fig. 3 (forFig13nowTest, mode=23)

Appendix 3 shows that for small r, function (25) takes the form

$$y = Ax^\beta, \tag{30a}$$

where A is a constant, and

$$\beta = \frac{1}{2}\left(-3 \pm \sqrt{3 + 4\chi^2}\right), \ \beta < 0. \tag{30в}$$

At the same time, the values $A, \propto, \chi$ should be known for the calculation using equations (25-30). Section 6 describes the procedure for calculating the above equations.

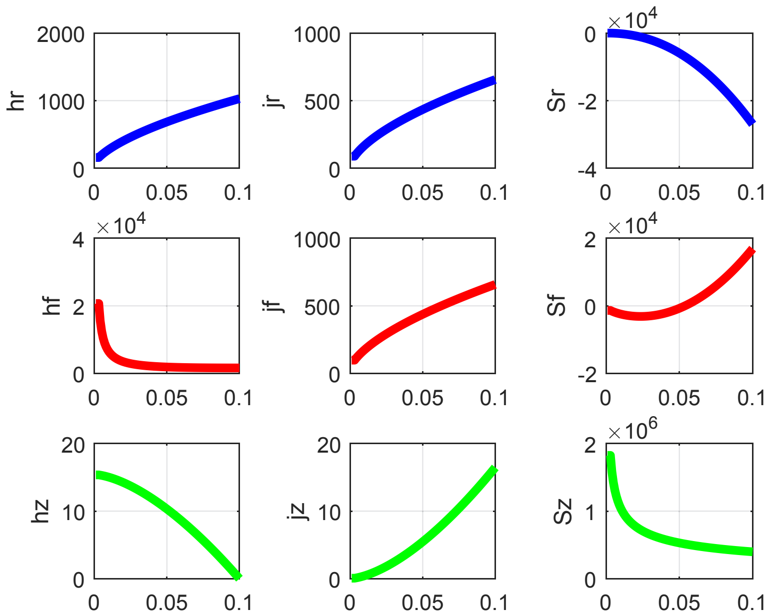


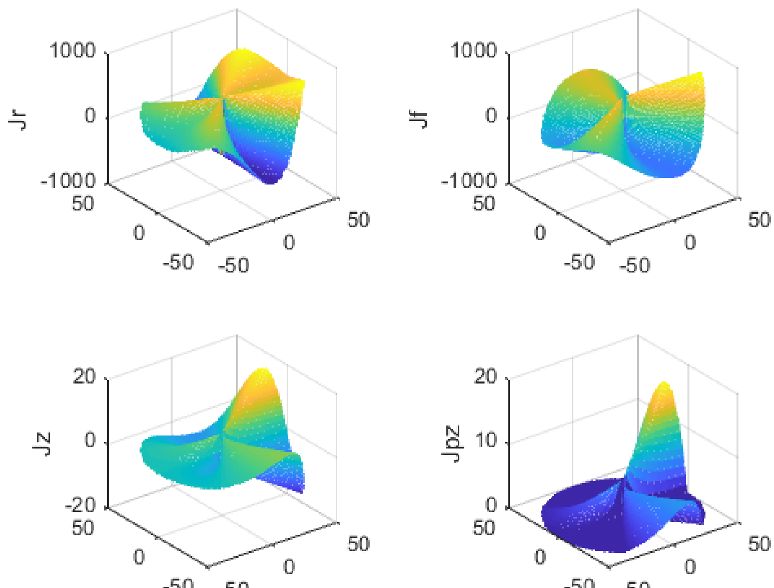
Fig. 3.1 (fig-5-3-1.m)

Function (25) has many options defined by the constants $A, \propto, \chi$. In fig. 3 shows the functions $j_\varphi(r)$, $j_r(r)$, respectively solid and dashed lines. Physically, this means that in the region $r<R$ there are radial currents $J_r(r)$ directed from the center. Here R is the radius of the wire.

Example 1. In fig. 3.1 shows graphs of functions $j_r(r)$, $j_\varphi(r)$, $j_z(r)$, $h_r(r)$, $h_\varphi(r)$, $h_z(r)$. These functions are calculated with the data $A=-2\cdot 10^{-5}10$, $\propto=1.5$, $\chi=0.4$ and the radius of the wire $R=0.1$. The first column shows the functions $j_r(r)$, $j_\varphi(r)$, $j_z(r)$, the second column shows the functions $h_r(r)$, $h_\varphi(r)$, $h_z(r)$, and the functions shown in the third column will be discussed later.

Fig. 3.2 illustrates functions (12-14), when $z=const$. The fourth window shows function

$$Jp_z(r,\varphi)=\begin{cases} J_z(r,\varphi), \text{ if } J_z(r,\varphi)>0, \\ 0, \text{ if } J_z(r,\varphi)\le 0. \end{cases}$$



(forFig32.m) Fig. 3.2

Let's determine current density in the wire of radius R:

$$\overline{J_z} = \frac{1}{\pi R^2} \iint_{r,\varphi} [J_z] dr \cdot d\varphi . \tag{31}$$

Taking into account (14), we find

$$\overline{J_z} = \frac{1}{\pi R^2} \iint_{r,\varphi} [j_z(r) si] dr \cdot d\varphi = \frac{1}{\pi R^2} \int_0^R j_z(r) \left(\int_0^{2\pi} (si \cdot d\varphi) \right) dr \cdot \tag{32}$$

Taking into account (11), we find

$$\overline{J_z} = \frac{1}{\alpha \pi R^2} \int_0^R j_z(r) \left(\cos(2\alpha\pi + \frac{2\omega}{c} z) - \cos(\frac{2\omega}{c} z) \right) dr . \tag{33}$$

From here it follows that total current $\overline{J_z}$ is changed depending on z coordinate. However, total given current with density J_o remains constant.

3. Energy Flows

The density of electromagnetic flow is Pointing vector

$$S = E \times H . \tag{1}$$

The currents are being corresponded by eponymous electrical intensities, i.e.

$$E = \rho \cdot J\ , \tag{2}$$

where ρ is electrical resistivity. Combining (1, 2), we get:

$$S = \rho J \times H = \frac{\rho}{\mu} J \times B\ . \tag{3}$$

Magnetic Lorentz force, acting on all the charges of the conductor per unit volume - the bulk density of magnetic Lorentz forces is equal to

$$F = J \times B\ . \tag{4}$$

From (3, 4), we find:

$$F = \mu S/\rho\ . \tag{5}$$

Therefore, in wire with constant current magnetic Lorentz force density is proportional to Poynting vector.

Example 1 To examine the dimension checking of the quantities in the above formulas - see Table 1 in system SI.

Table 1

Parameter		Dimension
Energy flux density	S	$kg \cdot s^{-3}$
Current density	J	$A \cdot m^{-2}$
Induction	B	$kg \cdot s^{-2} \cdot A$
Bulk density of magnetic Lorentz forces	F	$N \cdot m^{-3} = kg \cdot s^{-3} \cdot m^{-2}$
Permeability	μ	$kg \cdot s^{-2} \cdot m \cdot A^{-2}$
Resistivity	ρ	$kg \cdot s^{-3} \cdot m^{3} \cdot A^{-2}$
μ/ρ	μ/ρ	$s \cdot m^{-2}$

So, current with density J and magnetic field is generated energy flux with density S, which is identical with the magnetic Lorentz force density F - see (5). This Lorentz force acts on the charges moving in a current J, in a direction perpendicular to this current. So, it's fair to say that the Poynting vector produces an emf in the conductor. Another aspects of this problem are considered in Chapter 15, where this emf is called the fourth type of electromagnetic induction.

In cylindrical coordinates $r,\ \varphi,\ z$ the density flow of electromagnetic energy has three components $S_r,\ S_\varphi,\ S_z$, directed along вдоль the axis accordingly.

3.1. In each point of a cylinder surface there are two electromagnetic fluxes directed radially to the center with densities

$$S_{r1} = \rho J_\varphi H_z, \quad S_{r2} = -\rho J_z H_\varphi \tag{6}$$

- see Fig. 5. Total radially-directed flux density in each point of the cylinder surface,

$$S_r = S_{r1} + S_{r2} = \rho\left(J_\varphi H_z - J_z H_\varphi\right) \tag{7}$$

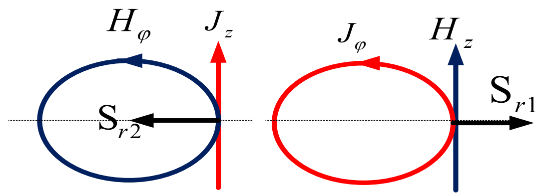


Fig. 5.

3.2. In each point of a cylinder surface there are two electromagnetic fluxes directed vertically with densities

$$S_{z1} = -\rho J_\varphi H_r, \quad S_{z2} = \rho J_r H_\varphi \tag{8}$$

- see Fig. 6. Total vertically-directed flux density in each point of the cylinder surface,

$$S_z = S_{z1} + S_{z2} = \rho\left(J_r H_\varphi - J_\varphi H_r\right) \tag{9}$$

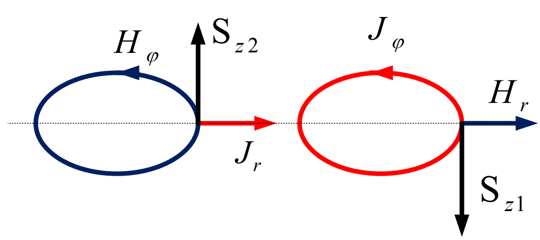


Fig. 6.

3.3. In each point of a cylinder surface there are two electromagnetic fluxes circumferentially directed with densities

$$S_{\varphi 1} = \rho J_z H_r, \quad S_{\varphi 2} = -\rho J_r H_z, \tag{10}$$

- see Fig. 7. Total circumferentially directed flux density in each point of the cylinder surface,

$$S_\varphi = S_{\varphi 1} + S_{\varphi 2} = \rho\left(J_z H_r - J_r H_z\right) \tag{11}$$

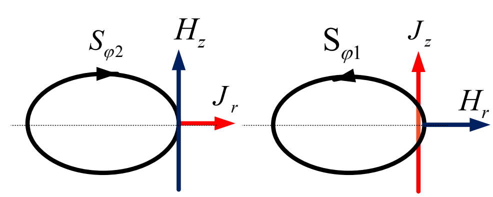


Fig. 7.

In view of the above, we can write the equation for electromagnetic flux density in a direct current wire:

$$S=\begin{bmatrix}S_r\\ S_\varphi\\ S_z\end{bmatrix}=\rho(J\times H)=\rho\begin{bmatrix}J_\varphi H_z-(J_z+J_o)(H_\varphi+H_{o\varphi})\\ J_z H_r-J_r H_z+J_o H_r\\ J_r H_\varphi-J_\varphi H_r+J_r H_{o\varphi}\end{bmatrix}. \tag{12}$$

Additional components in (12) appears due to the fact that energy fluxes are influenced by current density J_o and intensity

$$H_{o\varphi}=J_o r \tag{13}$$

- see (2.4). We substitute (13) into (12):

$$S=\begin{bmatrix}S_r\\ S_\varphi\\ S_z\end{bmatrix}=\rho(J\times H)=\rho\begin{bmatrix}J_\varphi H_z-(J_z+J_o)(H_\varphi+J_o r)\\ J_z H_r-J_r H_z+J_o H_r\\ J_r H_\varphi-J_\varphi H_r+J_r J_o r\end{bmatrix}. \tag{14}$$

Formula evaluation is very cumbersome and goes beyond the scope of this book. From this formula, we will select only a part of the form

$$\overline{S}=\begin{bmatrix}S_r\\ S_\varphi\\ S_z\end{bmatrix}=\rho(J\times H)=\rho\begin{bmatrix}J_\varphi H_z-J_z H_\varphi\\ J_z H_r-J_r H_z\\ J_r H_\varphi-J_\varphi H_r\end{bmatrix}. \tag{15}$$

We denote by:

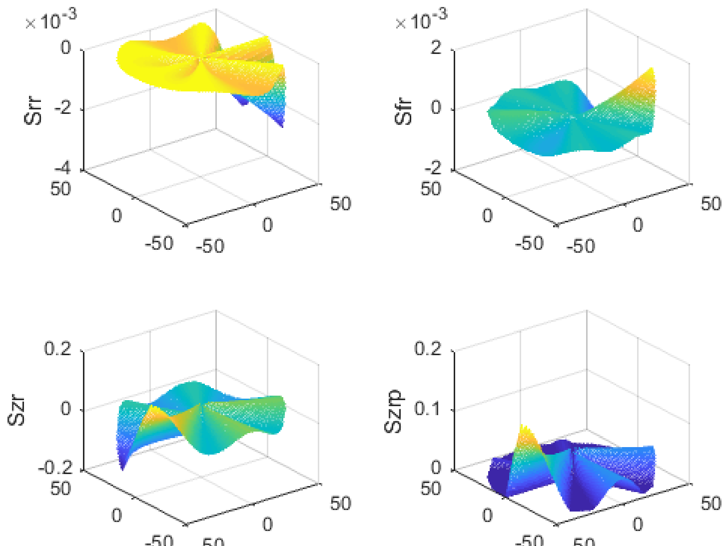
$$\begin{bmatrix}\overline{S_r}(r)\\ \overline{S_\varphi}(r)\\ \overline{S_z}(r)\end{bmatrix}=\begin{bmatrix}(j_\varphi h_z-j_z h_\varphi)\\ (j_z h_r-j_r h_z)\\ (j_r h_\varphi-j_\varphi h_r)\end{bmatrix}. \tag{16}$$

It follows from (2.12-2.17, 15, 16) that

$$\overline{S}=\begin{bmatrix}S_r\\ S_\varphi\\ S_z\end{bmatrix}=\rho\iiint\limits_{r,\varphi,z}\begin{bmatrix}\overline{S_r}(r)\cdot si^2\\ \overline{S_\varphi}(r)\cdot si\cdot co\\ \overline{S_z}(r)\cdot si\cdot co\end{bmatrix}dr\cdot d\varphi\cdot dz. \tag{17}$$

In Fig. 3.3 shows the functions (17) with $z=const$. The fourth window shows the function

$$Sp_z(r,\varphi)=\begin{cases}S_z(r,\varphi), \text{ if } S_z(r,\varphi)>0,\\ 0, \text{ if } S_z(r,\varphi)\le 0.\end{cases}$$



(forFig32.m) Fig. 3.3

Formula (17) refers to a solution in the form of functions (2.12-2.17). This solution has the form of functions

$$J_r = j_r co, \tag{21}$$

$$J_\varphi = j_\varphi si, \tag{22}$$

$$J_z = j_z si, \tag{23}$$

$$H_r = h_r co, \tag{24}$$

$$H_\varphi = h_\varphi si, \tag{25}$$

$$H_z = h_z si, \tag{26}$$

where the functions $j_r, j_\varphi, j_z, h_r, h_\varphi, h_z$, are found above. Obviously, it is similarly possible to find a solution for functions (21-26) in the form

$$\bar{J}_r = \bar{j}_r si, \tag{27}$$

$$\bar{J}_\varphi = \bar{j}_\varphi co, \tag{27a}$$

$$\bar{J}_z = \bar{j}_z co, \tag{28}$$

$$\bar{H}_r = \bar{h}_r si, \tag{30}$$

$$\bar{H}_\varphi = \bar{h}_\varphi co, \tag{31}$$

$$\bar{H}_z = \bar{h}_z co. \tag{32}$$

If both solutions exist simultaneously, the energy flux densities must be calculated by analogy with (16, 17):

$$S_r = J_\varphi H_z + J_\varphi \bar{H}_z + \bar{J}_\varphi H_z + \bar{J}_\varphi \bar{H}_z - J_z H_\varphi - J_z \bar{H}_\varphi - \bar{J}_z H_\varphi - \bar{J}_z \bar{H}_\varphi$$

or

$$S_r = \rho \iiint_{r,\varphi,z} \boxed{S_r} dr d\varphi dz \tag{33}$$

where

$$\boxed{S_r} = (j_\varphi h_z - j_z h_\varphi) si^2 + (\bar{j}_\varphi h_z - \bar{j}_z \bar{h}_\varphi) co^2 + (j_\varphi \bar{h}_z + \bar{j} h_z - j_z \bar{h}_\varphi - \bar{j}_z h_\varphi) si \cdot co$$

The integral of the last term in this formula is zero, so we can assume that

$$\boxed{S_r} = (j_\varphi h_z - j_z h_\varphi) si^2 + (\bar{j}_\varphi h_z - \bar{j}_z \bar{h}_\varphi) co^2. \tag{34}$$

Similarly, we find

$$S_\varphi = \rho \iiint_{r,\varphi,z} \boxed{S_\varphi} dr d\varphi dz \quad , \tag{35}$$

where

$$\boxed{S_\varphi} = (j_z \bar{h}_r - \bar{j}_r h_z) si^2 + (\bar{j}_z h_r - j_r \bar{h}_z) co^2; \tag{36}$$

$$S_z = \rho \iiint_{r,\varphi,z} \boxed{S_z} dr d\varphi dz, \tag{37}$$

where

$$\boxed{S_z} = (\bar{j}_r h_\varphi - j_\varphi \bar{h}_r) si^2 + (j_r \bar{h}_\varphi - \bar{j}_\varphi h_r) co^2. \tag{38}$$

It can be shown that the functions $j_r, j_\varphi, j_z, h_r, h_\varphi, h_z$ and the functions $\bar{j}_r, \bar{j}_\varphi, \bar{j}_z, \bar{h}_r, \bar{h}_\varphi, \bar{h}_z$ are pairwise equal. At the same time from (34, 36, 38) we find:

$$\boxed{S_r} = (j_\varphi h_z - j_z h_\varphi), \tag{39}$$

$$\boxed{S_\varphi} = (j_z h_r - j_r h_z), \tag{40}$$

$$\boxed{S_z} = (j_r h_\varphi - j_\varphi h_r). \tag{41}$$

Substituting (39-41) into (33, 35, 37) respectively, we get:

$$S_r = \rho \int_r \boxed{S_r} dr = const, \tag{42}$$

$$S_\varphi = \rho \int_\varphi \boxed{S_\varphi} dr = const, \tag{43}$$

$$S_z = \rho \int_z \boxed{S_z} dr = const. \tag{44}$$

The constancy of these quantities indicates the implementation of the law of conservation of energy. On the other hand, this means that **both**

solutions with different polarizations exist in the wire simultaneously.

So, in a wire the streams of electromagnetic energy circulate, keeping a constant value. They are internal. They are generated by currents and magnetic intensities generated by these currents. In turn, these flows affect the currents, as Lorentz forces. In this case, the total energy of these streams is partially spent on heat loss, but is mainly transferred to the load.

Longitudinal energy flow $\bar{S}_z$ equal to the power P transmitted over the wire:

$$P = S_z. \tag{45}$$

Note that this power varies along the wire, since part of the energy is spent on heat losses (for more details see section 6).

4. Speed of energy motion

Let us consider the speed of energy motion in a constant current wire. Just as in Chapter 1, we will use the concept of Umov [81], according to which the energy flux density s is a product of the energy density w and the velocity v_e of energy movement:

$$s = w \cdot v_e . \tag{1}$$

We will only consider the flow of energy along the wire. This flux is equal to the power P transmitted over the wire to the load:

$$s = P/\pi R^2 , \tag{2}$$

where R is the radius of the wire. The internal energy of the wire is the energy of the magnetic field of the main current I_o. This energy is

$$\mathrm{W}_m = \frac{L_i L I_o^2}{2}, \tag{3}$$

where L is the length of the wire, L_i the inductance of a unit of the wire length, and [83]

$$L_i \approx \frac{\mu_o}{2\pi} ln \frac{1}{\mathrm{R}} . \tag{4}$$

Wire volume

$$\mathrm{V} = L\pi \cdot R^2 . \tag{5}$$

From (3-5), we find the energy density in the wire

$$\mathrm{w} = \frac{\mathrm{W}_m}{V} = \frac{L_i I_o^2}{2\pi R^2} . \tag{6}$$

From (1, 2, 6) we find the velocity of the energy motion

$$v_\varphi = \frac{s}{w} = \frac{P}{\pi R^2} \Bigg/ \left(\frac{L_i I_o^2}{2\pi R^2} \right) = \frac{2P}{L_i I_o^2}. \tag{7}$$

Load resistance

$$R_H = \frac{P}{I_o^2} \tag{8}$$

Consequently,

$$v_\varphi = \frac{2R}{L_i}. \tag{9}$$

For example, if $R = 10^{-3}$ and $R_H = 1$, we have: $\ln\frac{1}{r} \approx 7$, $L_i \approx \frac{\mu_o}{2\pi}\ln\frac{1}{r} \approx 7 \cdot 10^{-7}$, $v_\varphi = 3 \cdot 10^6$. This speed is much less than the speed of light in a vacuum. With this speed, energy flows into the wire and out of it flows into the load. We do not take into account the energy of heat losses, since it is not transferred to the load.

When the load is switched on, the current in the wire increases according to the function

$$I_o = \frac{U}{R_H}\left(1 - exp\left(-\frac{t}{\tau}\right)\right), \tag{10}$$

where is the input voltage and

$$\tau = \frac{L_i L}{R_H}. \tag{11}$$

From (9, 10) we find:

$$v_\varphi = \frac{2P}{L_i I_o^2} = \frac{2U}{L_i I_o} = \frac{2U}{L_i} \Bigg/ \frac{U}{R}\left(1 - exp\left(-\frac{t}{\tau}\right)\right) = \frac{2R}{L_i} \Bigg/ \left(1 - exp\left(-\frac{t}{\tau}\right)\right). \tag{12}$$

Thus, the speed of energy moving in the transient process decreases from infinity (the speed of light in a vacuum) to the value (9).

5. The speed of energy from the batter

The characteristics of the "average battery" are presented below [92]:

Em - battery capacity	60 Ah
P is the density of the electrolyte	1250 kg / m ^ 3
G - weight of electrolyte	1.5 kg
V = G/p is the volume of the electrolyte	0.0012 m ^ 3
R - load resistance	0.047 Ohm
U - voltage on the load	12.8 V
I - load current (starting)	270 A
P = U * I = U ^ 2 / R - load power	3456 W

W = 3600 * Em * U - energy of the condenser (electrolyte)	2764800J
w = W / V is the energy density	2.3 * 10 ^ 9 J \ m ^ 3
S = P - energy flow 3456 W	
b - wire cross-section	100 mm ^ 2
s = S / (b * 10 ^ -6) - energy flux density	3.5 * 10 ^ 7 Wt
$v_\varphi = \frac{w}{s}$ - speed of energy movement	100 m / s
c is the speed of light	300 * 10 ^ 6 m / s

Thus, the speed of energy movement on the wire from the battery is **much less** than the speed of light.

6. Practical calculations

For the convenience of the reader, we combine all the calculated ratios given above.

Section 2 defines the density of the main current J_o, the density of additional currents J_r, J_φ, J_z and magnetic intensities, which have the following form:

$$J_r. = j_r(r) \cdot \mathrm{co}, \tag{2.12}$$

$$J_\varphi. = j_\varphi(r) \cdot \mathrm{si}, \tag{2.13}$$

$$J_z. = j_z(r) \cdot \mathrm{si}, \tag{2.14}$$

$$H_r. = h_r(r) \cdot \mathrm{co}, \tag{2.15}$$

$$H_\varphi. = h_\varphi(r) \cdot \mathrm{si}, \tag{2.16}$$

$$H_z. = h_z(r) \cdot \mathrm{si}, \tag{2.17}$$

where

$$\mathrm{co} = \cos(\alpha\varphi + \chi z), \tag{2.10}$$

$$\mathrm{si} = \sin(\alpha\varphi + \chi z), \tag{2.11}$$

where, in turn, α, χ are some constants and $j(r)$, $h(r)$ are some functions of the coordinate r, having the following form:

$$j_\varphi(r) = F_\alpha(r), \tag{2.25}$$

$$j_r(r) = \frac{-1}{\alpha}\left(j_\varphi(r) + r \cdot j'_\varphi(r)\right), \tag{2.26}$$

$$j_z(r) = \frac{\chi}{\alpha} r \cdot j_\varphi(r), \tag{2.27}$$

$$h_z(r) = \frac{1}{2\propto}\int_{r=R}^{0} \vartheta_z(r)dr, \tag{2.28}$$

$$h_\varphi(r) = \frac{1}{\chi}\left(\frac{h_z(r)}{r}\alpha - j_r(r)\right) \tag{2.29}$$

$$h_r(r) = \frac{-1}{\chi}\left(j_\varphi(r) + h_z'(r)\right). \tag{2.30}$$

Here the function (2.25) is defined in Appendix 3 and has the following form:

$$\frac{\partial^2 j_\varphi(r)}{\partial r^2} + \frac{3}{r}\frac{\partial j_\varphi(r)}{\partial r} - j_\varphi(r)\left(\frac{\alpha^2 - 1}{r^2} + \chi^2\right) = 0. \tag{2}$$

Appendix 3 shows that to solve this equation, the quantities $A, \propto, \chi$ should be specified.

From (3.45) we have

$$P = S_z. \tag{3}$$

Note that this power varies along the wire, since part of the energy is spent on heat loss.

Appendix 4 shows that $h_z(r)$ can take any value depending on $A, \propto, \chi$. However, from practice it is known that $h_z(r) = 0$. We will therefore assume in the calculations that for a conductor outside the magnetic field

$$h_z(r) \approx 0, \tag{5}$$

and for a conductor in a magnetic field, $h_z(r)$ is known.

6.1. Conductor outside the magnetic field

In this case, equations (2.28-230) take the form:

$$h_\varphi(r) = -\frac{1}{\chi} j_r(r), \tag{6}$$

$$h_r(r) = -\frac{1}{\chi} j_\varphi(r). \tag{7}$$

$$\int_{r=R}^{0} \vartheta_z(r) dr = 0. \tag{8}$$

In this case, the calculation is to solve the system of equations (2.25-2.27, 6-7, 3) with known $P, \cdot J_o$ _o and unknowns $j_r(r), j_\varphi(r), j_z(r), h_\varphi(r), h_r(r), A, \alpha, \chi$.

6.2. Conductor in a magnetic field

In this case, the calculation consists in solving the system of equations (2.25-2.20, 3) with the known $P, \cdot J_o, h_z(r)$ and unknowns $j_r(r), j_\varphi(r), j_z(r), h_\varphi(r), h_r(r), A, \alpha, \chi$.

7. Discussion

So, the complete solution of Maxwell's Equations for a wire with direct current consists of two parts:

1) known equation (3.13) in the following form: $H_{o\varphi} = J_o r$, and
2) equations (2.10-2.17, 2.25-2.30) obtained above.

The energy flow along the wire's axis S_z is created by the currents and intensities directed along the radius and the circles. This energy flow is equal to the power released in the load R_H and in the wire resistance. The currents flowing along the radius and the circle are also creating heat losses. Their powers are equal to the energy flows S_r, S_φ, directed along radius and circle.

The question of the way by in which the electromagnetic energy creates current is considered in [19]. There it is shown that there exists a fourth electromagnetic induction created by a change in electromagnetic energy flow. Further we must find the dependence of emf of this induction from the electromagnetic flow density and from the wire parameters. There is a well-known experiment which can provide evidence for existence of this type of induction [17].

It is shown that direct current has a complex structure and extends **inside** the wire along a helical trajectory. In the case of constant current the density of helical trajectory decreases with the decrease of the remaining load resistance. There are two components of the current. The density of the first component J_o is permanent of the whole wire section. The density of the second component is changing along the wire section so that the current is spreading n a spiral. In cylindrical coordinates r, φ, z this second component has coordinates J_r, J_φ, J_z. They can be found as the solution of Maxwell equations.

With invariable density of the main current in a wire the power transmitted by it depends on the structure parameters (α, χ) which influence the density of the turns of helical trajectory. Thus, the same current in a wire can transmit various values of power (depending on the load).

Let us again look at the Fig 1. On segment **AB** the wire transmits the load energy **P.** It is corresponded by a certain values of (α, χ) and the density of coils of the current's helical path. On the segment **CD** the wire transmits only small amount of energy. It corresponds to small value of χ and small density of the coils of current's helical path.

Naturally, the resistivity of the wire itself is also a load. Thus, as the current flows within the wire, the helix of the current's path straightens.

Thus, it is shown that there exists such a solution of Maxwell equations for a wire with constant current which corresponds to the idea of

- law of energy preservation
- helical path of constant current in the wire,
- energy transmission along and inside the wire,
- the dependence of helical path density on the transmitted strength.

Appendix 1

Let us consider the solution of equations (2.5-2.9) in the form of (2.12-2.17). Further the derivatives of r will be designated by strokes. In this case, we rewrite the equations (2.1-2.8) in the following order (2.5, 2.1, 2.2, 2.3, 2.4, 2.6, 2.7, 2.8) and renumber them:

$$\frac{j_r(r)}{r}+\frac{d}{dr}\big(j_r(r)\big)+\frac{j_\varphi(r)}{r}\alpha+\chi j_z(r)=0, \qquad (2.5) \qquad (1)$$

$$\frac{h_r(r)}{r}+h'_r(r)+\frac{h_\varphi(r)}{r}\alpha+\chi h_z(r)=0, \qquad (2.1) \qquad (2)$$

$$\frac{h_z(r)}{r}\alpha-\chi h_\varphi(r)=j_r(r), \qquad (2.2) \qquad (3)$$

$$-h_r(r)\chi-h'_z(r)=j_\varphi(r), \qquad (2.3) \qquad (4)$$

$$\frac{h_\varphi(r)}{r}+h'_\varphi(r)+\frac{h_r(r)}{r}\alpha=j_z(r), \qquad (2.4) \qquad (5)$$

$$\frac{j_z(r)}{r}\alpha-\chi j_\varphi(r)=0, \qquad (2.6) \qquad (6)$$

$$-j_r(r)\chi-\frac{d}{dr}\big(j_z(r)\big)=0, \qquad (2.7) \qquad (7)$$

$$\frac{j_\varphi(r)}{r}+\frac{d}{dr}\big(j_\varphi(r)\big)+\frac{j_r(r)}{r}\alpha=0. \qquad (2.8) \qquad (8)$$

First, we consider a group of 4 equations (1, 6, 7, 8) with respect to 3 unknown functions $j(r)$. Appendix 2 shows that these four equations are compatible, and equation (7) follows from equations (1, 6, 8). Wherein

$$j_\varphi(r)=F_\alpha(r). \qquad (14)$$

$$j_z(r)=-\frac{\chi}{\alpha}r\cdot j_\varphi(r), \qquad (15)$$

$$j_r(r) = \frac{1}{\alpha}\left(j_\varphi(r) + r \cdot j'_\varphi(r)\right). \tag{16}$$

The function $F_\alpha(r)$ is defined in Appendix 2. Having functions $j(r)$ known we solve the system of 4 equations (2-5) with respect to 3 unknown functions $h(r)$. From (3, 4) we find:

$$h_\varphi(r) = -\frac{1}{\chi}\left(\frac{\alpha}{r} \cdot h_z(r) - j_r(r)\right), \tag{17}$$

$$h_r(r) = \frac{1}{\chi}\left(j_\varphi(r) + h'_z(r)\right). \tag{18}$$

Let us use (17, 18) in (2). So we will find

$$\frac{-1}{r\chi}\left(j_\varphi(r) + h'_z(r)\right) - \frac{1}{\chi}\left(j'_\varphi(r) + h''_z(r)\right) + \frac{\alpha}{r\chi}\left(\frac{\alpha}{r} \cdot h_z(r) - j_r(r)\right) = 0$$

or

$$\left(\frac{\alpha^2}{r} \cdot h_z(r) - h'_z(r) - r h''_z(r)\right) - \left\{\alpha \cdot j_r(r) + j_\varphi(r) + r j'_\varphi(r)\right\} = 0. \tag{19}$$

In Appendix 4, the solution of equation (19) is found. It has the following form:

$$h_z(r) = \frac{1}{2\propto}\int_{r=R}^{0} \vartheta_z(r)dr. \tag{20}$$

where the function $\vartheta_z(r)$ is defined in Appendix 4.

Thus the required functions $j_r(r),\ j_\varphi(r),\ j_z(r),\ h_r(r),\ h_\varphi(r),\ h_z(r)$ shall be determined by (14, 16, 15, 18, 17, 20), respectively.

<u>The resulting solution did not use equation (2)</u>. Now we substitute (17, 18) into (2). Then we find

$$-\frac{1}{\chi r}\left(\dot{h}_z(r) + j_\varphi(r)\right) - \frac{1}{\chi}\left(\ddot{h}_z(r) + \frac{\partial}{\partial r} j_\varphi(r)\right)$$
$$+ \frac{\alpha}{\chi r}\left(\frac{\alpha}{r} h_z(r) - j_r(r)\right) + \chi h_z(r) = 0$$

or

$$-\left(\dot{h}_z(r) + j_\varphi(r)\right) - r\left(\ddot{h}_z(r) + \frac{\partial}{\partial r} j_\varphi(r)\right)$$
$$+ \alpha\left(\frac{\alpha}{r} h_z(r) - j_r(r)\right) + \chi^2 r h_z(r) = 0$$

or

$$\left(\chi^2 r + \frac{\alpha^2}{r}\right) h_z(r) - \dot{h}_z(r) - r\ddot{h}_z(r) -$$
$$\left(j_\varphi(r) + r\frac{\partial}{\partial r} j_\varphi(r) + \alpha j_r(r)\right) = 0. \tag{22}$$

In the above transformations, equation (2) was not used. Thus, the equation $\mathrm{div}(H)=0$ from which equation (2) is derived is transformed into equation (22). With the previously found functions $h_z(r), j_r(r), j_\varphi(r), j_z(r)$, this equation (22) is not always fulfilled, i.e. equation $\mathrm{div}(H)=0$ is not always fulfilled. Chapter 14 shows that

$div(H)=0$, if all currents $(j_r(r), j_\varphi(r), j_z(r))$ are missing	(23)
$div(H)\neq 0$, if all currents $(j_r(r), j_\varphi(r), j_z(r))$ exist.	

In this regard, we note that experiments also indicate that the divergence of magnetic intensity is not zero everywhere. Indeed, the observation of magnetic lines of force in sawdust or magnetic fluid suggests that the intensity on such a line is different from the intensity in the nearest vicinity - see, for example, fig. 2a in section 2. This is possible only when the divergence experiences a jump.

Therefore, you can search for a solution to the problem, excluding the equations of the divergence of magnetic intensity. Only the equality of this divergence to zero **on average** requires verification.

On the other hand, the free term on the right (instead of zero) in equation (22) can be considered as the density of magnetic **monopoles**. Chapter 14 shows that this implies the existence of magnetic **dipoles** in a conductor.

Appendix 2.

Let us consider equations (1, 6, 7, 8) from Appendix 1 and enumerate them:

$$\frac{j_r(r)}{r}+j_r'(r)+\frac{j_\varphi(r)}{r}\alpha+\chi\cdot j_z(r)=0, \tag{1}$$

$$\frac{1}{r}\cdot j_z(r)\alpha-j_\varphi(r)\chi=0, \tag{6}$$

$$-j_r(r)\chi-j_z'(r)=0, \tag{7}$$

$$\frac{j_\varphi(r)}{r}+j_\varphi'(r)+\frac{j_r(r)}{r}\cdot\alpha=0. \tag{8}$$

From (6) we find:

$$j_z(r)=\frac{\chi}{\alpha}r\cdot j_\varphi(r), \tag{11}$$

$$j_z'(r) = \frac{\chi}{\alpha}\left(j_\varphi(r) + r \cdot j_\varphi'(r)\right). \tag{12}$$

From (7, 12) we find:

$$-j_r(r)\chi - \frac{\chi}{\alpha}\left(j_\varphi(r) + r \cdot j_\varphi'(r)\right) = 0,$$

or

$$\frac{j_\varphi(r)}{r} + j_\varphi'(r) + \frac{j_r(r)}{r} \cdot \alpha = 0. \tag{13}$$

But equation (13) coincides with (8). Therefore, equation (7) can be excluded from the system of equations (1, 6, 7, 8).
From (6) we find:

$$j_\varphi = \frac{\alpha}{r\chi} \cdot j_z, \tag{14}$$

From (1, 14) we find:

$$\frac{j_r(r)}{r} + j_r'(r) + \alpha\frac{j_\varphi(r)}{r} + \frac{\chi^2}{\alpha} r \cdot j_\varphi(r) = 0. \tag{15}$$

From (8) we find:

$$j_r(r) = -\frac{1}{\alpha}\left(j_\varphi(r) + r \cdot j_\varphi'(r)\right), \tag{16}$$

$$j_r'(r) = -\frac{1}{\alpha}\left(2 j_\varphi'(r) + r \cdot j_\varphi''(r)\right). \tag{17}$$

From (15-17) we find:

$$-\frac{1}{\alpha}\left(\frac{j_\varphi(r)}{r} + j_\varphi'(r)\right) - \frac{1}{\alpha}\left(2 j_\varphi'(r) + r \cdot j_\varphi''(r)\right) + \alpha\frac{j_\varphi(r)}{r} + \frac{\chi^2}{\alpha} r \cdot j_\varphi(r) = 0. \tag{18}$$

Simplifying (18), we get:

$$-\left(\frac{j_\varphi(r)}{r} + \frac{\partial j_\varphi(r)}{\partial r}\right) - \left(2\frac{\partial j_\varphi(r)}{\partial r} + r\frac{\partial^2 j_\varphi(r)}{\partial r^2}\right) + \alpha^2\frac{j_\varphi(r)}{r} + \chi^2 r j_\varphi(r) = 0$$

or

$$j_\varphi(r)\left(\frac{\alpha^2 - 1}{r} + \chi^2 r\right) - 3\frac{\partial j_\varphi(r)}{\partial r} - r\frac{\partial^2 j_\varphi(r)}{\partial r^2} = 0 \tag{19}$$

or

$$\frac{\partial^2 j_\varphi(r)}{\partial r^2} + \frac{3}{r}\frac{\partial j_\varphi(r)}{\partial r} - j_\varphi(r)\left(\frac{\alpha^2 - 1}{r^2} + \chi^2\right) = 0 \tag{20}$$

Equation (20) is a modified Bessel equation - see Appendix 3. Further, we will denote this solution as $F_\alpha(r)$. So,

$$j_\varphi(r) = F_\alpha(r), \tag{21}$$

$$j'_\varphi(r) = \frac{d}{dr} F_\alpha(r), \tag{22}$$

Appendix 3.

Equation (9) from Appendix 2 is a modified Bessel equation, which has the following form:

$$\ddot{y} + 3\frac{\dot{y}}{x} - y\left(\frac{\alpha^2 - 1}{x^2} + \chi^2\right) = 0, \tag{1}$$

When $x \to 0$ equation (1) takes the form:

$$\ddot{y} + 3\frac{\dot{y}}{x} - y\chi^2 = 0. \tag{2}$$

His solution is:

$$y = Ax^\beta, \tag{3}$$

where A is a constant, and β is determined from the equation

$$\beta^2 + 3\beta - \chi^2 = 0, \tag{4}$$

i.e.

$$\beta = \frac{1}{2}\left(-3 \pm \sqrt{3 + 4\chi^2}\right), \ \ \beta < 0. \tag{5}$$

Thus, at the first iterations, you can search for a function y in the form (3), and then calculate it by (2). Therefore, to calculate by (1, 3), the values $A, \propto, \chi$ must be known.

In fig. 1, for example, the Bessel function and its derivatives are shown for $A = 1, \propto = 1.5, \chi = 0.4$.

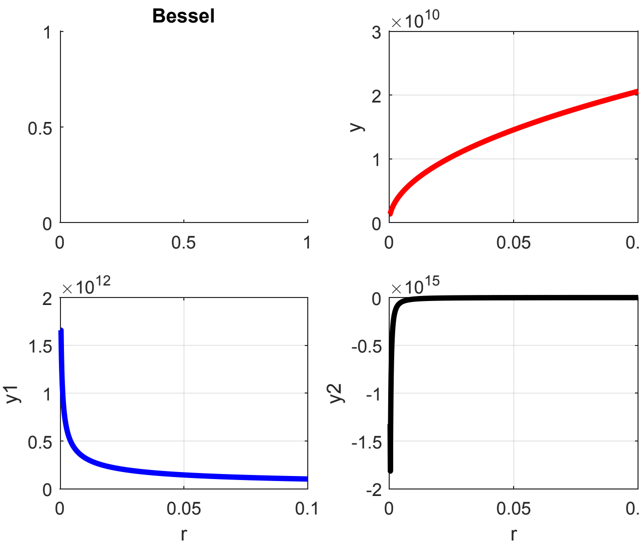

Bessel
1
0.5
0
0
0.5
1
×10^10
3
2
1
0
y
0
0.05
0.1
×10^12
2
1.5
1
0.5
0
y1
0
0.05
0.1
r
×10^15
0
-0.5
-1
-1.5
-2
y2
0
0.05
0.1
r

Fig. 1.

Chapter 5a. Milroy Engine

Contents

1. Introduction

The Milroy Engine (ME) [67] is well known. In "youtube" you can view experiments with ME [68-73]. There are attempts to theoretically explain the functioning of ME [74-77, 80]. In [80] the functioning of this engine is explained by the action of non-potential lateral Lorentz forces. In [74] the functioning of this engine is explained by the interaction of magnetic flow created by current spiral *I* in the shaft and modulated variable reluctance of the gap between the holders of the bearing with the currents inducted in the inner holder of the bearing. Without discussing the validity of these theories, it should be noted that they were not brought to the stage when they could be used to calculate ME technical parameters. But such calculations are necessary before mass production begins.

The photographs at the end of the chapter show the various ME constructions. Conductive shaft with flywheels can rotate in two bearings. Through the outer rings of the bearing and through the shaft an electric current is passed. The shift begins to spin up to any side after the first jot.

Along with a very simple design, ME has two considerable disadvantages:

1. Low efficiency
2. Initial acceleration of ME with other engine / motor (in the process ME continues rotation in the direction it was jerked for starting and increases the speed).

It should be noted that the latter disadvantage often has no importance. For example, ME installed on a bicycle could be accelerated by the bicyclist.

The engine ME presented by English physicist R. Milroy in the year 1967 [67]. V.V. Kosyrev, V.D. Ryabkov and N.N. Velman before Milroy in 1963 presented an engine of different construction [82]. Their engine differs fundamentally from the Milroy engine by the absence of one of bearings. The conductive shaft is pressed into the inner ring of the horizontal bearing. So the shaft is hanging on the bearing. The electrical circuit is closed through the outer ring of the bearing and the brush touching the lower face of the shaft. The authors see the cause of rotation in the fact that the shaft "rotates as a result of elastic deformation of the engine's parts when they are heated by electric current flowing through them".

Finally, often the functioning of this engine is explained by the Hoover's effect [77, 84].

Below we are giving another explanation of this engine's operating principle. We show that **inside** the conductor with current there appears a torque. It seems to the author that the Kosyrev's engine cannot be explained in another way.

2. Mathematical model

In Chapter 5, we considered solutions of Maxwell equations for wire with direct current with density J_{oz}. The density of this current is the same over the entire section of the wire. Maxwell equations in this case have the following form:

$$\mathrm{rot}(J) = 0, \tag{a}$$

$$\mathrm{rot}(H) - J = 0, \tag{b}$$

$$\mathrm{div}(J) = 0, \tag{c}$$

$$\mathrm{div}(H) = 0, \tag{d}$$

and current density J_{oz} is not included in equations (a, d) since all derivatives of this current are equal to zero.

It was shown that the complete solution of Maxwell equations in this case consists of two parts:

1) known equation of the form

$$H_{o\varphi} = J_{oz} r, \tag{1}$$

2) equations of the form (5.2.10-5.2.17) and (5.2.25-5.2.30) obtained in Chapter 5; these equations combine magnetic

intensities and current densities with known constants $(\alpha,\ \chi)$ and wire radius R.

The currents and intensities determined by these equations are formally independent of the given current J_{oz}. However, they define the flow of energy transmitted through the wire, i.e. that capacity which is produced by load current.

Below we consider the case when there is DC current directed along the circumference, ring current. For example, the coil of the solenoid can be represented as a solid ring cylinder with direct current around its circumference. We denote the density of this given current as $J_{o\varphi}$. Just as in the case of the given current J_{oz} the complete solution of Maxwell equations (a-d) in this case consists of two parts:

1) known equation of the form

$$-\frac{\partial H_{z0}}{\partial r} = J_{\varphi 0}, \tag{17}$$

2) equations (5.2.10-5.2.17) and (5.2.25-5.2.30).

Let us consider the source of current $J_{o\varphi}$. If there is no rotation of the rod, the direct current with density J_{oz} flows through it. Free electrons of this current move with some velocity along the rod. When the rod rotates, free electrons of this current also acquire the circumferential velocity. Thus, there is so called convection current, which is the current with density $J_{o\varphi}$. Aikhenvald has shown [86] that the convection current creates also the magnetic intensity. Therefore, the current with density $J_{o\varphi}$ creates the magnetic intensity (17).

Thus, the charges with density q and velocity v (*velocity of electrons in the wire)* move along the wire in the current J_o, where

$$J_o = qv. \tag{18}$$

If the rod rotates with angular rotation ω, then

$$J_{\varphi 0} = q\omega \cdot r \tag{19}$$

or, with consideration of (4),

$$J_{\varphi 0}(r) = J_o \omega \cdot r/v. \tag{20}$$

Consequently, in the rotating rod of the Milroy engine the direct convection current with density (20) flows along the wire circumference together with axial current J_o.

From (17, 20) we find:

$$H_{zo} = \frac{J_o \omega \cdot r^2}{2v}. \tag{21}$$

Further, it will be shown that the solution of equations (1-16) implies the existence of driving moment M in the rod. This driving moment increases the rotation speed, thereby increasing the convection current $J_{o\varphi}$. Balance occurs when the specified driving moment and the braking moment on the engine shaft are equal (at given current J_{oz}). This phenomenon is analogous to the fact that the currents flowing along the wire, under the influence of Ampere force, shift the wire as a whole (in ordinary electric motors).

Finally, it is possible to imagine a design where an additional radial magnetic intensities H_{or} is created in the rod.
One can also imagine a design where an additional axial magnetic intensities H_{2oz} is created in the rod.

3. Electromagnetic energy flux

Section 3 of Chapter 5 shows that the electromagnetic flux density and Lorentz magnetic force density in DC wire are connected by the following relationships:

$$S = E \times H, \tag{1}$$

$$S = \rho J \times H = \frac{\rho}{\mu} J \times B, \tag{3}$$

$$F = J \times B, \tag{4}$$

$$F = \mu S / \rho, \tag{5}$$

where ρ, μ - electrical resistivity and magnetic permeability. Consequently, in a wire with direct current the density of Lorentz magnetic force is proportional to Poynting vector.

In cylindrical coordinates, the densities of these flows of energy by coordinates are expressed by the formula of the form – see (5.3.12):

$$S = \begin{bmatrix} S_r \\ S_\varphi \\ S_z \end{bmatrix} = \rho (J \times H) = \rho \begin{bmatrix} J_\varphi H_z - (J_z + J_o)(H_\varphi + H_{o\varphi}) \\ J_z H_r - J_r H_z + J_o H_r \\ J_r H_\varphi - J_\varphi H_r + J_r H_{o\varphi} \end{bmatrix}. \tag{6}$$

For Milroy engine, this formula is amended due to values H_{zo}, $J_{\varphi o}$ and takes the following form:

$$S = \begin{bmatrix} S_r \\ S_\varphi \\ S_z \end{bmatrix} = \rho\left(J \times H\right) = \rho \begin{bmatrix} \left(J_\varphi + J_{\varphi o}\right)\left(H_z + H_{zo}\right) - \left(J_z + J_o\right)\left(H_\varphi + H_{o\varphi}\right) \\ \left(J_z + J_o\right)H_r - J_r\left(H_z + H_{zo}\right) \\ J_r\left(H_\varphi + H_{o\varphi}\right) - \left(J_\varphi + J_{\varphi o}\right)H_r \end{bmatrix}. \quad (7)$$

According to (5) we can find Lorentz forces acting on volume unit,

$$F = \begin{bmatrix} F_r \\ F_\varphi \\ F_z \end{bmatrix} = \frac{\mu}{\rho}\begin{bmatrix} S_r \\ S_\varphi \\ S_z \end{bmatrix}. \quad (8)$$

3a. Torque

In (3.8), in particular, F_φ is the rotational force acting on the shaft in the volume unit of layer with radius r. Therefore, density of driving moment acting on the shaft in the layer with radius r is equal to:

$$\mathrm{M}(r) = r \cdot F_\varphi. \quad (9)$$

From (7, 8) we can find:

$$S_\varphi = \rho\left[\left(J_z + J_o\right)H_r - J_r\left(H_z + H_{zo} + H_{2zo}\right)\right], \quad (11)$$

$$F_\varphi = \frac{\mu}{\rho} S_\varphi = \mu\begin{bmatrix} \left(J_z + J_o\right)\left(H_r + H_{ro}\right) - \\ - J_r\left(H_z + H_{zo} + H_{2zo}\right) \end{bmatrix}. \quad (12)$$

From (9, 12) we can find:

$$M(r) = r \cdot F_\varphi = \mu \cdot r\begin{bmatrix} \left(J_z + J_o\right)\left(H_r + H_{ro}\right) - \\ - J_r\left(H_z + H_{zo} + H_{2zo}\right) \end{bmatrix}$$

or, with consideration of (2.21),

$$M(r) = \mu \cdot r\begin{bmatrix} \left(J_z + J_o\right)\left(H_r + H_{ro}\right) - \\ - J_r\left(H_z + H_{2zo} + \dfrac{J_o\omega \cdot r^2}{2v}\right) \end{bmatrix}. \quad (13)$$

In Chapter 5 it is shown that $H_z \equiv 0$. Then

$$M(r) = \mu \cdot r\begin{bmatrix} \left(J_z + J_o\right)\left(H_r + H_{ro}\right) - \\ - J_r\left(H_{2zo} + \dfrac{J_o\omega \cdot r^2}{2v}\right) \end{bmatrix}. \quad (14)$$

Formula (14) determines the density of the torque acting on the shaft in a layer with a radius r. Recall from Chapter 5 that

$$J_r. = -j_r\left(r\right)\cos(\alpha\varphi + \chi z), \quad (15)$$

$$J_z. = j_z\left(r\right)\sin(\alpha\varphi + \chi z), \quad (16)$$

$$H_{r\cdot} = h_r(r)\cos(\alpha\varphi + \chi z), \tag{17}$$

where

$$j_\varphi(r) = F_\alpha(r), \tag{18}$$

$$j_r(r) = \left(j_\varphi(r) + r \cdot j'_\varphi(r)\right)/\alpha, \tag{19}$$

$$j_z(r) = -\frac{\chi}{\alpha} r \cdot j_\varphi(r), \tag{20}$$

$$h_r(r) = j_\varphi(r)/\chi, \tag{21}$$

Here the constants χ, α and the Bessel function $F_\alpha(r)$ are defined in Chapter 5. Combining (14-17), we get:

$$M(r) = \mu \cdot r \begin{bmatrix} \begin{bmatrix} \left(j_z(r)\sin(\alpha\varphi + \chi z) + J_o\right)\cdot \\ \cdot\left(h_r(r)\cos(\alpha\varphi + \chi z) + H_{ro}\right) \end{bmatrix} + \\ - H_{2zo} j_r(r)\cos(\alpha\varphi + \chi z) + \\ + \dfrac{J_o\omega \cdot r^2 j_r(r)}{2v}\cos(\alpha\varphi + \chi z) \end{bmatrix} \tag{22}$$

The total torque is calculated as an integral of the form

$$\overline{M} = \iiint\limits_{r,\varphi,z} M(r)drd\varphi dz. \tag{23}$$

This integral can be represented as the sum of integrals:

$$\overline{M} = \overline{M_1} + \overline{M_2} + \overline{M_3} + \overline{M_4} + \overline{M_5} + \overline{M_6}, \tag{24}$$

where the summands are defined in Appendix 1.

These relationships allow calculation of the mechanical torque in the Milroy engine.

In Appendix 1 it is shown that in the ordinary Milroy engine the magnitude of the moment (21) is negligible, if $\omega = 0$, i.e. there is no starting torque. However, when $H_{ro} \neq 0$ and\or $H_{2zo} \neq 0$ there is a **significant starting torque**.

4. An Additional Experiment

We may propose an experiment in which the previously suggested explanations of the reasons for the rotation of Milroy engine are not acceptable (in the author's view). We should give the opportunity to a rod with current to rotate freely. This can be realized in the following way – see Fig. 2. A copper roll with pointed ends is clamped between two carbon brushes so that it could rotate. The carbon brushes are needed in order that the contacts would not be welded at strong currents. In accordance with the theory contained in this paper, in such a structure the shaft must rotate. This will permit to refrain from the consideration of several hypothesis for the explanation of Milroy engine functioning.

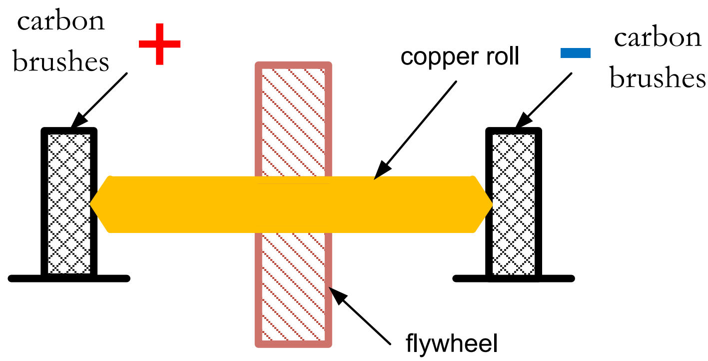


Fig. 2.

5. About the Law of Impulse Conservation

We need to pay attention to the fact that in the Milroy engine the Law of mechanical impulse conservation is clearly violated. This is due to the fact that in the rod there exist an electromagnetic impulse with a flow of electromagnetic energy. And this once more confirms that the torque exists **inside** the wire.

Appendix 1. Calculation of the torque

We transform (3a.22). Then we get:

$$M(r)=\mu\cdot r\left[\begin{array}{l} j_z(r)h_r(r)\sin(\alpha\varphi+\chi z)\cdot\cos(\alpha\varphi+\chi z)+ \\ +j_z(r)\sin(\alpha\varphi+\chi z)H_{ro}+J_oH_{ro}+ \\ +\left[J_o\left(h_r(r)+\dfrac{\omega\cdot r^2 j_r(r)}{2v}\right)-H_{2zo}j_r(r)\right]\cos(\alpha\varphi+\chi z) \end{array}\right].\quad(1)$$

The total torque is calculated as an integral of the form

$$\overline{M}=\iiint\limits_{r,\varphi,z}\mu\cdot r\left[\begin{array}{l} j_z(r)h_r(r)\sin(\ldots)\cdot\cos(\ldots)+ \\ +j_z(r)\sin(\ldots)H_{ro}+J_oH_{ro}+ \\ +\left[J_o\left(h_r(r)+\dfrac{\omega\cdot r^2 j_r(r)}{2v}\right)-H_{2zo}j_r(r)\right]\cos(\ldots) \end{array}\right]drd\varphi dz\,.\quad(2)$$

This integral can be represented as the sum of integrals:

$$\overline{M_1} = \iiint\limits_{r,\varphi,z} \mu \cdot r\left[J_o H_{ro}\right] dr d\varphi dz\,, \tag{3}$$

$$\overline{M_2} = \iiint\limits_{r,\varphi,z} \mu \cdot r\left[j_z(r) h_r(r) \sin(...) \cdot \cos(...)\right] dr d\varphi dz\,, \tag{4}$$

$$\overline{M_3} = \iiint\limits_{r,\varphi,z} \mu \cdot r\left[j_z(r) \sin(...) H_{ro}\right] dr d\varphi dz\,, \tag{5}$$

$$\overline{M_4} = \iiint\limits_{r,\varphi,z} \mu \cdot J_o r h_r(r) \cos(...) dr d\varphi dz\,, \tag{6}$$

$$\overline{M_5} = \iiint\limits_{r,\varphi,z} \mu \cdot J_o r\left(\frac{\omega \cdot r^2 j_r(r)}{2v}\right) \cos(...) dr d\varphi dz\,, \tag{7}$$

$$\overline{M_6} = -\iiint\limits_{r,\varphi,z} \mu \cdot r H_{2zo} j_r(r) \cos(...) dr d\varphi dz \tag{8}$$

or

$$\overline{M_1} = \mu \cdot J_o H_{ro} \iiint\limits_{r,\varphi,z} \cdot r dr d\varphi dz = \mu \cdot J_o H_{ro} \pi R^2 L\,, \tag{9}$$

$$\overline{M_2} = \mu \cdot \left(\int\limits_r M_{2r}(r) dr\right) M_{S2}\,, \tag{10}$$

$$\overline{M_3} = \mu \cdot H_{ro}\left(\int\limits_r M_{3r}(r) dr\right) M_{S3}\,, \tag{11}$$

$$\overline{M_4} = \mu \cdot J_o\left(\int\limits_r M_{4r}(r) dr\right) M_{S4}\,, \tag{12}$$

$$\overline{M_5} = \frac{\mu \cdot \omega}{2v} J_o\left(\int\limits_r M_{5r}(r) dr\right) M_{S4}\,, \tag{13}$$

$$\overline{M_6} = -\mu \cdot H_{2zo}\left(\int\limits_r M_{6r}(r) dr\right) M_{S4}\,. \tag{14}$$

where

$$M_{S2} = \left(\iint\limits_{\varphi,z} \left[\sin(...) \cdot \cos(...)\right] d\varphi dz\right), \tag{15}$$

$$M_{S3}(r) = \left(\iint\limits_{\varphi,z} \sin(...) d\varphi dz\right), \tag{16}$$

$$M_{S4} = \left(\iint\limits_{\varphi,z} \cos(\ldots) d\varphi dz \right), \tag{17}$$

$$M_{2r}(r) = r \cdot j_z(r) h_r(r), \tag{18}$$

$$M_{3r}(r) = r \cdot j_z(r), \tag{19}$$

$$M_{4r}(r) = r \cdot h_r(r), \tag{20}$$

$$M_{5r}(r) = r^3 j_r(r), \tag{21}$$

$$M_{6r}(r) = r \cdot j_r(r). \tag{22}$$

The integrals (10-14) include the $h_r(r)$, $j_r(r)$, $j_z(r)$, $f(r) = [j_z(r) h_r(r)]$, (18-22).

It is important to note the following. In the usual Milroye engine there is no intensities H_{ro}, H_{2zo}. Moreover, the terms (9, 11, 14) are equal to zero, i.e. in a conventional Milrow motor torque

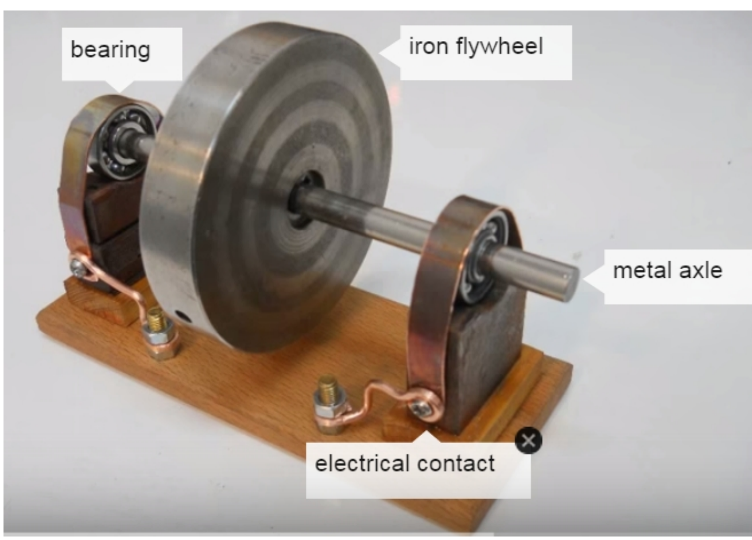
$$\overline{M} = \overline{M_2} + \overline{M_4} + \overline{M_5}\ . \tag{23}$$

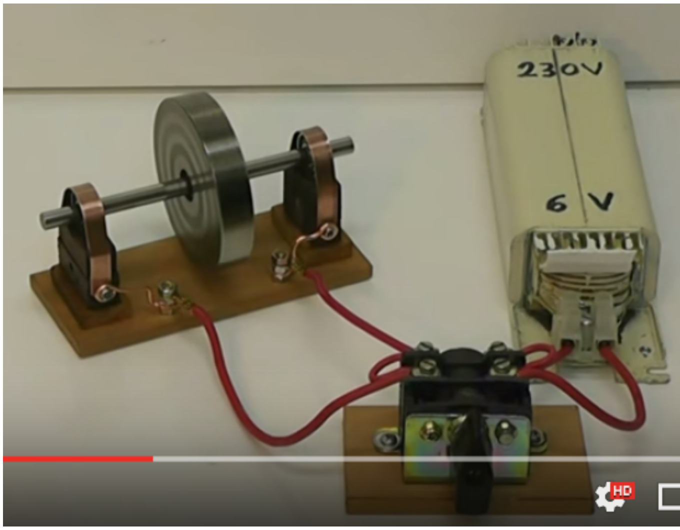
At $\omega = 0$ with only the torque remaining

$$\overline{M} = \overline{M_2} + \overline{M_4}\ , \tag{24}$$

This moment is a starting in the usual Milroy engine and its magnitude is negligible. However, when $H_{ro} \neq 0$ and\or $H_{2zo} \neq 0$, the torque exists, even at $\omega = 0$. Consequently, **when $H_{ro} \neq 0$ и\или $H_{2zo} \neq 0$ there is a significant starting torque**.

Photos

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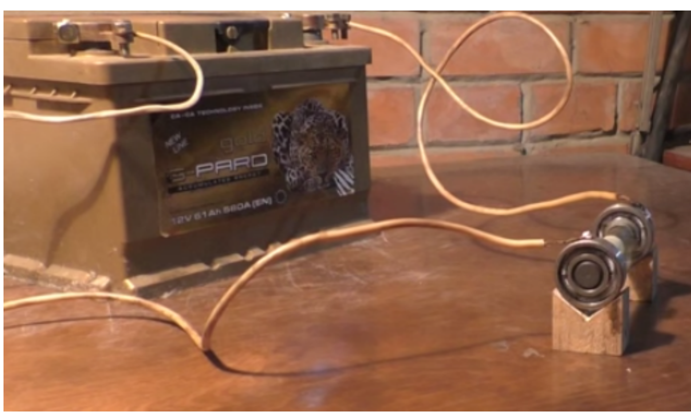
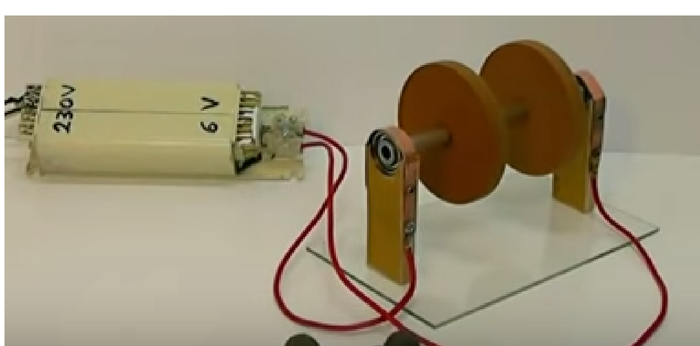
6 V
HD

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Chapter 5c. Magnetoresistance

The magnetoresistive effect is known, which consists in the fact that the electrical resistance of a material depends on the magnetic induction of the magnetic field in which the material is локатед, the so-called magnetoresistance [114]. Below, we consider a conductor with direct current in a magnetic field and show that the existence of magnetoresistance directly follows from the solution of Maxwell's equations.

Chapter 5 dealt with the solution of Maxwell's equations for a wire with direct current. It shows that in a wire with direct current the density of the Lorentz magnetic force acting along the wire axis is proportional to the Poynting vector - the energy flux density. This force drives electrical charges. It is this force that overcomes the resistance of the material of the wire to the movement of charges.

Chapter 5a shows the calculation of this force. It is shown that it also depends on the intensity of the external magnetic field. Consequently, the effect of an external magnetic field manifests itself as a change in the resistance of the wire.

Chapter 5d. The Solution of Maxwell's equations for a wire with a constant current in a magnetic field

Contents

1. Introduction

Here we look at the wire, which is in a constant magnetic field.

2. Wire with direct current

Chapter 5 deals with Maxwell's equations for a wire through which direct current flows with a density of J_o. The solution obtained there can be used without change in this case. It has the following form:

$$J_r. = j_r(r) \cdot \mathrm{co}\,, \tag{2}$$

$$J_\varphi. = -j_\varphi(r) \cdot \mathrm{si}\,, \tag{3}$$

$$J_z. = j_z(r) \cdot \mathrm{si}\,, \tag{4}$$

$$H_r. = -h_r(r) \cdot \mathrm{co}\,, \tag{5}$$

$$H_\varphi. = -h_\varphi(r) \cdot \mathrm{si}\,, \tag{6}$$

$$H_z. = h_z(r) \cdot \mathrm{si}\,, \tag{7}$$

$$\mathrm{co} = -\cos(\alpha\varphi + \chi z)\,, \tag{8}$$

$$\mathrm{si} = \sin(\alpha\varphi + \chi z)\,, \tag{9}$$

where α, χ are some constants, $j(r)$, $h(r)$ are some functions of the coordinate *r*, namely

$$j_\varphi(r) = F_\alpha(r), \tag{10}$$

$$j_r(r) = \left(j_\varphi(r) + r \cdot j'_\varphi(r)\right)/\alpha\,, \tag{11}$$

$$j_z(r) = -\frac{\chi}{\alpha} r \cdot j_\varphi(r), \tag{12}$$

$$h_z(r) \equiv 0, \tag{13}$$

$$h_\varphi(r) = j_r(r)/\chi, \tag{14}$$

$$h_r(r) = j_\varphi(r)/\chi, \tag{15}$$

moreover, the function $F_\propto(r)$ is a solution of the modified Bessel equation. For small r, this function takes the form

$$y = Ax^\beta, \tag{16}$$

where A is a constant, and

$$\beta = \frac{1}{2}\left(-3 \pm \sqrt{3 + 4\chi^2}\right), \ \beta < 0. \tag{17}$$

To calculate using these equations, the quantities $A, \propto, \chi$ should be known. The resulting solution determines the value of energy flux S entering the wire, i.e. power P which enters the wire. Thus, the values of $A, \propto, \chi$ <u>determine the magnitude of the power</u> P.

The value of J_o is determined by the magnitude of the power P and the load resistance. The existence of a non-zero current density $J_o$ensures the existence of a non-zero solution of the system of Maxwell equations, which follows from the equation

$$\frac{H_\varphi}{r} + \frac{\partial H_\varphi}{\partial r} - \frac{1}{r} \cdot \frac{\partial H_r}{\partial \varphi} = J_z, \tag{18}$$

Indeed, if J_z exists, then magnetic intensities H_r and \ or H_φ must also exist. At the same time, the Maxwell system of equations must have a nonzero solution. However, the constant J_o is not formally included in the solution of these equations. This is explained by the fact that J_o creates tension $H_{\varphi o} = J_o r$ and both of these values - $H_{\varphi o}, J_o$ can be excluded from equation (18).

Chapter 5 shows that the density of this energy flow is determined (in the SI system) by the formula:

$$S(r) = \rho\left(j_r(r) h_\varphi(r) - j_\varphi(r) h_r(r)\right), \tag{19}$$

where ρ is the resistivity of the wire. So, the solution of Maxwell's equations in the form of functions $j(r), h(r)$ determines the energy flux density $S(r)$. Obviously, there is an inverse relationship: $S(r)$ defines the functions $j(r), h(r)$. This inverse problem is mathematically much more complicated than the solution considered, but for further consideration it is important for us to emphasize that Nature solves this inverse problem.

3. Wire in a longitudinal magnetic field

In Section 2, it was assumed that there is a direct current with a density J_o in the wire. This current is created by **the flow of energy entering the wire from the end**. Suppose now that there is a **longitudinal** magnetic intensity H_z. The existence of a non-uniform and **non-uniformly distributed along the radius** of the longitudinal magnetic intensity H_z ensures the existence of a non-zero solution of the system of Maxwell equations, which follows from the equation

$$\frac{\partial H_r}{\partial z} - \frac{\partial H_z}{\partial r} = J_\varphi, \tag{1}$$

Indeed, if there is $\frac{\partial H_z}{\partial r}$, (since there is a magnetic intensity H_z unevenly distributed along the radius), then there must be a magnetic intensity H_r and current density J_φ. Moreover, the Maxwell system of equations must have a nonzero solution. It still has the form given in section 2.

It follows that in a wire that is in a non-uniform longitudinal magnetic field, there is a solution to the Maxwell equations in the form given in Section 2. Therefore, there is an energy flow in this wire, the density of which is determined by (2.19) The source of this energy flow obviously, is the source of magnetic intensity H_z.

This energy flow generates a longitudinal constant current in the wire. Thus, there is a conversion of the energy of the longitudinal constant magnetic field in the wire into electrical energy, which is transferred by direct current along the wire.

3a. Solenoid with the electrically conductive core

Consider a solenoid with a core. The current in the coil of the solenoid creates magnetic tension in the rod. However, the magnetic field inside the ideal solenoid is uniform. In accordance with the above, in this case, the current in the rod does not occur. However, if the coils of the solenoid were wound imperfectly (inclined to the axis, randomly, etc.) or the solenoid is short, then, according to the above, a **current appears in the solenoid rod**.

There is another reason for the appearance of current in an electrically conductive core, acting also in an ideal solenoid

The power consumed by a DC solenoid with a core is greater than that consumed by a solenoid without a core. The reason is that the magnetization of the core decreases under the action of thermal motion of the atoms and must be restored all the time by the magnetization current. This means that there is a stream of electromagnetic energy in the core, equal to the bias power to counteract the chaotic orientation of the domains under the influence of thermal energy of the environment. The flow of electromagnetic energy creates a current in the wire, which is an electrically conductive core.

In this sense, a DC solenoid with a core can be compared with a capacitor discharging on the resistance of a dielectric.

Consequently, in a DC solenoid with an electrically conductive core, there should be an electromagnetic field in which there is a longitudinal electrical intensity and energy flow. When there is energy flow in the solenoid, electrical tensions must exist. In this case, the Maxwell equations for a solenoid in the system of cylindrical coordinates r, φ, z completely coincide with the equations for the direct current wire. The difference is that the longitudinal flow of energy S_z

- in the DC wire is equal to the power transmitted through the wire to the load,
- in the solenoid, it is equal to the bias power to counteract the influence of thermal energy of the environment.

4. Wire in a circular magnetic field

Now suppose that there is a **circular** magnetic intensity H_φ **unevenly distributed along the radius**. The existence of such intensity ensures the existence of a non-zero solution of the system of Maxwell equations, which follows from the equation

$$\frac{H_\varphi}{r} + \frac{\partial H_\varphi}{\partial r} - \frac{1}{r} \cdot \frac{\partial H_r}{\partial \varphi} = J_z, \tag{1}$$

Indeed, if there is $\frac{\partial H_\varphi}{\partial r}$ (since there is a magnetic intensity H_φ unevenly distributed along the radius), then there must be a magnetic intensity H_r and \ or current density J_z. Moreover, the Maxwell system of equations must have a nonzero solution.

Similarly to the previous one, it follows that in a wire that is in an inhomogeneous circular magnetic field, there is a solution to Maxwell's equations in the form given in Section 2. Consequently, there is an energy flow in this wire, the density of which is determined by (2.19). Energy flow, obviously, is the source of magnetic intensity H_φ.

This energy flow generates a longitudinal constant current in the wire. Thus, there is a conversion of the energy of the ring constant magnetic field in the wire into electrical energy, which is transferred by direct current along the wire.

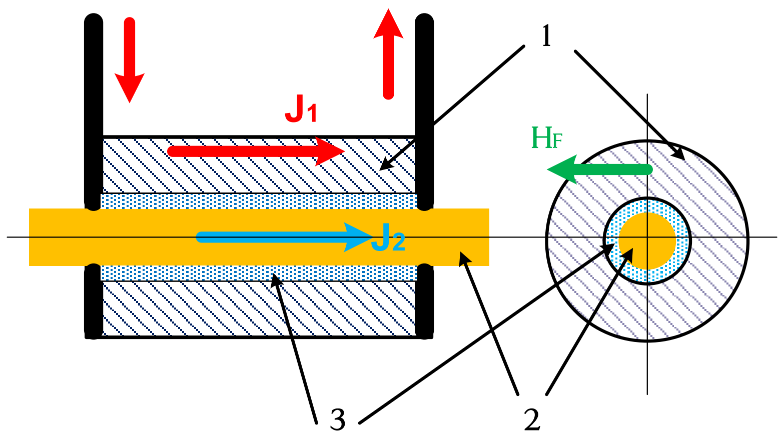


Fig. 1.

Example 1

In fig. 1 shows a tubular wire 1 inside which a wire 2 passes, insulated from wire 1 by a dielectric 3. If current J_2 flows through wire 2, then a ring magnetic field H_φ appears in the body of wire 1. In accordance with the above, a circular ring magnetic field in wire 1 creates a constant current J_1 in this wire. The effect should be stronger if wire 1 is ferromagnetic.

5. Wire in a transverse magnetic field

Now suppose that there is a transverse magnetic intensity H_r. The existence of such a strength ensures the existence of a nonzero solution of the system of Maxwell equations, which follows from the equation

$$\frac{H_\varphi}{r} + \frac{\partial H_\varphi}{\partial r} - \frac{1}{r} \cdot \frac{\partial H_r}{\partial \varphi} = J_z,$$

Indeed, if H_r exists, then magnetic intensity H_φ and \ or current density J_z must exist. Moreover, the Maxwell system of equations must have a nonzero solution.

Similarly to the previous one, it follows that in a wire that is in a circular magnetic field, there is a solution to Maxwell's equations in the form given in Section 2. Therefore, there is an energy flow in this wire, the density of which is determined by (2.19). The source of this energy flow, obviously, is the source of magnetic intensity H_r.

This energy flow generates a longitudinal constant current in the wire. Thus, there is a conversion of the energy of the radial constant magnetic field in the wire into electrical energy transferred by direct current along the wire.

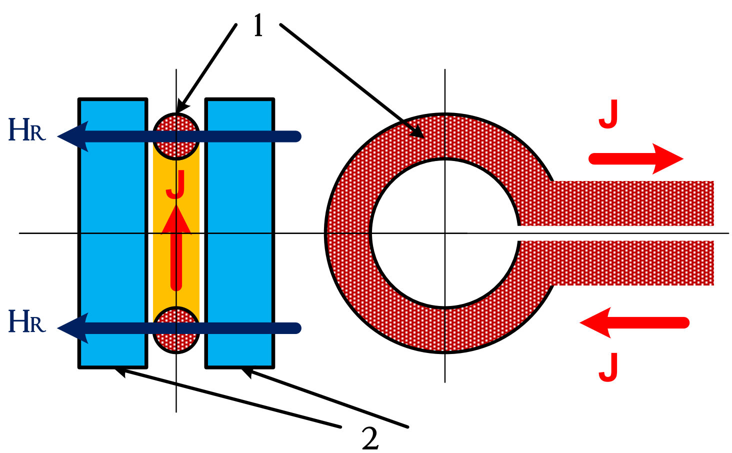


Fig. 1.

Example 1

In fig. 1 shows an annular wire 1 located in the gap of two permanent magnets 2. The magnetic intensity in this gap is the intensity H_r, which penetrates the wire 1 along the radius. In accordance with the above, the radial magnetic field in wire 1 creates a constant current J in this wire. The effect should be stronger if wire 1 is ferromagnetic.

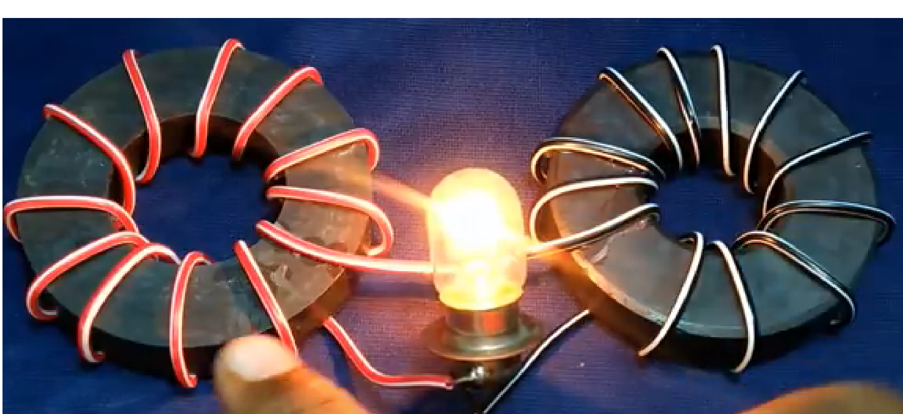


Fig. 1 from **https://www.youtube.com/watch?v=sPH1WNXMlow**.

Fig. 2 from http://www.inventedelectricity.com/free-energy-generator-magnet-coil-100-real-new-technology-new-idea-project/

Example 2

The magnetic intensity H_r can be created by a permanent ring magnet in the wire - the winding of this permanent magnet - see fig. 1 and fig. 2

6. Summary

The above shows that

1. a stream of electromagnetic energy is transmitted from a source of magnetic field to a wire in a magnetic field,

2. in a magnetic field together with a magnetic flux a stream of electromagnetic energy circulates,

3. the flow of electromagnetic energy creates an electromotive force that moves the charges in the wire - see Chapter 15,

4. while in the wire there is a longitudinal constant current.

The experiments shown in section 5 are often viewed as generators of unlimited energy stored in permanent magnets. However, in fact, they demonstrate the exact opposite - the limited energy of the permanent magnet: the light bulbs gradually go out.

Chapter 6. Single-Wire Energy Emission and Transmission

Contents

1. Wire Emission

Once again (as in Chapter 2), we deal with an AC low-resistance wire. It incurs radiation loss, though loses no heat. Emission comes from the side surface of the wire. Vector of emission energy flux density is directed along the wire radius and has S value, see 2.4.4 – 2.4.6 in Chapter 2. So,

$$\overline{S_r} = \eta \iint_{r,\varphi} \left[s_r \cdot si^2 \right] dr \cdot d\varphi, \tag{1}$$

where

$$s_r = \left(e_\varphi h_z - e_z h_\varphi \right) \tag{2}$$

or, with regard to formulas given in the Table 1 of Chapter 2,

$$s_r = -e_z(R) h_\varphi(R) = -\frac{2\chi R}{\alpha} \sqrt{\frac{\varepsilon}{\mu}} e_\varphi^2(R) = -\frac{2A^2 \chi R}{\alpha} \sqrt{\frac{\varepsilon}{\mu}} R^{2\alpha-2}, \tag{3}$$

where R means a wire radius. In addition, consider formula (see (32) in the Appendix 1 of Chapter 2).

$$\chi = \pm \frac{\omega}{c} \sqrt{\varepsilon\mu} \text{ или } \chi = sign(\chi) \cdot \frac{\omega}{c} \sqrt{\varepsilon\mu}, \text{ где } sign(\chi) = \pm 1. \tag{4}$$

Thus, we obtain:

$$s_r = -sign(\chi) \cdot \frac{2A^2 \omega\varepsilon}{\alpha c} R^{2\alpha-1}, \tag{5}$$

From (1,5) we obtain:

$$\overline{S_r} = -sign(\chi) \cdot \frac{2A^2 \omega\varepsilon}{\alpha c} R^{2\alpha-1} \eta \int_\varphi si^2 d\varphi = -sign(\chi) \cdot \frac{2A^2 \omega\varepsilon}{\alpha c} R^{2\alpha-1} \eta\pi .$$

With additional (1.4.2), we finally obtain:

$$\overline{S_r} = -sign(\chi) \cdot \frac{A^2 \omega\varepsilon}{2\alpha} R^{2\alpha-1}. \tag{6}$$

Obviously, the value must be positive, as emission does exist. By the way, this fact disproves a well-known theory of an energy flux propagating beyond the wire and entering it from the outside.

As value (6) is positive, condition

$$-sign(\chi)\cdot sign(\alpha)=1, \tag{7}$$

must assert, i.e. values χ, $\cdot\alpha$ must be of opposite sign. In this connection, for later use we take formula of the type

$$\overline{S_r}=\frac{A^2\omega\varepsilon}{2|\alpha|}R^{2\alpha-1}. \tag{8}$$

The formula calculates the amount of energy flux emitted by the wire of unit length. Correlate this formula with the one (2.4.15) for the density of energy flux flowing along the wire:

$$\overline{S_z}=\frac{A^2c\sqrt{\varepsilon/\mu}\left(1-\cos(4\alpha\pi)\right)}{8\pi\alpha(2\alpha-1)}R^{2\alpha-1}. \tag{9}$$

Consequently,

$$\zeta=\frac{\overline{S_r}}{\overline{S_z}}=\frac{4\pi(2\alpha-1)\omega\sqrt{\varepsilon\mu}}{c\cdot\left(1-\cos(4\alpha\pi)\right)}. \tag{10}$$

So, the wire emits a portion of a longitudinal energy flux of

$$\overline{S_r}=\zeta\cdot\overline{S_z}. \tag{11}$$

Let energy flux is $\overline{S_{zo}}$ in the beginning of wire. Energy flux the wire emits along the L length, can be obtained from the following formula

$$\overline{S_{rL}}=\overline{S_{zo}}(1-\zeta)^L. \tag{12}$$

Energy flux remaining in the wire

$$\overline{S_{zL}}=\overline{S_{zo}}-\overline{S_{rL}}=\overline{S_{zo}}\left(1-(1-\zeta)^L\right). \tag{13}$$

Thus, we can calculate the length of wire where the flux remains

$$\overline{S_{zL}}=\beta\cdot\overline{S_{zo}}. \tag{14}$$

The length can be found from the expression

$$\beta=\left(1-(1-\zeta)^L\right),$$

i.e.

$$L=\ln(1-\beta)/\ln(1-\zeta). \tag{15}$$

Example 1. With $\alpha=1.2,\ \varepsilon=1,\ \mu=1$, we obtain $\zeta\approx 10\omega/c$. If $\omega=3\cdot10^3$ so will $\zeta\approx3\cdot10\cdot10^3/3\cdot10^{10}=10^{-6}$. The length of wire that keeps 1% of initial flux makes

$$L=\ln(1-0.01)/\ln(1-\zeta)\approx 9950\ \text{sm}.$$

2. Single-Wire Transmission of Energy

A body of convincing experiments show the transmission of energy along one wire.

1. [29] analyses a transmitting antenna of long wire type that finds its use in amateur short-wave communication. The author says the antenna has "*an adequate circular pattern that allows the communication to be established almost in all directions*", whereas in the direction of wire axis "*a considerable amplification develops and grows as antenna length increases… As the length of the increases, the main lobe of the pattern tends to approach antenna axis as close as possible. In the process, emission directed towards the main lobe gets stronger*". Both from the fact that long wire emits in all directions and from the previous part it follows that energy flux flows along the wire. It is significant that energy flux exists without any external electrical voltage at the wire tips.

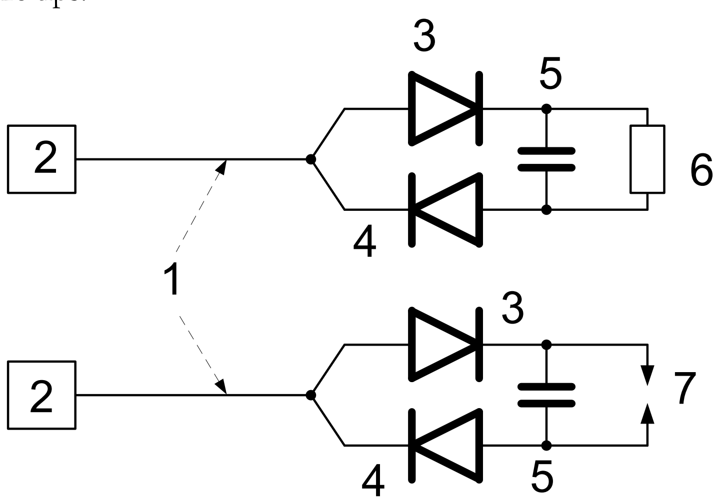


Рис. 1.

2. S.V. Avramenko's long-known experiment in single-wire transmission of electrical energy, also named Avramenko's fork. First, it was described in [30] and then in [31] -see Fig.1. [30] reported that the experimental arrangement included a generator 2 up to 100 kWt of power to generate 8 kHz voltage that went to Tesla's transformer. One tip of the secondary winding was loose, while the other end connected Avramenko's fork. Avramenko's fork was a closed circuit that included <u>two series diodes 3 and 4</u> , whose common point was connected to the wire 1, and a load, with capacitor 5 connected in parallel to it. Several incandescent lamps – resistance 6 (alternative 1) or discharger (alternative

2) formed the load. Open circuit allowed Avramenko to transmit about 1300 Wt of power between the generator and the load. Electrical bulbs glowed brightly. Wire current was very weak, and a thin tungsten wire in the line 1 did not even run hot. That was the main reason why the findings of the Avramenko's experiment were difficult to explain.

On the one hand, the structure offers quite an attractive method of electrical energy transmission, whereas, on the other hand, it apparently violates laws of electrical engineering. Since then, many authors experimented with that structure and offered theories to explain phenomena observed – see e.g. [32-34]. However, no theory has been universally accepted. the wire tips. Here also energy flux exists without any external electrical voltage at the wire tips.

3. Laser beam should also be included in this list. Laser obviously directs energy flux into the laser beam. The energy, that may be rather considerable, incurs almost no loss when transmitted along the laser beam and, on its exit, is converted into the heat energy.

4. Known are experiments by Kosinov [35] that showed the glowing of the burned incandescent lamps. It was reported that "*incandescent lamps burned most often in more than two places, with not only spiral, but current conductors of the lamp burning. With the first circuit break took place, over some time lamps light was even brighter than one produced before burning. The lamps kept glowing until burning of the next portion of the circuit. In this experiment, inner circuit of one lamp burned in as many as four places! Spiral burned in two places, as well as both lead electrodes in the lamp. The lamp went off no sooner than the fourth leg of the circuit burned, i.e. the electrode where the spiral is attached*". Here, too, energy flux exists with no external electrical voltage at the wire tips. It is significant that burned lamp consumes even more power sufficient to burn the next leg of the spiral.

5. There is an experiment known for charging a capacitor through the Avramenko's plug [66]. In this experiment, the circuit diagram shown in Figure 1 above is used but there is no resistor 6. The author of the experiment notes that the capacitor is charged from zero through the Avramenko's plug slowly (3 volts per 2 hours) but faster than without this plug (charge without plug is the charge of the capacitor together with the capacitance between the ground and one of the capacitor plates). Increasing the length of the wire up to 30 m does not affect the result. This experiment indicates that direct current of the charge flows along one wire.

Consideration of equation for the electromagnetic wave in the wire cannot reveal physical nature of the wave existence: any component of intensity, current and density of energy flux can be seen as an exposure governing all the rest. A longitudinal electrical intensity is accepted to be such an exposure. Facts reported earlier testify possible exceptions, e.g. when exposure is an energy flux at the wire inlet. In [19, 17] show that energy flux can be viewed as fourth electromagnetic induction.

Thus, inlet energy flux propagates along the wire, and, (almost with no loss, see pp. 2, 3, 4 above) reaches its distant end. Current can propagate alongside with the energy flux. Yet, this correlation does not need to be (see pp. 2, 3 above). It is significant output energy flux can be rather considerable and make a part of the load. The lack of energy flux – to-current correlation was approached and explained in the Section 2.5.

3. Experiments Review

Return to "long-wire" antenna. It emits in all directions. As is obvious from the Section 1, $\overline{S_r}$ energy flux emitted makes a part of a longitudinal $\overline{S_z}$ energy flux, see (1.11). Their coefficient of proportionality ζ relies, in its turn, on frequency ω - see Example 1. Because of this, reduction of frequency ω drops emission of energy flux $\overline{S_r}$.

Section 2.5. considered and correlated currents and energy fluxes in the wire. It showed that, generally, currents and energy fluxes inside the wire exist as "jets" of opposite direction. This fits with the existence of active and re-active energy fluxes.

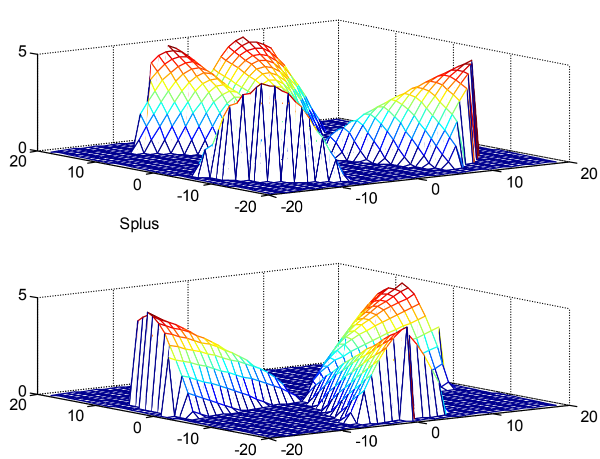


Fig.9. (SSMB)

Formation of such "jets" may be assumed in the “long wire”. If “long wire” emits all the incoming energy, then one of the fluxes (active power flux) prevails, and the generator wastes its energy to support it. If “long wire” does NOT emit, energy flux flowing in one direction returns the opposite way, the generator SAVES the energy (re-active power flux circulates), and no current forms in the wire. Clearly, there are some intermediate cases when “long wire” emits only a part of energy it receives.

With some combinations of parameters, <u>total currents</u> in opposing jets have are equal in absolute value, and, as well as <u>total energy fluxes</u> of opposing jets. For the sake of reader’s convenience, Fig.9 from the Section 4 is replicated above. It shows the functions of the opposing jets:

$Splus$ - energy flux jet directed from the energy source;

$Sminus$ - energy flux jet directed to the energy flux;

For illustration, functions plots are shown with the opposite sign. They obey the following relationships between integrals of sectional area, Q, of the wire:

$$\int_Q Splus \cdot dQ = -\int_Q Sminus \cdot dQ ,$$

$$\int_Q Jplus \cdot dQ = -\int_Q Jminus \cdot dQ .$$

<u>As follows from experiments</u> (рассмотренных above), currents and jets can complete at the broken wire – see Fig.3, where 1 means a wire, 2 means a direct “jet”, 3 means a reverse “jet”, and 4 means a closing circuit. In this case, there arises the question of the nature of electromotive force that makes the current to overcome the spark gap. [19, 17] show that energy flux can be viewed as fourth electromagnetic induction.

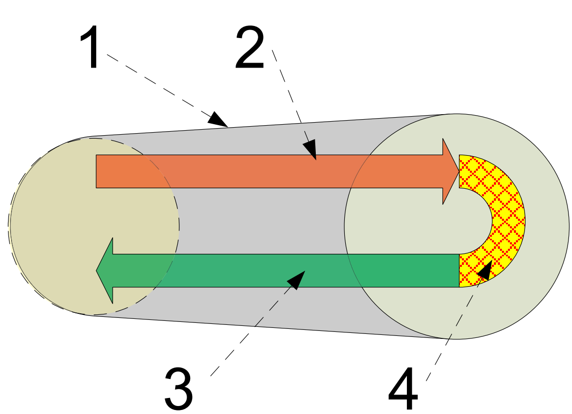


Рис. 3.

Prominent experiments by Kosinov [35] evidently prove the hypothesis offered: the arch that forms at the broken spiral is to have a beginning and an end. Electromotive force should be applied between them. When expanding arch reaches the next leg of the spiral, this leg, together with connecting arch, joins a long line etc. Kosinov observed as many as eight such legs.

Avramenko's fork is a circuit that includes two series diodes and a load – see Fig.1. The circuit forms the arch shown in Fig.3. An air gap of discharger 7 can serve as a load, an equivalent of arch from Kosinov's experiments. Resistor 6 – energy receiver in single-wire energy transmission system – can, too, serve as a load. Wire 1 of this structure can be identified with "long wire". In this case (at low frequency of 8 kHz) the wire 1 does not emit. Consequently, it carries two opposing energy fluxes but no current.

Which means single-wire energy transmission follows from Maxwell's equations without any contradiction.

Chapter 7. Solving Maxwell's equations for a capacitor in a DC circuit. The nature of the potential energy of a capacitor.

Contents

1. Introduction

A charged capacitor always discharges in some resistance R, even if there is no shunt resistance. Even in a vacuum, the capacitor is discharged due to the fact that it emits energy, which can also be considered as the existence of some leakage resistance. In this case, a stream of electromagnetic energy propagates along the capacitor, equal to the power of thermal losses in the resistance R. Therefore, an electromagnetic field must exist in the capacitor, in which there are a longitudinal electrical intensity and energy flows. Next is the solution of the Maxwell equations that satisfies these conditions.

When there is a flow of energy in a capacitor, magnetic intensitions must exist. In this case, Maxwell's equations for a charged capacitor in the system of cylindrical coordinates $r,\ \varphi,\ z$ have the following form:

$$\frac{E_r}{r} + \frac{\partial E_r}{\partial r} + \frac{1}{r} \cdot \frac{\partial E_\varphi}{\partial \varphi} + \frac{\partial E_z}{\partial z} = 0, \tag{1}$$

$$\frac{1}{r}\frac{\partial E_z}{\partial \varphi}-\frac{\partial E_\varphi}{\partial z}=0, \tag{2}$$

$$\frac{\partial E_r}{\partial z}-\frac{\partial E_z}{\partial r}=0, \tag{3}$$

$$\frac{E_\varphi}{r}+\frac{\partial E_\varphi}{\partial r}-\frac{1}{r}\frac{\partial E_r}{\partial \varphi}=0, \tag{4}$$

$$\frac{H_r}{r}+\frac{\partial H_r}{\partial r}+\frac{1}{r}\cdot\frac{\partial H_\varphi}{\partial \varphi}+\frac{\partial H_z}{\partial z}=0, \tag{5}$$

$$\frac{1}{r}\frac{\partial H_z}{\partial \varphi}-\frac{\partial H_\varphi}{\partial z}=0, \tag{6}$$

$$\frac{\partial H_r}{\partial z}-\frac{\partial H_z}{\partial r}=0, \tag{7}$$

$$\frac{H_\varphi}{r}+\frac{\partial H_\varphi}{\partial r}-\frac{1}{r}\frac{\partial H_r}{\partial \varphi}=0. \tag{8}$$

We will look for unknown functions in the form

$$H_r.=h_r(r)co, \tag{9}$$

$$H_\varphi.=h_\varphi(r)si, \tag{10}$$

$$H_z.=h_z(r)si, \tag{11}$$

$$E_r.=e_r(r)si, \tag{12}$$

$$E_\varphi.=e_\varphi(r)co, \tag{13}$$

$$E_z.=e_z(r)co, \tag{14}$$

where $h(r)$, $e(r)$ is some functions of coordinate r,

$$co=\cos(\alpha\varphi+\chi z), \tag{15}$$

$$si=\sin(\alpha\varphi+\chi z), \tag{16}$$

where, in turn, $\propto$, χ are some constants.

2. Energy flows

Also, as in Chapter 1, the energy flux densities by coordinates are determined by the formula

$$S=\begin{bmatrix}S_r\\S_\varphi\\S_z\end{bmatrix}=\eta(E\times H)=\eta\begin{bmatrix}E_\varphi H_z-E_z H_\varphi\\E_z H_r-E_r H_z\\E_r H_\varphi-E_\varphi H_r\end{bmatrix} \tag{1}$$

or, taking into account the previous formulas,

$$S_r = \eta\left(e_\varphi h_z - e_z h_\varphi\right) co \cdot si \tag{2}$$

$$S_\varphi = \eta\left(e_z h_r co^2 - e_r h_z si^2\right) \tag{3}$$

$$S_z = \eta\left(e_r h_\varphi si^2 - e_\varphi h_r co^2\right) \tag{4}$$

where $\eta = c/4\pi$ in the GHS system and $\eta = 1$ in the SI system.

It will be shown below that these energy flux densities satisfy the energy conservation law, if

$$h_r = k e_r, \tag{5}$$

$$h_\varphi = -k e_\varphi. \tag{6}$$

$$h_z = -k e_z. \tag{7}$$

It follows from (2, 6, 7) that

$$S_r = \eta\left(- e_\varphi k e_z + k e_z e_\varphi\right) co \cdot si = 0, \tag{8}$$

i.e. there is no radial energy flow and there is a standing wave on the radiuses. It follows from (3,5, 7) that

$$S_\varphi = \eta\left(e_z k e_r co^2 + k e_r e_z si^2\right) = \eta k e_r e_z, \tag{9}$$

i.e. the energy flux density along the circumference at a given radius does not depend on time and other coordinates. It follows from (5-7) that

$$S_z = \eta e_r h_\varphi \left(si^2 + co^2\right) = \eta k e_r e_\varphi, \tag{10}$$

i.e. the energy flux density along the vertical for a given radius is independent of time and other coordinates. These statements were the purpose of the assumptions (5-7).

So in a charged capacitor

1. There is no radial flow of energy.
2. The flow of energy along the axis of the capacitor is equal to the active power consumed when charging or discharging the capacitor.
3. There is a flow of energy around the circumference.

Consequently, in a charged capacitor there is a stationary flow of electromagnetic energy, and that energy that is contained in a capacitor and which is generally considered to be electrical potential energy is electromagnetic energy stored in a capacitor in the form of a stationary flow. It is in this flow that electromagnetic energy stored in the capacitor circulates. Consequently, the energy that is contained in the capacitor and which is commonly thought of electric potential energy is electromagnetic energy stored in the condenser as a stationary flow.

3. Intensities

Equations (1.1-1.16) and (2.5-2.7) take the form:

$$\frac{e_r}{r}+\dot{e}_r-\frac{e_\varphi}{r}\alpha-\chi e_z=0, \quad (1)$$

$$-\frac{e_z}{r}\alpha+e_\varphi\chi=0, \quad (2)$$

$$-\dot{e}_z+e_r\chi=0, \quad (3)$$

$$\frac{e_\varphi}{r}+\dot{e}_\varphi-\frac{e_r}{r}\alpha=0, \quad (4)$$

$$k\frac{e_r}{r}+k\dot{e}_r-k\frac{e_\varphi}{r}\alpha-k\chi e_z=0, \quad (5)$$

$$-k\frac{e_z}{r}\alpha+ke_\varphi\chi=0, \quad (6)$$

$$k\dot{e}_z-ke_r\chi=0, \quad (7)$$

$$-k\frac{e_\varphi}{r}-k\dot{e}_\varphi+k\frac{e_r}{r}\alpha=0. \quad (8)$$

It can be seen that equations (1-4) and (5-8) coincide. Therefore, it suffices to solve equations (1-4). Appendix 1 shows the solution of the system of equations (1-4). It has the following form:

$$\ddot{e}_z+\frac{\dot{e}_z}{r}-e_z\chi^2-\frac{e_z}{r^2}\alpha^2=0. \quad (9)$$

This equation is a modified Bessel equation and its solution e_z is considered in Appendix 2. The function $\dot{e}_z$. is also considered there.

If e_z, $\dot{e}_z$ are known, e_r,$e_\varphi$can be found by (2, 3). Adding (2, 3), we find:

$$-\frac{e_z}{r}\alpha-\dot{e}_z+(e_\varphi+e_r)\chi=0, \quad (10)$$

Subtracting (3) from (2), we find:

$$-\frac{e_z}{r}\alpha+\dot{e}_z+(e_\varphi-e_r)\chi=0, \quad (11)$$

Adding and subtracting (10, 11), we find::

$$e_\varphi = \frac{e_z \alpha}{r\,\chi}, \tag{12}$$

$$e_r = \frac{\dot{e}_z}{\chi}. \tag{13}$$

The equations (9, 12, 13, 2.5-2.7) define functions, and these functions $h(r)$, $e(r)$, together with the constants $\propto$, χ, determine the electric and magnetic intensities (1.9-1.14)

It follows that in a charged capacitor there are **electrical and magnetic intensities**. Therefore, it can be argued that there is an electromagnetic field in a charged capacitor, and the mathematical description of this field is a solution to Maxwell's equations.

Experiments on the detection of a magnetic field between the plates of a charged capacitor using a compass [49, 50] are known. In accordance with the above, only the location of the compass needle perpendicular to the radius of the circular capacitor should be observed in a circular capacitor. The deviation of the arrow, observed in these experiments, from the axis of the capacitor can be explained by the nonuniformity of the charge distribution over the square plate.

Example 1

In fig. 1 shows the functions $e_r, e_\varphi, e_z, S_r, S_\varphi, S_z$ with $\eta = 1, k = 0.001, \propto = 3, \chi = 1, A = -2 \cdot 10^4, R = 0.1$. In fig. 2 shows the same functions, where, unlike the previous one, $\propto = 0$. It is seen that in this case there is no energy flow along the axis of the capacitor. However, the flow of energy around the circle is always present.

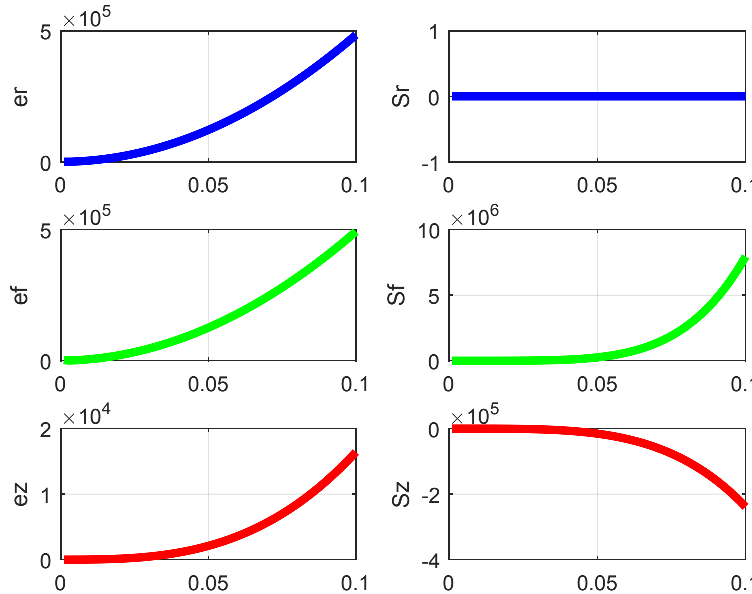


Fig.1 (CondErL.m)

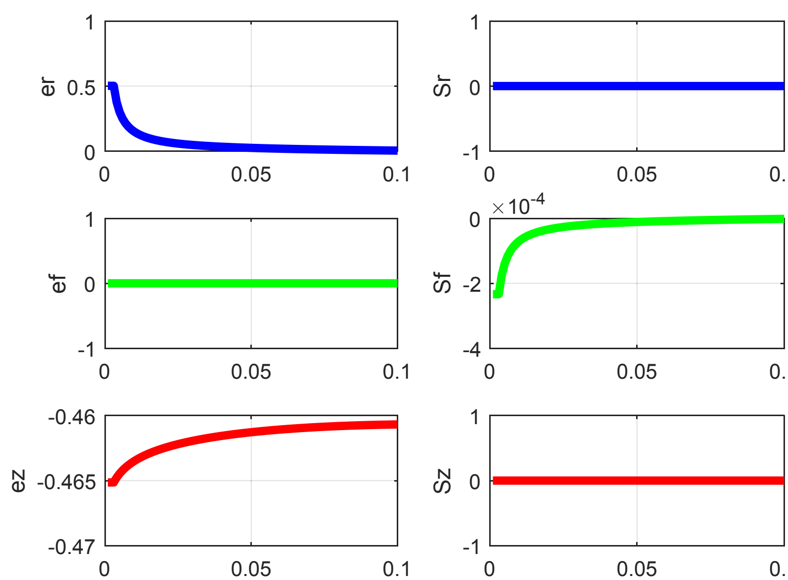


Fig.2 (CondErL.m)

Таким образом, **плотность энергии электромагнитной волны в конденсаторе одинакова на всех точках цилиндра данного радиуса**.

Полная энергия конденсатора с внешним радиусом R:

$$W = \int_0^R W_r dr. \tag{2}$$

В приложении 3 подробнее рассматривается вопрос о способе вычисления с учетом этой формулы.

3a Energy

The energy density on a circle with radius r in a disk capacitor is determined by (2a.4.2)

$$W_r = \varsigma \cdot (\varepsilon + k\mu)\left((e_r si)^2 + (e_\varphi co)^2 + (e_z co)^2\right). \tag{1}$$

where $\varsigma = \frac{1}{8\pi}$ in the CGS system and $\varsigma = \frac{1}{8\pi}$ in the SI system.

Thus, **the energy density of an electromagnetic wave in a capacitor is the same at all points of a cylinder of a given radius**.

The total energy of a capacitor with an external radius R:

$$W = \int_0^R W_r dr. \tag{2}$$

In Appendix 3 discusses in more detail the question of how to calculate with regard with account this formula.

4. Ring capacitor

We now consider the ring capacitor, in which the plates are not disks, but rings, and the width of the ring is such that the second derivative of e_z with respect to r can be neglected: $\ddot{e}_z = 0$. Then the equation (3.9) takes the form:

$$\frac{\dot{e}_z}{r} - e_z\chi^2 - \frac{e_z}{r^2}\alpha^2 = 0. \tag{1}$$

or

$$\dot{e}_z = e_z\left(\chi^2 r + \alpha^2/r\right). \tag{2}$$

Example 1

In fig. 3 shows the functions $e_r, e_\varphi, e_z, S_r, S_\varphi, S_z$ with $\eta = 1, k = 0.001, \propto = 3, \chi = 1, e_z = 2 \cdot 10^4, R_1 = 0.1, R_2 = 0.11$. In fig. 4 shows the same functions, where, unlike the previous one, $\propto = 0$. It is seen that in this case there is no energy flow along the axis of the capacitor. However, the flow of energy around the circle is always present.

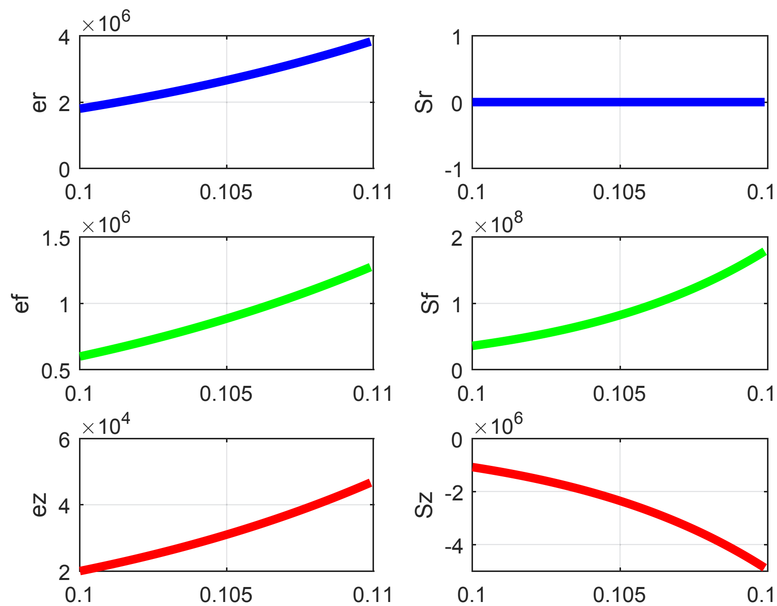


Fig.1 (ConderLK.m)

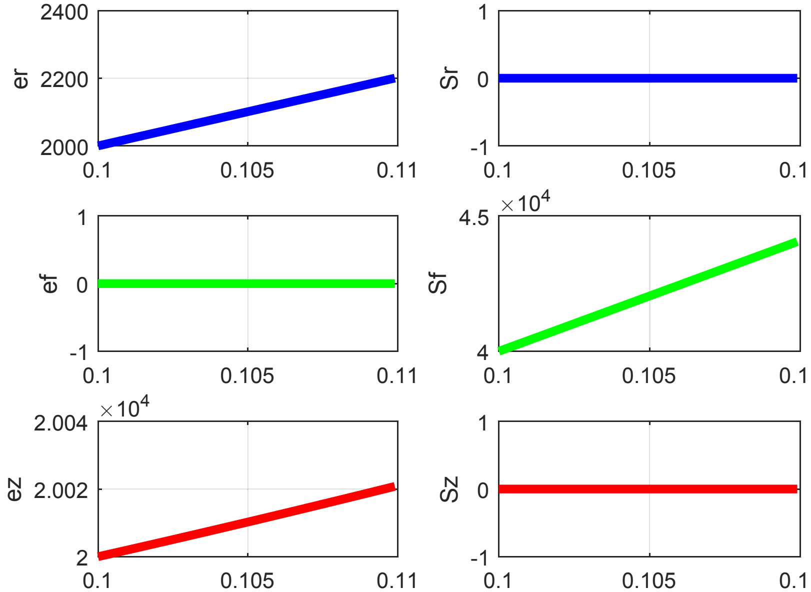


Fig.2 (ConderLK.m)

A high-voltage electric motor is known, which is a high-voltage air condenser [131]. In it, one lining is made in the form of a wire, and the second in the form of a strip of foil - see fig. 3. With a high voltage between the plates, an ion wind arises, which allows us to consider this device as a constantly discharging capacitor. The device takes off. This effect was initially explained by the action of ion current and ion wind. More careful measurements show that the ion wind creates about 60% of the lift. The source of 40% of the lifting force was not identified. The authors argue that the lifting force also occurs in a vacuum (where there is no ion wind).

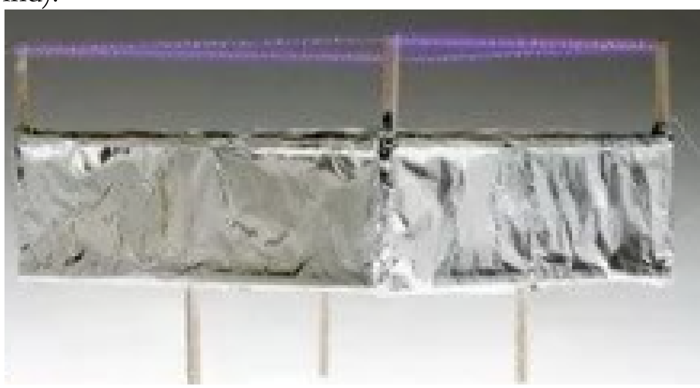


Рис. 3

In the first approximation, you can consider this capacitor as a ring capacitor. Then it can be argued that in this device there is a constant flow of electromagnetic energy along the perimeter of the capacitor. With a constant discharge, there is also a vertical flow of electromagnetic energy. Further, it will be shown that such phenomena can cause a lift.

5. Discharge capacitor

As before, in chapters 1 and 5 we consider the velocity of the energy. The concept of Umov [81] is generally accepted, according to which the energy flux density is the product of energy density s and energy velocity v_e:

$$s = w \cdot v_e . \tag{6}$$

Capacitor energy

$$\mathrm{W}_e = \frac{CU^2}{2}, \tag{7}$$

and the energy density

$$\mathrm{w_e} = \frac{\mathrm{W}_e}{bd}. \tag{8}$$

where U, b, d are the voltage on the capacitor, the area of the plates, the thickness of the dielectric, respectively, and the capacity

$$C = \varepsilon \cdot b/d . \tag{9}$$

When a capacitor is discharged to a resistor R, the energy flow S nto the resistor is equal to the power P released in the resistor, i.e.

$$S = P = UI = \frac{U^2}{R}. \tag{10}$$

If the capacitor is connected to the load with the entire surface of the plates, then the energy flux density

$$\mathrm{s} = \frac{S}{b} = \frac{U^2}{bR}, \tag{11}$$

and power of a source

$$P = sb . \tag{12}$$

Then the speed of energy through the capacitor, defined by (8),

$$\mathrm{v}_\varphi = \frac{\mathrm{s}}{w_\mathrm{e}} = \frac{U^2}{bR} \Big/ \frac{\mathrm{W}_e}{bd} = \frac{U^2}{bR} \Big/ \frac{CU^2}{2bd} = \frac{2d}{CR}. \tag{13}$$

or, subject to (9),

$$v_\varphi = \frac{2d^2}{\varepsilon bR}, \tag{14}$$

i.e. this speed does not depend on voltage! It may have a value substantially less than the speed of light.

Appendix 1.

Consider the solution of the system of equations (3.1, 3.2, 3.3) from section 3. After substituting e_φ from (3.2) and e_r from (3.3) into (3.1), we find:

$$\ddot{e}_z + \frac{\dot{e}_z}{r} - e_z\chi^2 - \frac{e_z}{r^2}\alpha^2 = 0. \tag{1}$$

Now consider the solution of the system of equations (3.2, 3.3, 3.4) from section 3. After substituting e_φ from (3.2) and e_r from (3.3) into (3.4), we again find (1). Consequently, the solution of four equations (3.2-3.4) has the form (1).

Appendix 2.

We know a modified Bessel equation, which has the following form:

$$\ddot{y} + \frac{\dot{y}}{x} - y\left(1 + \frac{\nu^2}{x^2}\right) = 0, \tag{1}$$

where ν is the order of the equation. With a real argument, it has a real solution. This solution and its derivative can be found by a numerical method.

Equation (3.9)

$$\ddot{e}_z + \frac{\dot{e}_z}{r} - e_z\left(\frac{\chi^2}{2} + \frac{\alpha^2}{r^2}\right) = 0. \tag{2}$$

in Appendix 1 like equation (1) and its solution and its derivative can also be found by a numerical method

When $r \to 0$, equation (2) takes the form:

$$\ddot{e}_z + \frac{\dot{e}_z}{r} - e_z\frac{\alpha^2}{r^2} = 0. \tag{3}$$

His solution is:

$$e_z = Ar^\beta, \tag{4}$$

where A is a constant, and β is determined from the equation

$$\beta^2 + \beta - \alpha^2 = 0, \tag{5}$$

i.e.

$$\beta = \frac{1}{2}\left(- 1 \pm \sqrt{1 + 4\alpha^2}\right), \quad \beta < 0 \tag{6}$$

Thus, at the first iterations, you can search for the function e_z in the form (4), and then calculate it from (2).

Appendix 3

It can be assumed that the function $e_z(r)$ is identical to the charge distribution function on the plate $\rho(r)$.. Then one can find such $\propto$, χ for which $e_z(r) = \rho(r)$.

The capacitor energy depends on the capacitance C and the voltage U on it:

$$W = \frac{CU^2}{2}. \tag{1}$$

Another way to determine the energy is to calculate by (3a.2). Denote the calculated value as W_2. For this calculation, we know all the quantities in (3a.2), except for k. If we compute W_2 with $k = 1$, then we can find the real value of k as

$$k = \frac{W}{W_2}. \tag{2}$$

Chapter 7a. Electrically conductive dielectric capacitor

Contents

1. Introduction

Here (unlike Chapter 7), consider a capacitor with a conductive dielectric.

2. Condenser charge by longitudinal magnetic field

Chapter 5d shows that in a wire that is in a non-uniform longitudinal magnetic field, a longitudinal direct current is created. Consequently, a constant current is also generated in a capacitor with a conductive dielectric. This current charges the capacitor. In other words, **the capacitor is charged in an external inhomogeneous magnetic field**.

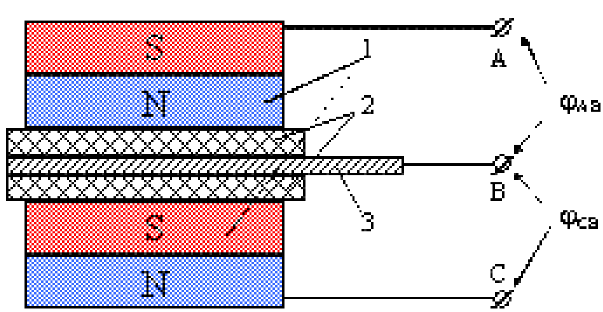


Fig. 1.

This phenomenon is detected experimentally. In [116] describes the construction shown in Fig. 1, which shows one of the options for the practical implementation of this phenomenon. Two insulating spacers 2 and metal foil 3 are placed in the inhomogeneous magnetic field of conductive magnets 1. Magnets 1 and foil 3 act as electrodes A, B and C. A constant potential difference that arises at the time of creation of this structure is fixed between electrodes AB and CB.

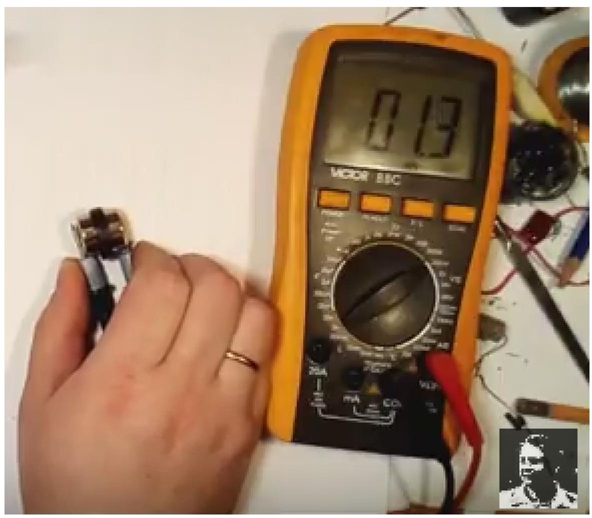


Fig. 2.

In [125] an experiment is described (see Fig. 2), where its author checks the voltage on several structures:

1) single disk neodymium magnet (NM)
2) several NM,
3) ferrite disk (FD),
4) ferrite disc magnet (FD-magnet),
5) a stack of blocks FD-magnets.

In these constructions, ferrite FD is a conductive dielectric. The author notes that

1. in 1) there is no voltage
2. in 2)-4) there is a voltage
3. in 4) the voltage is greater than in 3),
4. in 5) the voltage is greater than in 4),
5. The voltage decreases with time, but is restored in the next experiment.

Example 1

Consider a construction that differs from that shown in Fig. 1 by the fact that electromagnets are used instead of permanent magnets, and the dielectric is a ferromagnet - see fig. 3, which shows an electromagnet 1 with a winding 2. In the gap of the electromagnet 1, there is a capacitor with a dielectric 3 and plates 4. From the previous, it follows that a voltage should appear on the capacitor located between the magnets.

This design can be considered as a <u>transformer of direct current</u> J in the winding 2 of the electromagnet 1 to a <u>constant voltage</u> U on the plates 4 of the capacitor. This voltage can be loaded on the external resistance R. In this case, the current source J transmits power to the resistance R.

Thus, the considered design is a <u>power transformer of constant voltage</u> (type 1).

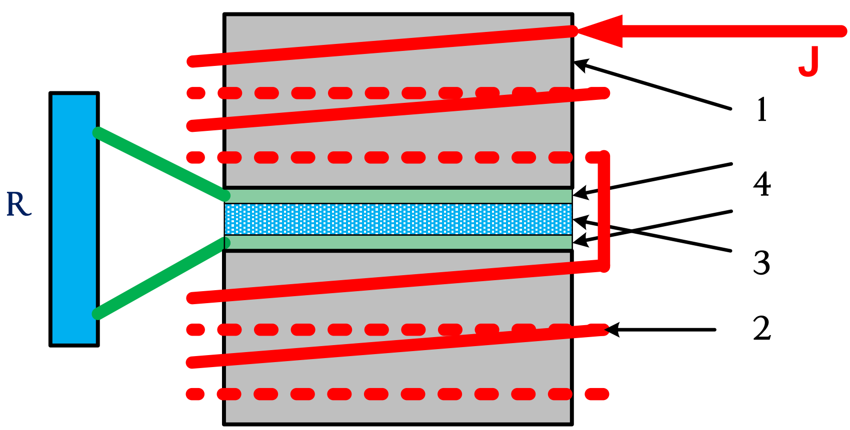


Fig. 3.

Such a scheme operates as follows. At some point in time, the capacitor under the influence of magnets accumulates magnetic energy W_m and charges up to voltage U, i.e. acquires electrical energy W_c. Next, the capacitor is discharged through its <u>own internal resistance</u> *R*. In this case, the voltage on the plates decreases. However, from the magnetic energy, it is again charged to the voltage *U*. Thus, this process can be considered as a constant discharge of a capacitor, the voltage on which is maintained by an external source of energy.

Formal relations are discussed in Appendix 1.

3. Condenser charge by circular magnetic field

Chapter 5d shows that a longitudinal constant current is created in a wire that is in a circular magnetic field. Consequently, a constant current is also generated in a capacitor with a conductive dielectric. This current charges the capacitor. In other words, **the capacitor is charged in an external circular magnetic field**.

Thus, if a conductor with a constant current passes through a capacitor, a longitudinal intensity arises in the capacitor.

Example 2

Consider the construction shown in fig. 4, which shows a capacitor with a conductive dielectric 1 and plates 2. This capacitor has a hole through which the wire 3 passes. If a current J passes through the wire, a circular magnetic field with an intensity of H_{φ} is created in the capacitor. In accordance with the above, a longitudinal constant current (directed parallel to the current in the wire) is created in the conductive dielectric. This current passes through an external resistance R.

Naturally, instead of a single wire, you can make a multi-turn winding. This design can be considered as a transformer of direct current J (in the specified wire) to a constant voltage U on the capacitor plates. This voltage can be loaded on the external resistance R. In this case, the current source transmits power to the resistance R.

Thus, the considered design is a power transformer of constant voltage (type 2).

Such a scheme operates as follows. At some point in time, the capacitor under the influence of current I accumulates magnetic energy W_m and charges up to voltage U, i.e. acquires electrical energy W_c. Next, the capacitor is discharged through its own internal resistance *R*. In this case, the voltage on the plates decreases. However, from the magnetic energy, it is again charged to the voltage U. Thus, this process can be considered as a constant discharge of a capacitor, the voltage on which is maintained by an external source of energy.

Formal relations are discussed in Appendix 1.

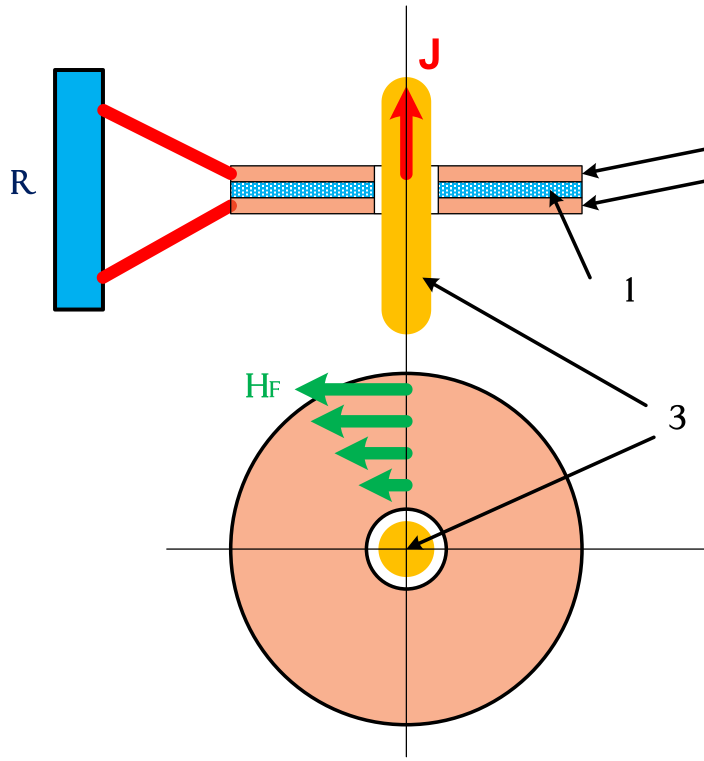


Рис. 4.

4. The density of electrical energy

It is known that oxide-semiconductor and electrolytic capacitors have a very large specific capacity. The electrolyte or semiconductor serves as a dielectric in such capacitors. Such a dielectric is electrically conductive. The dielectric constant of such dielectrics is about 3 times greater than the dielectric constant of ordinary (non-conductive) dielectrics. However, this is impossible to explain a very large increase in specific capacity. It is also known that the specific capacitance increases with decreasing resistance. Previous results allow us to explain why conduction increases the capacitance of a capacitor.

Chapter 5 shows that at a constant density of the main current in the wire, the power transmitted through it depends on the structure parameters (α, χ), i.e. from the density of the screw path of current: as the parameter χ decreases, the power increases and the density of the screw path of current increases. In this case, the total length of the trajectory increases. Likewise, the length of the line on which the electric intensity is proportional to this current increases. But capacitance is proportional to the square of the length at which the electric intensity exists. Consequently, the capacity of the wire increases with increasing density of the screw current path, i.e. with increasing transmit power. Exact relationships between electrical energy and heat power can be found from the relationships found in Chapter 5 - see (2.25-2.30, 3.14) and Appendix 3. Since electrical energy is proportional to capacitance, then the capacitance of the wire can be found from these relationships.

In a conductive capacitor equivalent to a wire, all thermal power is released in the capacitor itself. Consequently, **the heat output from the condenser substantially enhances the capacitance of the capacitor**.

Appendix 1.

Consider the formal relations for sections 2 and 3. Denote:

P is the power consumed by the capacitor load,

P_1 is the power of the current source *I*,

ρ is the resistance of the wire (in section 2) or the windings of electromagnets (in section 3),

L is the inductance of the capacitor,

W_c, W_m is electric and magnetic energy of the capacitor,

P_2 is power loss in the wire,

r is the apparent resistance of the wire (in section 2) or the windings of electromagnets (in section 3) are the load resistance for the current source *I*.

We have:

$$P_2 = I^2\rho, \tag{1}$$

$$P = U^2R, \tag{2}$$

$$W_m = LI^2/2, \tag{3}$$

$$W_c = CU^2/2, \tag{4}$$

$$P_1 = I^2r = P + P_2 = U^2R + I^2\rho, \tag{5}$$

Then

$$r = {I^2}/{P_1} = \frac{U^2R}{I^2} + \rho. \tag{6}$$

Obviously, for consistent work, the time constants of inductance charge circuit and capacitor discharge circuit must coincide, i.e.

$$L/\rho = RC. \tag{7}$$

Then

$$R = \frac{L}{\rho C} \tag{8}$$

It is known that for the torus

$$L = \frac{\mu q}{l} \qquad (9)$$

where

μ is the absolute magnetic permeability of the torus,

q is the cross-sectional area of the core,

l is the length of the average magnetic field line of the torus.

Obviously

$$q = Dd/2, \qquad (10)$$

$$l = \pi D, \qquad (11)$$

where D is the diameter of the torus, d is the height of the torus. Then from (9-11) we find:

$$L = \frac{\mu d}{2\pi} \qquad (13)$$

Capacitor capacitance

$$C = \frac{\varepsilon\pi D^2}{4d} \qquad (14)$$

Then from 8, 13, 14 we find:

$$R = \left(\frac{\mu d}{2\pi\rho}\right)\Big/\left(\frac{\varepsilon\pi D^2}{4d}\right) = \frac{2\mu d^2}{\pi^2\varepsilon D^2\rho} \qquad (15)$$

Appendix 2.

Chapter 5 defines the density of the main current J_o, the densities of additional currents $J_r,\ J_\varphi,\ J_z$ and magnetic intensities $H_r,\ H_\varphi,\ H_z$.

Consider also the density of thermal energy released in the wire,

$$T = \rho\left(J_r^2 + J_\varphi^2 + J_z^2 + J_o^2\right). \qquad (2)$$

The same values are determined in an electrically conductive capacitor. Consider the electrical energy of this capacitor:

$$W_e = 0.5\varepsilon E^2, \qquad (3)$$

where

$$E^2 = E_r^2 + E_\varphi^2 + E_z^2 = \rho^2\left(J_r^2 + J_\varphi^2 + J_z^2 + J_o^2\right). \qquad (4)$$

The capacitance of a capacitor can be determined through its electrical energy:

$$C = 2W_e/U^2. \qquad (5)$$

Combining (2-5), we find:

$$C = \varepsilon\rho T/U^2. \qquad (6)$$

For a non-conductive capacitor, the capacitance is determined by the value of ε and the geometric dimensions. However, in this case, the capacitance depends on the specific resistance ϱ of the dielectric and the parameters of the electric circuit U and P, in which it is included.

Consider another case where all the thermal energy is released in the condenser. In this case, from (2-4) we find:

$$W_e = 0.5\varepsilon\rho T. \tag{7}$$

Insofar as

$$T = U^2/R, \tag{8}$$

where R is the electrical resistance of the capacitor, then

$$W_e = 0.5\varepsilon\rho U^2/R. \tag{9}$$

Denote by b, d the area of b, d the plate and the distance between the plates of the capacitor. Then

$$C = \varepsilon b/d, \tag{10}$$

$$R = \rho d/b. \tag{11}$$

From (9-11) we get:

$$W_e = 0.5\varepsilon\rho U^2 b/\rho d = 0.5\varepsilon U^2 b/d = 0.5CU^2, \tag{12}$$

which coincides with formula (5). Thus, the electrical conductivity of a capacitor does not change its energy.

Chapter 7b. Maxwell's Equations for the Neighborhood of a Magnet End

Contents

1. Mathematical model

In Chapter 7, a charged capacitor was considered, between the plates of which there is a constant electrical intensity.

Consider now **the gap in the ring magnet**. There is a magnetic intensity between the planes that limit this gap.

Due to the symmetry of Maxwell's equations, an electromagnetic field must exist in the "gap" of such a magnet, similar to the field in the gap of a charged capacitor. The difference between these fields lies in the fact that in the field equations the electric and magnetic intensities change places. In particular, there is electrical intensity $(E_z \neq 0)$ in a charged round capacitor and there is no magnetic intensity $(H_z = 0)$. In an uncharged round capacitor with a magnet, there is magnetic intensity $(H_z \neq 0)$ and no electrical intensity $(E_z = 0)$.

The solution of Maxwell's equations for the "gap" of a magnet is completely analogous to that for a capacitor, and we will not repeat it here.

Thus, in the gap of our magnet (i.e. where there is intensity H_z), there are electrical and magnetic intensities. With the existence of these intensities in the gap of our magnet, a stationary flow of electromagnetic energy is formed. In this case (as well as in the condenser)

При существовании этих напряженностей в зазоре нашего магнита формируется стационарный поток электромагнитной энергии. При этом (также, как и в конденсаторе)

1. Отсутствует радиальный поток энергии.
2. Присутствует поток энергии по оси зазора.
3. Присутствует поток энергии по окружности.

As shown in Chapter 1.5, along with such energy flows in an electromagnetic wave, there are also momentums directed along the radius, along the circumference, along the axis. There is also angular momentum about any radius, any circle, and about an axis.

Obviously, all these conclusions do not depend on the length of the gap. Therefore, it can be argued that

> energy flows, momentum and angular momentums exist in the vicinity of the end of the magnet.

In particular, as shown in (1.5.6), the angular momentum relative to the axis of the magnet at a given point of the "gap"

$$L_z(r,\varphi,z) = \frac{r}{c} S_z(r,\varphi,z) \tag{1}$$

or, subject to (7.2.10),

$$L_z(r,\varphi,z) = \frac{r}{c} \eta k e_r(r) e_\varphi(r). \tag{2}$$

The total angular momentum on the entire circumference of a given radius and at a given distance from the end

$$L_{zr}(r) = \int_0^{2\pi} L_z(r,\varphi,z) d\varphi = \frac{2\pi r}{c} \eta k e_r(r) e_\varphi(r). \tag{3}$$

2. Experiments on the detection of angular momentum in a magnet

The existence of angular momentum in the magnet could be verified experimentally. But the author does not have such opportunities. Therefore, it is proposed to consider experiments that (probably!) Demonstrate the existence of such an angular momentum in a magnet.

1. An experiment known on the Internet is shown in Fig. 1 where

• M - magnet with induction B,

• K - an iron ring with a gap V (which is needed so that when searching for an explanation not to assume that a current is flowing along the ring),

• N - thread

• L, D, A, C, d - dimensions.

When the rings are lowered to a certain position, T starts to rotate and rotate for a while, and then stops and starts to rotate in the opposite direction t<<T times and subside.

The author repeated this experiment as follows:
option 1: B=1 Tesla, T=30 sec, (L, D, A, C, d)=(200, 15, 10, 15, d) mm;
option 2: B=1 Tesla, T=20 sec, (L, D, A, C, d)=(200, 20, 05, 15, d) mm.

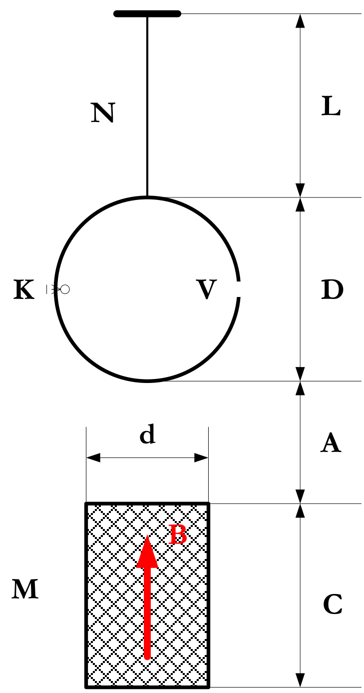


Fig. 1.

This experiment can be explained by the existence of torque, which in the steady state is balanced by the torque of the thread. Otherwise, this experiment is explained by a change in the torque of the thread, when it is pulled by the attraction of the ring K to the magnet M. This explanation seems unconvincing when you do this experiment with your own hands.

2. On the Internet [46] another experiment is shown - see fig. 2 where

- M - magnet,
- K - a magnet in the form of an iron ring,
- S - wooden rod,
- P - rod holder S.

Ring K is kept at some distance from the end face of the magnet M and rotates on a wooden rod S. The idea of this experiment can be used to strictly experimentally test the existence of angular momentum around the axis of the magnet.

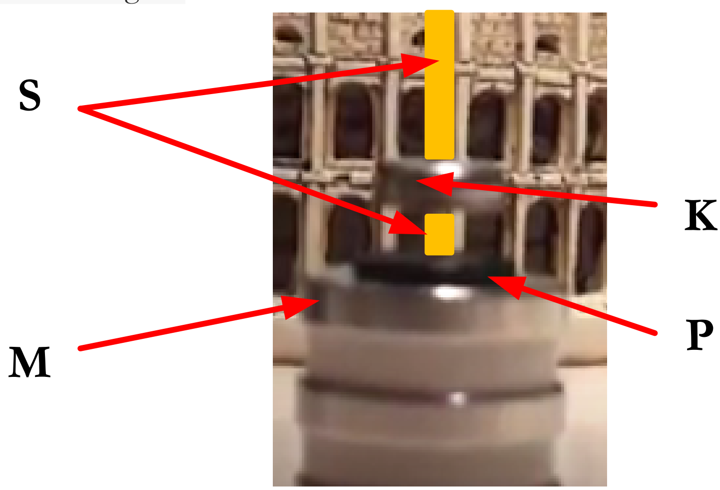


Fig. 2.

3. On the Internet [47] another experiment is shown that is easy to repeat. Two ring magnets are hung by a hook on a long string - see fig. 3.1. In the first case, the magnets interlock with the planes of the rings (see fig. 3.2), and in the second they touch the external cylindrical surfaces (see fig. 3.3). In the first case, the design hangs quietly, and in the second - rotates. Since the weight of the structure does not change, <u>the influence of the thread is excluded</u>.

Fig. 3.1.

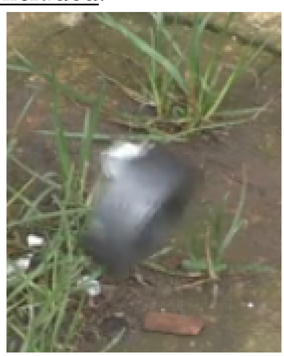


Fig. 3.2.

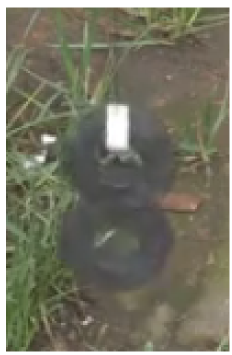


Fig. 3.3.

4. An experiment similar to experiment 3, where the lower ring magnet was replaced by a solid rectangular magnet, is also known on the Internet — see fig. 4, where the notation from fig. 1. The design rotated in the same way as in experiment 3 [48]. The explanation may be the existence of angular momentum around the magnet axis.

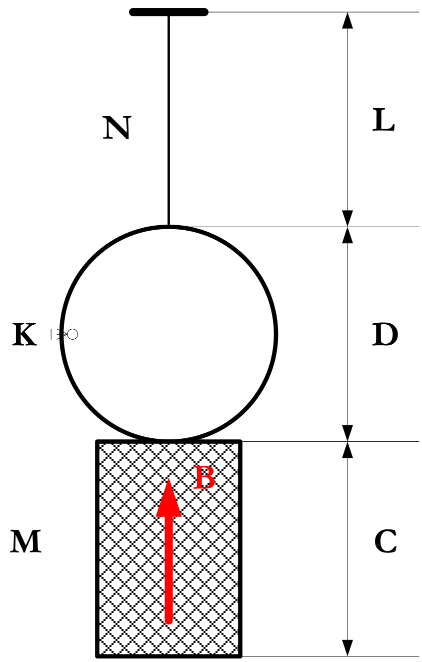


Fig. 4.

Two ring magnets in Experiment 3 can be considered as two combined structures from Fig. four:

• the bottom ring as a magnet for the top ring,

• the top ring as a magnet for the bottom ring,

In this case, all 4 experiments are explained by the existence of the angular momentum in the magnet.

Experiments 1,3, 4 can be represented by the general scheme - see fig. 5. Magnet M creates a magnetic flux B1, directed into ring K. (We do not consider the other part of the magnet flux M). This stream splits in the ring K into two flows B2. Further, flows B2 are closed by flow B3 inside the ring and flow B4 outside the ring. In this way,

B1 = 2 * B2 - B3, B4 = 2 * B2 - B3, B1 = B4,

i.e. there is always a stream B3> 0. This flow, as shown above, has angular momentum.

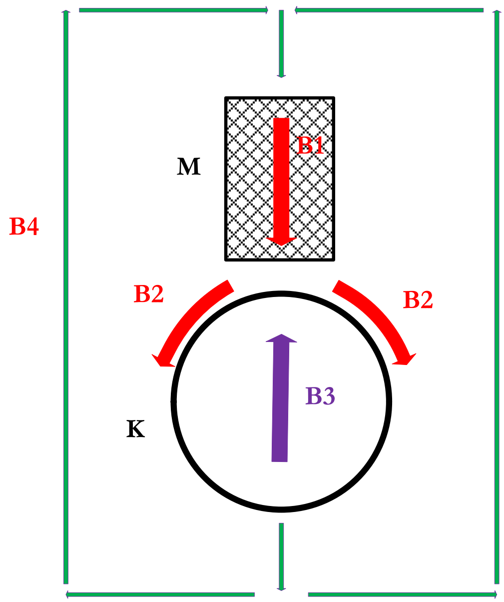


Fig. 5.

3. On the demagnetization rate of the magnets

Consider the speed of movement of energy from the magnet. As in Chapter 1, we will use the concept of Umov [81], according to which the energy flux density s is a product of energy density w and speed v_e of movement of energy:

$$s = w \cdot v_e . \tag{1}$$

If the movement of energy is that it radiates from the body perpendicular to some section of the body, then from (1) it follows:

$$s = \frac{P}{Q} = \frac{dW/dt}{Q} = w \cdot v_e , \tag{2}$$

where Q is the cross-sectional area, P is the radiation power, W is the energy of the body. Consequently, in this case, we can measure the speed of the movement of energy as

$$v_e = \frac{dW/dt}{w \cdot Q} . \tag{3}$$

We apply this formula to calculate the speed of energy moving when demagnetizing a magnet. From [93] we consider, for example, the dependence of the decrease in magnetic induction over time for an alloy UNDK25A - see fig. 1, where functions are shown depending on the time elapsed from the moment of magnetization. The time is shown in days. In the window 1 shows the magnetic induction function from [93]. The rate of change of magnetic induction

$$\frac{dB}{dt} = 2 \cdot 10^{-6} \frac{T}{sec} \tag{4}$$

In the window 2 shows the function of magnetic energy density.

$$w = 10^{-4} B^2 . \tag{5}$$

From (4, 5) it follows that

$$\frac{dw}{dt} = 2 \cdot 10^{-4} \frac{dB}{dt} B = 4 \cdot 10^{-10} B \tag{6}$$

We will assume, in the absence of more accurate data, that

$$W = w, Q = 1, B = 1 . \tag{7}$$

Then from (3) we find:

$$v_e = \frac{dW/dt}{w \cdot Q} = \frac{4 \cdot 10^{-10} B}{10^{-4} B^2} = 4 \cdot 10^{-6} \frac{m}{sec}. \tag{8}$$

This speed is much less than the speed of light, as required to show.

It can be assumed that the flow of energy from the magnet is converted into thermal energy and the magnet is cooled. But along with the cooling of the magnet, the heat flux enters it from outside, restoring the temperature of the magnet. Consequently, the existence of a magnet, possibly, is provided by the external environment and when cooled, the magnetic properties disappear, which is observed as the Curie point. The process of the exchange of thermal energy of the magnet and the environment is described in detail in [124].

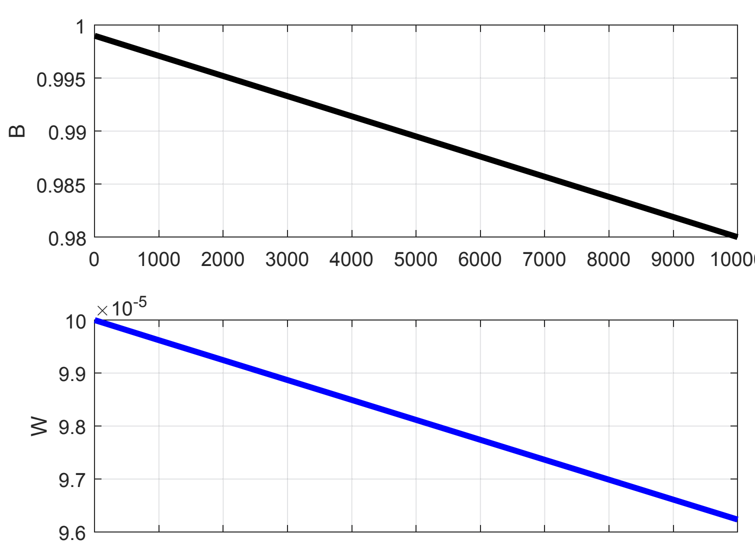


Fig. 1. PoletMy.m

Chapter 8. Solution of Maxwell's Equations for Spherical Coordinates

Contents

The first solution. Maxwell's equations in spherical coordinates in the absence of charges and currents.

1. Solution of the Maxwell equations

Fig. 1 shows the spherical coordinate system (ρ, θ, φ). Expressions for the rotor and the divergence of vector E in these coordinates are given in Table 1 [4]. The following notation is used:

E - electrical intensities,

H - magnetic intensities,

μ - absolute magnetic permeability,

ε - absolute dielectric constant.

The Maxwell's equations in spherical coordinates in the absence of charges and currents have the form given in Table. 2. Next, we will seek a solution for $E_\rho = 0,\ H_\rho = 0$ and in the form of the functions $E,\ H$ presented in Table 3, where the function $g(\theta)$ and functions of the species $E_{\varphi\rho}(\rho)$ are to be calculated. We assume that the intensities $E,\ H$ do not depend on the argument φ. Under these conditions, we transform Table 1 in Table 3a. Further we substitute functions from Table 3 in Table 3a. Then we get Table 4.

Substituting the expressions for the rotors and divergences from Table 4 into the Maxwell's equations (see Table 2), differentiating with respect to time and reducing the common factors, we obtain a new form of the Maxwell's equations - see Table 5.

Consider the Table 5. From line 2 it follows:

$$\frac{H_{\varphi\rho}}{\rho} + \frac{\partial H_{\varphi\rho}}{\partial \rho} = 0, \tag{2}$$

$$\chi H_{\varphi\rho} + \frac{\omega\varepsilon}{c} E_{\theta\rho} = 0. \tag{3}$$

Consequently,

$$H_{\varphi\rho} = \frac{h_{\varphi\rho}}{\rho}, \tag{4}$$

$$H_{\varphi\rho} = -\frac{\omega\varepsilon}{\chi c} E_{\theta\rho}, \tag{5}$$

where $h_{\varphi\rho}$ is some constant. Likewise, from lines 3, 5, 5 should be correspondingly:

$$H_{\theta\rho} = \frac{h_{\theta\rho}}{\rho}, \tag{6}$$

$$H_{\theta\rho} = \frac{\omega\varepsilon}{\chi c} E_{\varphi\rho}, \tag{7}$$

$$E_{\varphi\rho} = \frac{e_{\varphi\rho}}{\rho}, \tag{8}$$

$$E_{\varphi\rho} = \frac{\omega\mu}{\chi c} H_{\theta\rho}, \tag{9}$$

$$E_{\theta\rho} = \frac{e_{\theta\rho}}{\rho}, \tag{10}$$

$$E_{\theta\rho} = -\frac{\omega\mu}{\chi c} H_{\varphi\rho}. \tag{11}$$

It follows from (5) that

$$E_{\theta\rho} = -\frac{\chi c}{\omega\varepsilon} H_{\varphi\rho}, \tag{12}$$

and from a comparison of (11) and (12) it follows that

$$\frac{\omega\mu}{\chi c} = \frac{\chi c}{\omega\varepsilon}$$

or

$$\chi = \frac{\omega}{c}\sqrt{\varepsilon\mu}. \tag{13}$$

The same formula follows from a comparison of (7) and (9).
It follows from (5, 13) that

$$H_{\varphi\rho} = -\sqrt{\frac{\varepsilon}{\mu}} E_{\theta\rho}, \tag{14}$$

and it follows from (14, 4, 11, 12) that

$$h_{\varphi\rho} = -e_{\theta\rho}\sqrt{\frac{\varepsilon}{\mu}}, \tag{15}$$

Similarly, it follows from (7, 13) that

$$H_{\theta\rho} = -\sqrt{\frac{\varepsilon}{\mu}} E_{\varphi\rho}, \tag{16}$$

and it follows from (16, 6, 8, 12) that

$$h_{\theta\rho} = -e_{\varphi\rho}\sqrt{\frac{\varepsilon}{\mu}}. \tag{17}$$

From a comparison of (15) and (17) it follows that

$$\frac{h_{\varphi\rho}}{h_{\theta\rho}} = \frac{e_{\theta\rho}}{e_{\varphi\rho}} = q, \tag{18}$$

$$\frac{h_{\varphi\rho}}{e_{\theta\rho}} = \frac{h_{\theta\rho}}{e_{\varphi\rho}} = -\sqrt{\frac{\varepsilon}{\mu}}. \tag{19}$$

Further we notice that lines 1, 4, 7 and 8 coincide, from which it follows that the function $g(\theta)$ is a solution of the differential equation

$$\frac{g(\theta)}{\mathrm{tg}(\theta)} + \frac{\partial(g(\theta))}{\partial\theta} = 0. \tag{20}$$

In Appendix 1 it is shown that the solution of this equation is the function

$$g(\theta) = \frac{1}{A \cdot |\sin(\theta)|}, \tag{20a}$$

where A is a constant. We note that in the well-known solution $g(\theta) = \sin(\theta)$. It is easy to see that such a function does not satisfy equation (20). Consequently,

> **in the known solution 4 Maxwell's equations with expressions $\mathrm{rot}_\rho(E)$, $\mathrm{rot}_\rho(H)$, $\mathrm{div}(E)$, $\mathrm{div}(H)$ are not satisfied.**

Thus, the solution of the Maxwell's equations for a spherical wave in the far zone has the form of the intensities presented in Table 3, where

$$H_{\varphi\rho} = \frac{h_{\varphi\rho}}{\rho},\ H_{\theta\rho} = \frac{h_{\theta\rho}}{\rho},\ E_{\varphi\rho} = \frac{e_{\varphi\rho}}{\rho},\ E_{\theta\rho} = \frac{e_{\theta\rho}}{\rho} \tag{21}$$

$$\chi = \frac{\omega}{c}\sqrt{\varepsilon\mu} \quad \text{(см. 13)}, \quad g(\theta) = \frac{1}{A \cdot |\sin(\theta)|} \quad \text{(см. 20a)}$$

and the constants $h_{\varphi\rho}$, $h_{\theta\rho}$, $e_{\theta\rho}$, $e_{\varphi\rho}$ satisfy conditions

$$\frac{h_{\varphi\rho}}{h_{\theta\rho}} = \frac{e_{\theta\rho}}{e_{\varphi\rho}} = q \quad \text{(см. 18)}, \qquad \frac{h_{\varphi\rho}}{e_{\theta\rho}} = \frac{h_{\theta\rho}}{e_{\varphi\rho}} = -\sqrt{\frac{\varepsilon}{\mu}}. \quad \text{(см. 19)}$$

From Table. 3 it follows that

> **the same (with respect to the coordinates φ and θ) electric and magnetic intensities are shifted in phase by a quarter of the period.**

This corresponds to experimental electrical engineering. In Fig. 2 shows the intensities vectors in a spherical coordinate system.

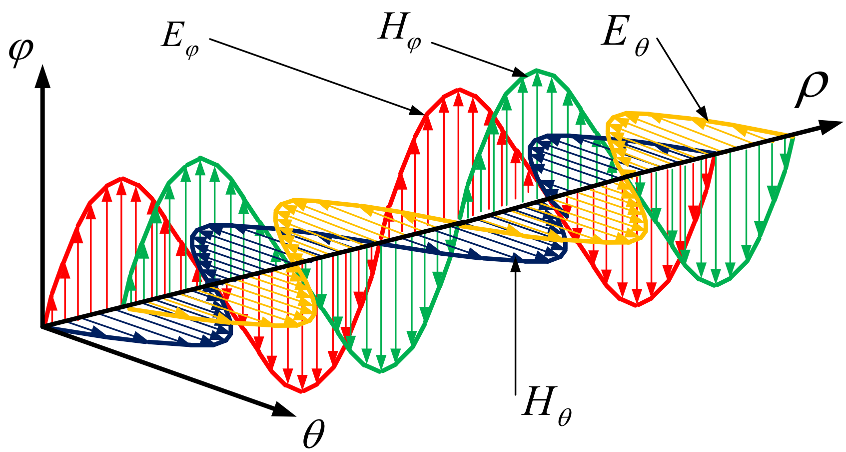


Fig. 2.

3. Energy Flows

Also, as in [1], the flow density of electromagnetic energy - the Poynting vector is

$$S = \eta E \times H , \tag{1}$$

where

$$\eta = c/4\pi . \tag{2}$$

In spherical coordinates φ, θ, ρ the flow density of electromagnetic energy has three components S_φ, S_θ, S_ρ directed along the radius, along the circumference, along the axis, respectively. They are determined by the formula

$$S = \begin{bmatrix} S_\varphi \\ S_\theta \\ S_\rho \end{bmatrix} = \eta\left(E \times H\right) = \eta \begin{bmatrix} E_\theta H_\rho - E_\rho H_\theta \\ E_\rho H_\varphi - E_\varphi H_\rho \\ E_\varphi H_\theta - E_\theta H_\varphi \end{bmatrix}. \tag{4}$$

From here and from Table 3 it follows that

$$S_\varphi = 0$$
$$S_\theta = 0 \qquad . \qquad (5)$$
$$S_\rho = \eta \begin{pmatrix} E_{\varphi\rho} H_{\theta\rho} \left(g(\theta)\sin(\chi\rho+\omega t)\right)^2 - \\ - E_{\theta\rho} H_{\varphi\rho} \left(g(\theta)\cos(\chi\rho+\omega t)\right)^2 \end{pmatrix}$$

It follows from (1.9, 1.11) that

$$E_{\varphi\rho} H_{\theta\rho} = \frac{\omega\mu}{\chi c}\left(H_{\theta\rho}\right)^2, \qquad (6)$$

$$E_{\theta\rho} H_{\varphi\rho} = -\frac{\omega\mu}{\chi c}\left(H_{\varphi\rho}\right)^2. \qquad (7)$$

It follows from (6, 7, 1.4, 1.6) that

$$E_{\varphi\rho} H_{\theta\rho} = \frac{\omega\mu}{\chi c}\left(h_{\theta\rho}\right)^2 \frac{1}{\rho^2}, \qquad (8)$$

$$E_{\theta\rho} H_{\varphi\rho} = -\frac{\omega\mu}{\chi c}\left(h_{\varphi\rho}\right)^2 \frac{1}{\rho^2}. \qquad (9)$$

From (5, 8, 9) we obtain:

$$S_\rho = \eta \cdot g^2(\theta) \frac{\omega\mu}{\chi c} \frac{1}{\rho^2} \begin{pmatrix} \left(h_{\theta\rho}\right)^2 \left(\sin(\chi\rho+\omega t)\right)^2 + \\ + \left(h_{\varphi\rho}\right)^2 \left(\cos(\chi\rho+\omega t)\right)^2 \end{pmatrix}. \qquad (9)$$

Further from (9, 1.13, 1.18) it follows that

$$S_\rho = \eta \cdot g^2(\theta) \omega \sqrt{\frac{\mu}{\varepsilon}} \frac{1}{\rho^2} \begin{pmatrix} \left(h_{\theta\rho}\right)^2 \left(\sin(\chi\rho+\omega t)\right)^2 + \\ + \left(q h_{\theta\rho}\right)^2 \left(\cos(\chi\rho+\omega t)\right)^2 \end{pmatrix}, \qquad (10)$$

where q is a previously undefined constant. If we take

$$q = 1, \qquad (10a)$$

then we get

$$S_\rho = \eta \cdot g^2(\theta) \omega \sqrt{\frac{\mu}{\varepsilon}} \frac{h_{\theta\rho}^2}{\rho^2}. \qquad (11)$$

We also note that the surface area of a sphere with a radius ρ is equal to $4\pi\rho^2$. Then the flow of energy passing through a sphere with a radius ρ is

$$\bar{\bar{S}}_\rho = \int_\theta 4\pi\rho^2 S_\rho d\theta = 4\pi\rho^2 \eta\omega \frac{h_{\theta\rho}^2}{\rho^2} \int_\theta^{2\pi} g^2(\theta) d\theta$$

Because the

$$\int_0^{2\pi} g^2(\theta)d\theta = C,$$

where C is a constant, then

$$\bar{\bar{S}}_\rho = 4\pi C\eta\omega h_{\theta\rho}^2. \tag{12}$$

It follows from (12) that

> **in a spherical electromagnetic wave, the energy flux passing through the spheres along the radius remains constant with increasing radius and does not change with time.**

This strictly corresponds to the law of conservation of energy.

It follows from (12) that the energy flow density varies along the meridian in accordance with the law $g^2(\theta)$.

4. Conclusion

An exact solution of the Maxwell equations for the far zone, which is presented in the table 3 is obtained, where

$H_{\varphi\rho}(\rho)$, $H_{\theta\rho} = (\rho)$, $E_{\varphi\rho} = (\rho)$, $E_{\theta\rho} = (\rho)$ are functions defined by (1.21, 1.18, 1.19),

$g(\theta)$ is a function defined by (1.20a),

χ is the constant determined by (1.13).

- The electric and magnetic intensities of the same name (with respect to the coordinates φ and θ) are phase shifted by a quarter of a period.
- In a spherical electromagnetic wave, the energy flux passing through the spheres along the radius remains constant with increasing radius and does NOT change with time and this strictly corresponds to the law of conservation of energy.
- The energy density varies along the meridian according to the law $g^2(\theta)$.

Appendix 1

We consider (1.20):

$$\frac{g(\theta)}{\mathrm{tg}(\theta)} + \frac{\partial(g(\theta))}{\partial\theta} = 0 \tag{1}$$

or

$$\frac{\partial(g(\theta))}{\partial\theta} = -\mathrm{ctg}(\theta)\cdot g(\theta) \qquad (2)$$

We have:

$$\frac{\partial}{\partial\theta}(\ln(g(\theta))) = \frac{\partial(g(\theta))}{g(\theta)}. \qquad (3)$$

From (2, 3) we find:

$$\ln(g(\theta)) = -\int_\theta \mathrm{ctg}(\theta)\partial\theta. \qquad (4)$$

It is known that

$$\int_\theta \mathrm{ctg}(\theta)\partial\theta = \ln(A\cdot|\sin(\theta)|). \qquad (5)$$

where A is a constant. From (4, 5) we obtain:

$$\ln(g(\theta)) = -\ln(A\cdot|\sin(\theta)|) \qquad (6)$$

or

$$g(\theta) = \frac{1}{A\cdot|\sin(\theta)|}. \qquad (8)$$

Tables

Table 1.

1	**2**	**3**
1	$\mathrm{rot}_\rho(E)$	$\frac{E_\varphi}{\rho\mathrm{tg}(\theta)} + \frac{\partial E_\varphi}{\rho\partial\theta} - \frac{\partial E_\theta}{\rho\sin(\theta)\partial\varphi}$
2	$\mathrm{rot}_\theta(E)$	$\frac{\partial E_\rho}{\rho\sin(\theta)\partial\varphi} - \frac{E_\varphi}{\rho} - \frac{\partial E_\varphi}{\partial\rho}$
3	$\mathrm{rot}_\varphi(E)$	$\frac{E_\theta}{\rho} + \frac{\partial E_\theta}{\partial\rho} - \frac{\partial E_\rho}{\rho\partial\varphi}$
4	$\mathrm{div}(E)$	$\frac{E_\rho}{\rho} + \frac{\partial E_\rho}{\partial\rho} + \frac{E_\theta}{\rho\mathrm{tg}(\theta)} + \frac{\partial E_\theta}{\rho\partial\theta} + \frac{\partial E_\varphi}{\rho\sin(\theta)\partial\varphi}$

Table 2.

1	2
1.	$\mathrm{rot}_{\rho} H - \frac{\varepsilon}{c} \frac{\partial E_{\rho}}{\partial t} = 0$
2.	$\mathrm{rot}_{\theta} H - \frac{\varepsilon}{c} \frac{\partial E_{\theta}}{\partial t} = 0$
3.	$\mathrm{rot}_{\varphi} H - \frac{\varepsilon}{c} \frac{\partial E_{\varphi}}{\partial t} = 0$
4.	$\mathrm{rot}_{\rho} E + \frac{\mu}{c} \frac{\partial H_{\rho}}{\partial t} = 0$
5.	$\mathrm{rot}_{\theta} E + \frac{\mu}{c} \frac{\partial H_{\theta}}{\partial t} = 0$
6.	$\mathrm{rot}_{\varphi} E + \frac{\mu}{c} \frac{\partial H_{\varphi}}{\partial t} = 0$
7.	$\mathrm{div}(E) = 0$
8.	$\mathrm{div}(H) = 0$

Table 3.

1	2
	$E_{\theta} = E_{\theta\rho}(\rho) g(\theta) \cos(\chi\rho + \omega t)$
	$E_{\varphi} = E_{\varphi\rho}(\rho) g(\theta) \sin(\chi\rho + \omega t)$
	$E_{\rho} = 0$
	$H_{\theta} = H_{\theta\rho}(\rho) g(\theta) \sin(\chi\rho + \omega t)$
	$H_{\varphi} = H_{\varphi\rho}(\rho) g(\theta) \cos(\chi\rho + \omega t)$
	$H_{\rho} = 0$

Table 3a.

1	**2**	**3**
1	$\mathrm{rot}_\rho(E)$	$\frac{E_\varphi}{\rho \mathrm{tg}(\theta)} + \frac{\partial E_\varphi}{\rho \partial \theta}$
2	$\mathrm{rot}_\theta(E)$	$-\frac{E_\varphi}{\rho} - \frac{\partial E_\varphi}{\partial \rho}$
3	$\mathrm{rot}_\varphi(E)$	$\frac{E_\theta}{\rho} + \frac{\partial E_\theta}{\partial \rho}$
4	$\mathrm{div}(E)$	$\frac{E_\theta}{\rho \mathrm{tg}(\theta)} + \frac{\partial E_\theta}{\rho \partial \theta}$

Table 4.

1	**2**	**3**
1	$\mathrm{rot}_\rho(E)$	$\frac{E_\varphi}{\rho \mathrm{tg}(\theta)} + \frac{\partial E_\varphi}{\rho \partial \theta}$
2	$\mathrm{rot}_\theta(E)$	$-\left(\frac{E_{\varphi\rho}}{\rho}\sin(\ldots) + \frac{\partial E_{\varphi\rho}}{\partial \rho}\sin(\ldots) + \chi E_{\varphi\rho}\cos(\ldots)\right) g(\theta)$
3	$\mathrm{rot}_\varphi(E)$	$\left(\frac{E_{\theta\rho}}{\rho}\cos(\ldots) + \frac{\partial E_{\theta\rho}}{\partial \rho}\cos(\ldots) - \chi E_{\theta\rho}\sin(\ldots)\right) g(\theta)$
4	$\mathrm{div}(E)$	$\frac{E_\theta}{\rho \mathrm{tg}(\theta)} + \frac{\partial E_\theta}{\rho \partial \theta}$
5	$\mathrm{rot}_\rho(H)$	$\frac{H_\varphi}{\rho \mathrm{tg}(\theta)} + \frac{\partial H_\varphi}{\rho \partial \theta}$
6	$\mathrm{rot}_\theta(H)$	$-\left(\frac{H_{\varphi\rho}}{\rho}\cos(\ldots) + \frac{\partial H_{\varphi\rho}}{\partial \rho}\cos(\ldots) - \chi H_{\varphi\rho}\sin(\ldots)\right) g(\theta)$
7	$\mathrm{rot}_\varphi H$	$\left(\frac{H_{\theta\rho}}{\rho}\sin(\ldots) + \frac{\partial H_{\theta\rho}}{\partial \rho}\sin(\ldots) + \chi H_{\theta\rho}\cos(\ldots)\right) g(\theta)$
8	$\mathrm{div}(H)$	$\frac{H_\theta}{\rho \mathrm{tg}(\theta)} + \frac{\partial H_\theta}{\rho \partial \theta}$

Table 5.

1	2
1.	$\frac{g(\theta)}{\mathrm{tg}(\theta)}+\frac{\partial(g(\theta))}{\partial\theta}=0$
2.	$-\frac{H_{\varphi\rho}}{\rho}\cos(...)-\frac{\partial H_{\varphi\rho}}{\partial\rho}\cos(...)+\chi H_{\varphi\rho}\sin(...)+\frac{\omega\varepsilon}{c}E_{\theta\rho}\sin(...)=0$
3.	$\frac{H_{\theta\rho}}{\rho}\sin(...)+\frac{\partial H_{\theta\rho}}{\partial\rho}\sin(...)+\chi H_{\theta\rho}\cos(...)-\frac{\omega\varepsilon}{c}E_{\varphi\rho}\cos(...)=0$
4.	$\frac{g(\theta)}{\mathrm{tg}(\theta)}+\frac{\partial(g(\theta))}{\partial\theta}=0$
5.	$-\frac{E_{\varphi\rho}}{\rho}\sin(...)-\frac{\partial E_{\varphi\rho}}{\partial\rho}\sin(...)-\chi E_{\varphi\rho}\cos(...)+\frac{\omega\mu}{c}H_{\theta\rho}\sin(...)=0$
6.	$\frac{E_{\theta\rho}}{\rho}\cos(...)+\frac{\partial E_{\theta\rho}}{\partial\rho}\cos(...)-\chi E_{\theta\rho}\sin(...)-\frac{\omega\mu}{c}H_{\varphi\rho}\sin(...)=0$
7.	$\frac{g(\theta)}{\mathrm{tg}(\theta)}+\frac{\partial(g(\theta))}{\partial\theta}=0$
8.	$\frac{g(\theta)}{\mathrm{tg}(\theta)}+\frac{\partial(g(\theta))}{\partial\theta}=0$

The second solution. The Maxwell equations in spherical coordinates in the general case

1. Introduction

Above in «The first solution» a solution of the Maxwell equations for a spherical wave in the far field was proposed. Next, we consider the solution of Maxwell's equations for a spherical wave in the entire region of existence of a wave (without splitting into bands).

2. Solution of the Maxwell's equations

So, we will use spherical coordinates (ρ, θ, φ). Next, we will place the formulas in tables and use the following notation:

T (table_number) - (column_number) - (line_number)

Table T1-3 lists the expressions for the rotor and the divergence of the vector E in these coordinates [4]. Here and below

$\boldsymbol{E}$ is electrical intensities,

$\boldsymbol{H}$ is magnetic intensities,

$\boldsymbol{J}$ is the density of the electric displacement current,

$\boldsymbol{M}$ is the density of the magnetic displacement current,

μ is absolute magnetic permeability,

ε is absolute dielectric constant.

We establish the following notation:

$$\Psi(E_\rho) = \frac{E_\rho}{\rho} + \frac{\partial E_\rho}{\partial \rho} \tag{1}$$

$$T(E_\varphi) = \left(\frac{E_\varphi}{tg(\theta)} + \frac{\partial(E_\varphi)}{\partial(\theta)}\right) \tag{2}$$

With these designations taken into account, the formulas in Table **T1-3** take the form given in Table **T1-4**. In the table **T1A-2** we write the Maxwell equations.

Thus, there are eight Maxwell equations with six unknowns. This system is overdetermined. It is generally accepted that there are no radial tensions in the spherical wave (although this has not been proved). In this case, a system of eight Maxwell equations with four unknowns appears. A solution of this problem was found in «The first solution». In essence, there is a solution of 4 equations (see **T1A-2.2, 3, 6, 7**). In this solution, the intensities functions have the same factor for all functions - the function $g(\theta)$ of the argument θ. The remaining 4 equations are satisfied for a certain choice of this function. This solution turns out to be such that it

We have to admit that in a spherical wave there are radial intensities. However, even so, the system of Maxwell's equations remains redefined. Let us also assume that there are radial electric currents of displacement. This assumption does not remove the problem of over determination, but adds one more problem. The point is that the sphere has an ideal symmetry and the solution must obviously be symmetrical.

It is suggested that there are also radial **magnetic displacement currents**. Such an assumption does not require the existence of magnetic monopoles just like as the existence of electric bias currents does not follow from the existence of electric charges.

Next, we will look for the solution in the form of the functions E, H, J, M, presented in Table **T2-2**, where the actual functions of the form $g(\theta)$ and $e(\rho)$, $h(\rho)$, $j(\rho)$, $m(\rho)$ are to be calculated, and the coefficients $\propto, \omega$ are known.

Under these conditions, we transform the formulas **T1-3** into **T1-4**, where the following notations are adopted:

$$\boxed{e_\varphi} = \frac{\partial(e_\varphi(\rho))}{\partial(\rho)}, \tag{3}$$

$$q = \chi\rho + \omega t \tag{4}$$

From (2, 4) we find:

$$T(E_\varphi) = \left(\frac{\sin(\theta)}{\mathrm{tg}(\theta)} + \cos(\theta)\right) e_\varphi \cos(q) = 2e_\varphi \cos(\theta)\cos(q) \tag{5}$$

Similarly,

$$T(E_\theta) = 2e_\theta \cos(\theta)\sin(q) \tag{6}$$

$$T(H_\varphi) = 2h_\varphi \cos(\theta)\sin(q) \tag{7}$$

$$T(H_\theta) = 2h_\theta \cos(\theta)\cos(q) \tag{8}$$

With these designations taken into account, the formulas in Table **T1-3** take the form given in Table **T1-4**.

Further, using the above formulas and using the formulas from Table **T2**, we construct the tables **T2i, T2ρ, T2Ψ**.

In Table **T3-2** we write the Maxwell equations taking into account the radial displacement currents. Further, we take condition

$$\alpha = 0 \tag{9}$$

We substitute the rotors and divergences from Table **T1-4** into **T1A-2** equations, take into account condition (9), shorten the obtained expressions on the functions of argument θ and write the result in Table **T1A-3**. Then substitute the functions from the tables $T2i$,$T2\rho$,$T2\Psi$ in the function **T1A-3** and write the result in Table **T4-2**. In this table, we use the notation of the form

$$\mathrm{si} = \sin(\chi\rho + \omega t), \tag{10}$$

$$\mathrm{co} = \cos(\chi\rho + \omega t). \tag{11}$$

Further, each equation in Table **T4-2** is replaced by two equations, one of which contains terms with a factor si and the other with a factor co. The result will be written in Table **T5-2**.

Equations **T5-2-2, 6, 3, 7** have a solution, found in «The first solution» and having the following form (which can be verified by direct substitution):

$$\chi = \frac{\omega}{c}\sqrt{\varepsilon\mu} \tag{12}$$

$$e_\varphi = A/\rho\,, e_\theta = A/\rho, \tag{13}$$

$$h_\varphi = -B/\rho\,, h_\theta = B/\rho, \tag{14}$$

$$\frac{B}{A} = \sqrt{\frac{\varepsilon}{\mu}} \tag{15}$$

Consider the equations **T5-2.4, T5-2.8**. Their solution is considered in Appendix 1, where functions $e_\rho(\rho)$, $\bar{\bar{e}}_\rho(\rho)$, $h_\rho(\rho)$, $\bar{\bar{e}}_\rho(\rho)$ are found. After this, the functions $j_\rho(\rho)$, $\bar{\bar{j}}_\rho(\rho)$, $m_\rho(\rho)$, $\bar{\bar{m}}_\rho(\rho)$ can be found using the equations **T5-2.1, T5-2.5**.

This completes the task.

In particular, for A=B and a small value of χ, these functions take the following form:

$$h_\rho = e_\rho = -\frac{1}{\rho}\left(G + 2A\cdot\ln(\rho)\right), \tag{16}$$

$$\bar{\bar{h}}_\rho = \bar{\bar{e}}_\rho = \frac{D}{\rho}, \tag{17}$$

$$j_\rho = \frac{2A}{\rho^2} - \frac{\mu\omega}{c}\cdot\frac{D}{\rho}, \tag{18}$$

$$\bar{\bar{j}}_\rho = -\frac{\mu\omega}{c}\cdot\frac{1}{\rho}\left(G + 2A\cdot\ln(\rho)\right), \tag{19}$$

$$m_\rho = -\frac{2B}{\rho^2} + \frac{\varepsilon\omega}{c}\cdot\frac{D}{\rho}, \tag{20}$$

$$\bar{\bar{m}}_\rho = -\frac{\varepsilon\omega\cdot}{c}\frac{1}{\rho}\left(G + 2A\cdot\ln(\rho)\right). \tag{21}$$

Here G is a constant that can take different values for the functions e_ρ and h_ρ, D is a constant that can take different values for the functions $\bar{\bar{e}}_\rho$ and $\bar{\bar{h}}_\rho$.

3. Energy Flows

Density of electromagnetic energy flow - Poynting vector

$$S = \eta E \times H \,, \tag{1}$$

where

$$\eta = c/4\pi \,. \tag{2}$$

In the SI system formula (1) takes the form:

$$S = E \times H \,. \tag{3}$$

In spherical coordinates φ, θ, ρ the flux density of electromagnetic energy has three components S_φ, S_θ, S_ρ, directed along the radius, along the circumference, along the axis, respectively. It was shown in [4] that they are determined by the formula

$$S = \begin{bmatrix} S_\varphi \\ S_\theta \\ S_\rho \end{bmatrix} = \eta(E \times H) = \eta \begin{bmatrix} E_\theta H_\rho - E_\rho H_\theta \\ E_\rho H_\varphi - E_\varphi H_\rho \\ E_\varphi H_\theta - E_\theta H_\varphi \end{bmatrix}. \tag{4}$$

We first find a radial flux of energy. Substituting in here the formulas from Table **T2** and (1.4, 2.13, 2.14), we find:

$$S_\rho = \frac{A}{\rho} sin(\theta) sin(q) \frac{B}{\rho} sin(\theta) sin(q) - \frac{A}{\rho} sin(\theta) cos(q) \frac{-B}{\rho} sin(\theta) cos(q) = \frac{AB}{\rho^2} sin^2(\theta) \left(sin^2(q)\right. \tag{4a}$$

or, taking into account (2.15),

$$S_\rho = \frac{A^2}{\rho^2} \sqrt{\frac{\varepsilon}{\mu}} sin^2(\theta) \tag{5}$$

Note that the surface area of a sphere with a radius ρ is $4\pi\rho^2$. Then the flow of energy passing through a sphere with a radius ρ is

$$\bar{\bar{S}}_\rho = \int_\theta 4\pi\rho^2 S_\rho d\theta = -4\pi\rho^2 \eta \frac{A^2}{\rho^2} \sqrt{\frac{\varepsilon}{\mu}} \int_\theta sin^2(\theta) d\theta$$

or

$$\bar{\bar{S}}_\rho = -4\pi\eta A^2 \sqrt{\frac{\varepsilon}{\mu}} \int_0^{2\pi} sin^2(\theta) d\theta$$

or

$$\bar{\bar{S}}_\rho = -4\pi^2 \eta A^2 \sqrt{\frac{\varepsilon}{\mu}} \tag{6}$$

Thus, the energy flux density passing through the sphere does not depend on the radius and does not depend on time, i.e. this flux has the same value on a spherical surface of any radius at any instant of time. In other words, the energy flux directed along the radius retains its value with increasing radius and does not depend on time, which corresponds to the law of conservation of energy.

Let us now find the energy flux

$$S_\varphi = \eta\left(E_\theta H_\rho - E_\rho H_\theta\right), \tag{7}$$

Substituting here the formulas from Table **T2** and (2.13, 2.14, 2.16, 2.17), we find:

$$S_\varphi = \eta\begin{pmatrix} \frac{A}{\rho}\sin(\theta)\cos(q)\cos(\theta)\left(h_\rho\sin(q) + \bar{\bar{h}}_\rho\cos(q)\right) \\ -\cos(\theta)\left(e_\rho\cos(q) + \bar{\bar{e}}_\rho\sin(q)\right)\frac{B}{\rho}\sin(\theta)\sin(q) \end{pmatrix}$$

$$= \frac{\eta\cdot\sin(\theta)\cos(\theta)}{\rho}\begin{pmatrix} A\cos(q)\left(h_\rho\sin(q) + \bar{\bar{h}}_\rho\cos(q)\right) \\ -B\sin(q)\left(e_\rho\cos(q) + \bar{\bar{e}}_\rho\sin(q)\right) \end{pmatrix}$$

$$= \frac{\eta\cdot\sin(\theta)\cos(\theta)}{\rho}\begin{pmatrix} \left(h_\rho A\cos(q)\sin(q) + \bar{\bar{h}}_\rho A\cos^2(q)\right) \\ -\left(e_\rho B\sin(q)\cos(q) + \bar{\bar{e}}_\rho B\sin^2(q)\right) \end{pmatrix}$$

or, taking into account (2.16, 2.17),

$$S_\varphi = \frac{\eta\cdot\sin(\theta)\cos(\theta)}{\rho}\begin{pmatrix} \left(e_\rho A\cos(q)\sin(q) + \bar{\bar{e}}_\rho A\cos^2(q)\right) \\ -\left(e_\rho B\sin(q)\cos(q) + \bar{\bar{e}}_\rho B\sin^2(q)\right) \end{pmatrix}$$

or

$$S_\varphi = \frac{\eta\cdot\sin(\theta)\cos(\theta)}{\rho}\left(e_\rho(A-B)\cos(q)\sin(q) + \bar{\bar{e}}_\rho\left(A\cos^2(q) + B\sin^2(q)\right)\right) \tag{7}$$

Let us now find the energy flux

$$S_\theta = \eta\left(E_\rho H_\varphi - E_\varphi H_\rho\right). \tag{8}$$

Similarly to the previous one, we find:

$$S_\theta = \frac{\eta \cdot \sin(\theta)\cos(\theta)}{\rho}\begin{pmatrix} -\left(e_\rho B\cos(q)\sin(q) + \bar{\bar{e}}_\rho B\cos^2(q)\right) \\ -\left(e_\rho A\sin(q)\cos(q) + \bar{\bar{e}}_\rho A\sin^2(q)\right)\end{pmatrix}$$

or

$$S_\theta = -\frac{\eta \cdot \sin(\theta)\cos(\theta)}{\rho}\left(e_\rho (A+B)\cos(q)\sin(q) + \bar{\bar{e}}_\rho\left(A\cos^2(q) + B\sin^2(q)\right)\right) \tag{9}$$

In particular, for $\varepsilon = \mu$, for example, for a vacuum, we find from (2.15) that A = B, and from (7, 9) we obtain:

$$S_\varphi = \frac{\eta \cdot \sin(\theta)\cos(\theta)}{\rho} A\bar{\bar{e}}_\rho, \tag{10}$$

$$S_\theta = -\frac{\eta \cdot \sin(\theta)\cos(\theta)}{\rho}\left(2Ae_\rho\cos(q)\sin(q) + A\bar{\bar{e}}_\rho\right). \tag{11}$$

or

$$S_\varphi = \frac{\eta \cdot \sin(2\theta)}{2\rho} A\bar{\bar{e}}_\rho, \tag{12}$$

$$S_\theta = -\frac{A\eta \cdot \sin(2\theta)}{2\rho}\left(e_\rho \sin(2q) + \bar{\bar{e}}_\rho\right). \tag{13}$$

From (12, 13) we find the density of the total energy flux directed along the tangent to a sphere of a given radius,

$$S_{\varphi\theta} = S_\varphi + S_\theta = -\frac{A\eta \cdot}{2\rho} e_\rho \sin(2\theta)\sin(2q).$$

or

$$S_{\varphi\theta} = -\frac{A\eta \cdot}{4\rho} e_\rho\left(\cos(2\theta - 2q) - \cos(2\theta + 2q)\right)$$

or

$$S_{\varphi\theta} = -\frac{A\eta \cdot}{4\rho} e_\rho \begin{pmatrix} \cos(2(\chi\rho + \omega t - \theta)) \\ -\cos(2(\chi\rho + \omega t + \theta))\end{pmatrix}. \tag{14}$$

This means that standing waves exist on the circles of the sphere.

4. Conclusion

1. A solution of Maxwell's equations, free from the above disadvantages, is presented in Table **T2**.
2. The solution is monochromatic.
3. There are electrical and magnetic intensities along all axes of coordinates.

4. The amplitudes of the transverse wave intensities are proportional to ρ^{-1}.

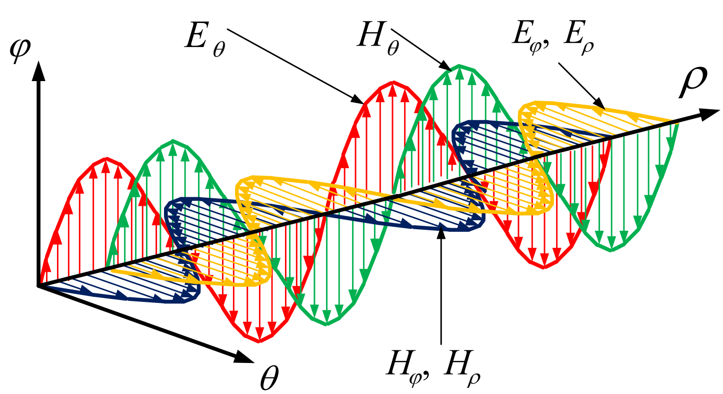
5. The electric and magnetic intensities of the same name (according to coordinates ρ, φ, θ) are phase shifted by a quarter of a period.

6. There is a longitudinal electromagnetic wave having electric and magnetic components, there is a longitudinal electromagnetic wave component of the electric and magnetic components, i.e. there are radial electrical and magnetic intensities.

7. The energy flux directed along the radius retains its value with increasing radius and does not depend on time, which corresponds to the law of conservation of energy.

8. There are radial electric and magnetic intensities.

9. There are radial electric and magnetic displacement currents.



Appendix 1.

From **T5-4.1** and (2.13) we:

$$\overset{=}{e}_\rho = -\frac{1}{\chi}\boxed{e_\rho} - \frac{1}{\chi\rho}e_\rho - \frac{2A}{\chi\rho^2}. \qquad (1)$$

Differentiating (1), we obtain:

$$\boxed{\overset{=}{e}_\rho} = -\frac{1}{\chi}\boxed{e_\rho} - \frac{1}{\chi\rho}\boxed{e_\rho} + \frac{1}{\chi\rho^2}e_\rho + \frac{4A}{\chi\rho^3}. \qquad (2)$$

We substitute (2) in **T5-4.2** and find:

$$\left(-\frac{1}{\chi\rho}\boxed{e_\rho} - \frac{1}{\chi\rho^2}e_\rho - \frac{2A}{\chi\rho^3} - \chi e_\rho - \frac{1}{\chi}\boxed{e_\rho} - \frac{1}{\chi\rho}\boxed{e_\rho} + \frac{1}{\chi\rho^2}e_\rho + \frac{4A}{\chi\rho^3}\right) = 0$$

or

$$\boxed{e_\rho} + \frac{2}{\rho}\boxed{e_\rho} + \chi^2 e_\rho - \frac{2A}{\rho^3} = 0. \qquad (3)$$

From this differential equation one can find the function $e_\rho(\rho)$, and from this known function and the differential equation **T5-4.2**, find the function $\bar{\bar{e}}_\rho(\rho)$.

From **T5-8.1** and (2.14) we:

$$\bar{h}_\rho = \frac{1}{\chi}\boxed{h_\rho} + \frac{1}{\chi\rho}h_\rho + \frac{2B}{\chi\rho^2}. \tag{4}$$

Differentiating (4), we obtain:

$$\boxed{\bar{h}_\rho} = \frac{1}{\chi}\boxed{h_\rho} + \frac{1}{\chi\rho}\boxed{h_\rho} - \frac{1}{\chi\rho^2}h_\rho - \frac{4B}{\chi\rho^3}. \tag{5}$$

We substitute (5) in **T5-8.2** and find:

$$\left(\frac{1}{\chi\rho}\boxed{h_\rho} + \frac{1}{\chi\rho^2}h_\rho + \frac{2B}{\chi\rho^3} + \chi h_\rho + \frac{1}{\chi}\boxed{h_\rho} + \frac{1}{\chi\rho}\boxed{h_\rho} - \frac{1}{\chi\rho^2}h_\rho - \frac{4B}{\chi\rho^3}\right) = 0$$

or

$$\boxed{h_\rho} + \frac{2}{\rho}\boxed{h_\rho} + \chi^2 h_\rho - \frac{2B}{\rho^3} = 0 \tag{6}$$

From this differential equation one can find the function $h_\rho(\rho)$, and from this known function and the differential equation **T5-8.2**, find the function $\bar{h}_\rho(\rho)$.

In particular, for $\varepsilon = \mu$, for example, for a vacuum, we find from (2.15) that A=B and, comparing (3) and (6), we find that

$$h_\rho = e_\rho. \tag{7}$$

If A=B and the value of χ is small, the equations **T5-4.1** and **T5-8.1** coincide and take the form

$$\dot{y} + \frac{2}{\rho}y - \frac{2A}{\rho^3} = 0, \tag{8}$$

where

$$y = \boxed{h_\rho} = \boxed{e_\rho}. \tag{9}$$

The method for solving such an equation is given in [9, p. 50]. Following this method, we find

$$y = \frac{C + 2Aln(\rho)}{\rho^2} \tag{10}$$

where C is a constant that can take different values for the functions $\boxed{e_\rho}$ and $\boxed{h_\rho}$. From (9, 10) we find:

$$h_\rho = e_\rho = -\frac{C}{\rho} - 2A\left(\frac{1 + ln(\rho)}{\rho}\right) = -\frac{1}{\rho}(G + 2A \cdot ln(\rho)) \tag{11}$$

where G is a constant that can take different values for the functions e_ρ and h_ρ.

For a small value of χ, the equations **T5-4.1** and **T5-8.1** coincide and take the form

$$\dot{z} + \frac{1}{\rho} z = 0, \qquad (12)$$

where

$$z = \bar{\bar{h}}_\rho = \bar{\bar{e}}_\rho. \qquad (13)$$

The solution of this equation has the form:

$$\bar{\bar{h}}_\rho = \bar{\bar{e}}_\rho = \frac{D}{\rho}, \qquad (14)$$

wher D is a constant that can take different values for the functions $\bar{\bar{e}}_\rho$ and $\bar{\bar{h}}_\rho$.

From **T5-2.1** and (2.13, 14, 11) we:

$$j_\rho = \frac{2}{\rho} e_\varphi - \frac{\mu}{c} \omega \bar{\bar{h}}_\rho = \frac{2A}{\rho^2} - \frac{\mu\omega}{c} \cdot \frac{D}{\rho}, \qquad (15)$$

$$\bar{\bar{j}}_\rho = \frac{\mu}{c} \omega h_\rho = - \frac{\mu\omega}{c} \cdot \frac{1}{\rho} (G + 2A \cdot ln(\rho)). \qquad (16$$

From **T5-2.2** and (2.14, 14, 11) we:

$$m_\rho = \frac{2}{\rho} h_\varphi + \frac{\varepsilon}{c} \omega \bar{\bar{e}}_\rho = - \frac{2B}{\rho^2} + \frac{\varepsilon\omega}{c} \cdot \frac{D}{\rho}, \qquad (17)$$

$$\bar{\bar{m}}_\rho = \frac{\varepsilon}{c} \omega e_\rho = - \frac{\varepsilon\omega \cdot 1}{c \ \rho} (G + 2A \cdot ln(\rho)). \qquad (18)$$

Tables

Table 1.

1	**2**	**3**	**4**
1	$\mathrm{rot}_\rho(E)$	$\frac{E_\varphi}{\rho \mathrm{tg}(\theta)} + \frac{\partial E_\varphi}{\rho \partial \theta} - \frac{\partial E_\theta}{\rho \sin(\theta) \partial \varphi}$	$\frac{T(E_\varphi)}{\rho} - \frac{i\alpha E_\theta}{\rho \sin(\theta)}$
5	$\mathrm{rot}_\rho(H)$	$\frac{H_\varphi}{\rho \mathrm{tg}(\theta)} + \frac{\partial H_\varphi}{\rho \partial \theta} - \frac{\partial H_\theta}{\rho \sin(\theta) \partial \varphi}$	$\frac{T(H_\varphi)}{\rho} - \frac{i\alpha H_\theta}{\rho \sin(\theta)}$
2	$\mathrm{rot}_\theta(E)$	$\frac{\partial E_\rho}{\rho \sin(\theta) \partial \varphi} - \frac{E_\varphi}{\rho} - \frac{\partial E_\varphi}{\partial \rho}$	$\frac{i\alpha E_\rho}{\rho \sin(\theta)} - \psi(E_\varphi)$
3	$\mathrm{rot}_\varphi(E)$	$\frac{E_\theta}{\rho} + \frac{\partial E_\theta}{\partial \rho} - \frac{\partial E_\rho}{\rho \partial \varphi}$	$\psi(E_\theta) - \frac{i\alpha E_\rho}{\rho}$
6	$\mathrm{rot}_\theta(H)$	$\frac{\partial H_\rho}{\rho \sin(\theta) \partial \varphi} - \frac{H_\varphi}{\rho} - \frac{\partial H_\varphi}{\partial \rho}$	$\frac{i\alpha H_\rho}{\rho \sin(\theta)} - \psi(H_\varphi)$
7	$\mathrm{rot}_\varphi H$	$\frac{H_\theta}{\rho} + \frac{\partial H_\theta}{\partial \rho} - \frac{\partial H_\rho}{\rho \partial \varphi}$	$\psi(H_\theta) - \frac{i\alpha H_\rho}{\rho}$

4	$\operatorname{div}(E)$	$\frac{E_\rho}{\rho}+\frac{\partial E_\rho}{\partial\rho}+\frac{E_\theta}{\rho\operatorname{tg}(\theta)}+ +\frac{\partial E_\theta}{\rho\partial\theta}+\frac{\partial E_\varphi}{\rho\sin(\theta)\partial\varphi}$	$\psi(E_\rho)+\frac{T(E_\theta)}{\rho}+\frac{i\alpha E_\varphi}{\rho\sin(\theta)}$
8	$\operatorname{div}(H)$	$\frac{H_\rho}{\rho}+\frac{\partial H_\rho}{\partial\rho}+\frac{H_\theta}{\rho\operatorname{tg}(\theta)}+ +\frac{\partial H_\theta}{\rho\partial\theta}+\frac{\partial H_\varphi}{\rho\sin(\theta)\partial\varphi}$	$\psi(H_\rho)+\frac{T(H_\theta)}{\rho}+\frac{i\alpha H_\varphi}{\rho\sin(\theta)}$

Table 1A.

1	**2**	**3**
1.	$rot_\rho(E)+\frac{\mu\partial H_\rho}{c\ \partial t}-M_\rho=0$	$\frac{T(E_\varphi)}{\rho}+\frac{i\omega\mu H_\rho}{c}-M_\rho=0$
5.	$rot_\rho(H)-\frac{\varepsilon\partial E_\rho}{c\ \partial t}-J_\rho=0$	$\frac{T(H_\varphi)}{\rho}-\frac{i\omega\varepsilon E_\rho}{c}-J_\rho=0$
2.	$rot_\theta(E)+\frac{\mu\partial H_\theta}{c\ \partial t}=0$	$-\Psi(E_\varphi)+\frac{i\omega\mu H_\theta}{c}=0$
3.	$rot_\varphi(E)+\frac{\mu\partial H_\varphi}{c\ \partial t}=0$	$\Psi(E_\theta)+\frac{i\omega\mu H_\varphi}{c}=0$
6.	$rot_\theta(H)-\frac{\varepsilon\partial E_\theta}{c\ \partial t}=0$	$-\Psi(H_\varphi)-\frac{i\omega\varepsilon E_\theta}{c}=0$
7.	$rot_\varphi(H)-\frac{\varepsilon\partial E_\varphi}{c\ \partial t}=0$	$\Psi(H_\theta)-\frac{i\omega\varepsilon E_\varphi}{c}=0$
4.	$\operatorname{div}(E)=0$	$\Psi(E_\rho)+\frac{T(E_\theta)}{\varrho}=0$
8.	$\operatorname{div}(H)=0$	$\Psi(H_\rho)+\frac{T(H_\theta)}{\varrho}=0$

Table 2.

1	**2**
	$E_\theta=e_\theta sin(\theta)cos(\chi\rho+\omega t)$
	$E_\varphi=e_\varphi sin(\theta)sin(\chi\rho+\omega t)$
	$E_\rho=cos(\theta)\left(e_\rho cos(\chi\rho+\omega t)+\bar{\bar{e}}_\rho sin(\chi\rho+\omega t)\right)$
	$J_\rho=cos(\theta)\left(j_\rho sin(\chi\rho+\omega t)+\bar{\bar{j}}_\rho cos(\chi\rho+\omega t)\right)$
	$H_\theta=h_\theta sin(\theta)sin(\chi\rho+\omega t)$
	$H_\varphi=h_\varphi sin(\theta)cos(\chi\rho+\omega t)$
	$H_\rho=cos(\theta)\left(h_\rho sin(\chi\rho+\omega t)+\bar{\bar{h}}_\rho cos(\chi\rho+\omega t)\right)$
	$M_\rho=cos(\theta)\left(m_\rho cos(\chi\rho+\omega t)+\bar{\bar{m}}_\rho sin(\chi\rho+\omega t)\right)$

Table 2i.

1	2
	$i\omega E_\theta = \omega sin(\theta)\big(- e_\theta sin(\chi\rho + \omega t)\big)$
	$i\omega E_\varphi = \omega sin(\theta)\big(e_\varphi cos(\chi\rho + \omega t)\big)$
	$i\omega E_\rho = \omega cos(\theta)\big(- e_\rho sin(\chi\rho + \omega t) + \bar{\bar{e}}_\rho cos(\chi\rho + \omega t)\big)$
	$i\omega H_\theta = \omega sin(\theta)\big(h_\theta cos(\chi\rho + \omega t)\big)$
	$i\omega H_\varphi = \omega sin(\theta)\big(- h_\varphi sin(\chi\rho + \omega t)\big)$
	$i\omega H_\rho = \omega cos(\theta)\big(h_\rho cos(\chi\rho + \omega t) - \bar{\bar{h}}_\rho sin(\chi\rho + \omega t)\big)$

Table 2ρ.

1	2
	$\frac{\partial E_\theta}{\partial\rho} = \chi sin(\theta)\big(- e_\theta sin(\chi\rho + \omega t)\big)$
	$\frac{\partial E_\varphi}{\partial\rho} = \chi sin(\theta)\big(e_\varphi cos(\chi\rho + \omega t)\big)$
	$\frac{\partial E_\rho}{\partial\rho} = \chi cos(\theta)\big(- e_\rho sin(\chi\rho + \omega t) + \bar{\bar{e}}_\rho cos(\chi\rho + \omega t)\big)$
	$\frac{\partial H_\theta}{\partial\rho} = \chi sin(\theta)\big(- h_\varphi sin(\chi\rho + \omega t)\big)$
	$\frac{\partial H_\varphi}{\partial\rho} = \chi sin(\theta)\big(- h_\varphi sin(\chi\rho + \omega t)\big)$
	$\frac{\partial H_\rho}{\partial\rho} = \chi cos(\theta)\big(h_\rho cos(\chi\rho + \omega t) - \bar{\bar{h}}_\rho sin(\chi\rho + \omega t)\big)$

Table 2Ψ.

2
$\Psi(E_\theta)=\frac{E_\theta}{\rho}+\frac{\partial E_\theta}{\partial\rho}=sin(\theta)\left(\frac{1}{\rho}(e_\theta co)+\chi(-e_\theta si)+(\boxed{e_\theta}co)\right)$
$\Psi(E_\varphi)=\frac{E_\varphi}{\rho}+\frac{\partial E_\varphi}{\partial\rho}=sin(\theta)\left(\frac{1}{\rho}(e_\varphi si)+\chi(e_\varphi co)+(\boxed{e_\varphi}si)\right)$
$\Psi(E_\rho)=\frac{E_\rho}{\rho}+\frac{\partial E_\rho}{\partial\rho}=cos(\theta)\left(\frac{1}{\rho}(e_\rho co)+\frac{1}{\rho}(\bar{e}_\rho si)+\chi(\bar{e}_\rho co)-\chi(e_\rho si)+(\boxed{e_\rho}c\right.$
$\Psi(H_\theta)=\frac{H_\theta}{\rho}+\frac{\partial H_\theta}{\partial\rho}=sin(\theta)\left(\frac{1}{\rho}(h_\theta si)+\chi(h_\theta co)+(\boxed{h_\theta}si)\right)$
$\Psi(H_\varphi)=\frac{H_\varphi}{\rho}+\frac{\partial H_\varphi}{\partial\rho}=sin(\theta)\left(\frac{1}{\rho}(h_\varphi co)+\chi(-h_\varphi si)+(\boxed{h_\varphi}co)\right)$
$\Psi(H_\rho)=\frac{H_\rho}{\rho}+\frac{\partial H_\rho}{\partial\rho}=cos(\theta)\left(\frac{1}{\rho}(h_\rho si)+\frac{1}{\rho}(\bar{h}_\rho co)-\chi(\bar{h}_\rho si)+\chi(h_\rho co)+(\boxed{h_\rho}\right.$

Table 4.

1	**2**
1.	$\frac{2}{\rho}(e_\varphi si)-\frac{\mu}{c}\omega(\bar{h}_\rho si)=j_\rho si$ $\frac{\mu}{c}\omega(h_\rho co)=\bar{\bar{j}}_\rho co$
5.	$\frac{2}{\rho}(h_\varphi co)+\frac{\varepsilon}{c}\omega(\bar{e}_\rho co)=m_\rho co$ $\frac{\varepsilon}{c}\omega(e_\rho si)=\bar{\bar{m}}_\rho si$
2.	$-\left(\frac{1}{\rho}(e_\varphi si)+\chi(e_\varphi co)+(\boxed{e_\varphi}si)\right)+\frac{\mu}{c}\omega(h_\theta co)=0$
3.	$\left(\frac{1}{\rho}(e_\theta co)+\chi(-e_\theta si)+(\boxed{e_\theta}co)\right)+\frac{\mu}{c}\omega(-h_\varphi si)=0$
6.	$-\left(\frac{1}{\rho}(h_\varphi co)+\chi(-h_\varphi si)+(\boxed{h_\varphi}co)\right)-\frac{\varepsilon}{c}\omega(-e_\theta si)=0$
7.	$\left(\frac{1}{\rho}(h_\theta si)+\chi(h_\theta co)+(\boxed{h_\theta}si)\right)-\frac{\varepsilon}{c}\omega(e_\varphi co)=0$
4.	$\left(\frac{1}{\rho}(e_\rho co)+\chi(\bar{e}_\rho co)+(\boxed{e_\rho}co)\right)+\frac{2}{\rho}(e_\theta co)=0$ $\left(\frac{1}{\rho}(\bar{e}_\rho si)-\chi(e_\rho si)+(\boxed{\bar{e}_\rho}si)\right)=0$
8.	$\left(\frac{1}{\rho}(h_\rho si)-\chi(\bar{h}_\rho si)+(\boxed{h_\rho}si)\right)+\frac{2}{\rho}(h_\theta si)=0$ $\left(\frac{1}{\rho}(\bar{h}_\rho co)+\chi(h_\rho co)+(\boxed{\bar{h}_\rho}co)\right)=0$

Table 5

1	**2**
1.	$\frac{2}{\rho}e_\varphi-\frac{\mu}{c}\omega\bar{h}_\rho=j_\rho;\ \frac{\mu}{c}\omega h_\rho=\bar{\bar{j}}_\rho$
5.	$\frac{2}{\rho}h_\varphi+\frac{\varepsilon}{c}\omega\bar{\bar{e}}_\rho=m_\rho;\ \frac{\varepsilon}{c}\omega e_\rho=\bar{\bar{m}}_\rho$
2.	$\boxed{e_\varphi}=-\frac{1}{\rho}e_\varphi;\ -\chi e_\varphi+\frac{\mu\omega}{c}h_\theta=0$

6.	$\boxed{h_\varphi} =-\frac{1}{\rho}h_\varphi; \chi h_\varphi + \frac{\varepsilon\omega}{c}e_\theta$	
3.	$\boxed{e_\theta} =-\frac{1}{\rho}e_\theta; \ -\chi e_\theta - \frac{\mu\omega}{c}h_\varphi = 0$	
7.	$\boxed{h_\theta} =-\frac{1}{\rho}h_\theta; \chi h_\theta - \frac{\varepsilon\omega}{c}e_\varphi$	
2.	$\boxed{e_\varphi} =-\chi e_\varphi - \frac{1}{\rho}e_\varphi + \frac{\mu\omega}{c}h_\varphi$	
6.	$\boxed{h_\varphi} = \chi h_\varphi - \frac{1}{\rho}h_\varphi - \frac{\varepsilon\omega}{c}e_\theta$	
3.	$\boxed{e_\theta} = \chi e_\theta - \frac{1}{\rho}e_\theta - \frac{\mu\omega}{c}h_\varphi$	
7.	$\boxed{h_\theta} =-\chi h_\theta - \frac{1}{\rho}h_\theta + \frac{\varepsilon\omega}{c}e_\varphi$	
4.	1	$\left(\frac{1}{\rho}e_\rho + \chi\bar{\bar{e}}_\rho + \boxed{e_\rho}\right) + \frac{2}{\rho}e_\theta = 0$
	2	$\left(\frac{1}{\rho}\bar{\bar{e}}_\rho - \chi e_\rho + \boxed{\bar{\bar{e}}_\rho}\right) = 0$
8.	1	$\left(\frac{1}{\rho}h_\rho - \chi\bar{\bar{h}}_\rho + \boxed{h_\rho}\right) + \frac{2}{\rho}h_\theta = 0$
	2	$\left(\frac{1}{\rho}\bar{\bar{h}}_\rho + \chi h_\rho + \boxed{\bar{\bar{h}}_\rho}\right) = 0$

The third solution. Maxwell's equations in spherical coordinates for an electrically conductive medium.

1. An approximate solution

Above in the "The second solution" we considered the solution of the Maxwell equations for a sphere in a medium that has ε nd μ different from unity. Further, suppose that the medium has some electrical conductivity σ. In this case an equation of the form

$$\mathrm{rot}H - \frac{\varepsilon}{c}\frac{\partial E}{\partial t} = 0 \tag{1}$$

is replaced by an equation of the form

$$\mathrm{rot}H - \frac{\varepsilon}{c}\frac{\partial E}{\partial t} - \sigma E = 0 \tag{2}$$

We will seek a solution in the form of the functions E, H, J, M presented in Table **T2-2** (see “The second solution") and rewrite it in a complex form as **T1-2**. Then equation (2) takes the form:

$$rot(H) - \frac{i\omega\varepsilon}{c}E - \sigma E = 0 \tag{3}$$

or

$$rot(H) - wE = 0, \qquad (4)$$

where the complex number

$$w = \frac{i\omega\varepsilon}{c} + \sigma. \qquad (5)$$

We now rewrite Table **T1A** (see "The second solution") in a complex form in Table **T2**, taking into account formula (4). We assume that the conduction currents are substantially larger than the displacement currents on the circles of the sphere, i.e. on the circles one can take into account only the conduction currents. In Table **T2-3**, we obtain a system of 8 algebraic equations with 8 complex unknowns *E, H,* J_ρ, M_ρ.

The solution can be performed in the following order.

1. The systems of two equations **T2-2** and **T2-7** with respect to the unknowns E_φ and H_θ are solved.
2. The systems of two equations **T2-3** and **T2-6** with respect to the unknowns E_θ and H_φ are solved.
3. With the data E_θ and H_θ the equations **T2-4** and **T2-8** are solved and the unknowns E_ρ and H_ρ, respectively, are determined.
4. For the data E_φ and H_ρ, the equations T2-1 are solved and the unknown M_ρ is determined.
5. For the data H_φ and E_ρ, the equations **T2-1** are solved and the unknown J_ρ is determined.

2. The exact solution

We now consider the table **T2**, in which all 6 displacement currents are indicated. This table contains 8 algebraic equations with 12 complex unknowns E, H, J, M and is overdetermined.

Consider the equations of energy fluxes (3.4) from the section "The second solution":

$$S_\varphi = \eta(E_\theta H_\rho - E_\rho H_\theta), \qquad (1)$$

$$S_\theta = \eta(E_\rho H_\varphi - E_\varphi H_\rho), \qquad (2)$$

$$S_\rho = \eta(E_\varphi H_\theta - E_\theta H_\varphi). \qquad (3)$$

From the law of conservation of energy it follows that the flow of energy can not change in time. This means that the quantities (1-3) must be real. Consequently,

$$Im(E_\theta H_\rho - E_\rho H_\theta) = 0, \qquad (4)$$

$$Im(E_\rho H_\varphi - E_\varphi H_\rho) = 0, \qquad (5)$$

$$Im(E_\varphi H_\theta - E_\theta H_\varphi) = 0. \qquad (6)$$

We also assume that one of the intensities is known, for example,

$$e_\varphi = A/\rho, \tag{7}$$

where A is a constant. In this case, we have a system of 12 nonlinear equations **T3-3** and (4-7) with 12 complex unknowns E, H, J, M. Methods for solving such systems are known.

Tables

Table 1.

1	2
	$E_\theta = e_\theta sin(\theta)$
	$E_\varphi = ie_\varphi sin(\theta)$
	$E_\rho = cos(\theta)\left(e_\rho + i\bar{\bar{e}}_\rho\right)$
	$J_\rho = cos(\theta)\left(ij_\rho + \bar{\bar{j}}_\rho\right)$
	$H_\theta = ih_\theta sin(\theta)$
	$H_\varphi = h_\varphi sin(\theta)$
	$H_\rho = cos(\theta)\left(ih_\rho + \bar{\bar{h}}_\rho\right)$
	$M_\rho = cos(\theta)\left(m_\rho + i\bar{\bar{m}}_\rho\right)$

Table 2.

1	2	3
1.	$rot_\rho(E) - \frac{i\omega\mu}{c}H_\rho - M_\rho = 0$	$\frac{T(E_\varphi)}{\rho} + \frac{i\omega\mu H_\rho}{c} - M_\rho = 0$
5.	$rot_\rho(H) - wE_\rho - J_\rho = 0$	$\frac{T(H_\varphi)}{\rho} - wE_\rho - J_\rho = 0$
2.	$rot_\theta(E) - \frac{i\omega\mu}{c}H_\theta = 0$	$-\Psi(E_\varphi) + \frac{i\omega\mu H_\theta}{c} = 0$
7.	$rot_\varphi(H) - wE_\varphi = 0$	$\Psi(H_\theta) - wE_\varphi = 0$
3.	$rot_\varphi(E) - \frac{i\omega\mu}{c}H_\varphi = 0$	$\Psi(E_\theta) + \frac{i\omega\mu H_\varphi}{c} = 0$
6.	$rot_\theta(H) - wE_\theta = 0$	$-\Psi(H_\varphi) - wE_\theta = 0$
4.	$\mathrm{div}(E) = 0$	$\Psi(E_\rho) + \frac{T(E_\theta)}{\rho} = 0$
8.	$\mathrm{div}(H) = 0$	$\Psi(H_\rho) + \frac{T(H_\theta)}{\rho} = 0$

Table 3.

1	2	3
1.	$rot_\rho(E)-\frac{i\omega\mu}{c}H_\rho-M_\rho=0$	$\frac{T(E_\varphi)}{\rho}+\frac{i\omega\mu H_\rho}{c}-M_\rho=0$
5.	$rot_\rho(H)-wE_\rho-J_\rho=0$	$\frac{T(H_\varphi)}{\rho}-wE_\rho-J_\rho=0$
2.	$rot_\theta(E)-\frac{i\omega\mu}{c}H_\theta-M_\theta=0$	$-\Psi(E_\varphi)+\frac{i\omega\mu H_\theta}{c}-M_\theta=0$
7.	$rot_\varphi(H)-wE_\varphi-J_\varphi=0$	$\Psi(H_\theta)-wE_\varphi=0$
3.	$rot_\varphi(E)-\frac{i\omega\mu}{c}H_\varphi-M_\varphi=0$	$\Psi(E_\theta)+\frac{i\omega\mu H_\varphi}{c}-M_\varphi=0$
6.	$rot_\theta(H)-wE_\theta-J_\theta=0$	$-\Psi(H_\varphi)-wE_\theta-J_\theta=0$
4.	$\mathrm{div}(E)=0$	$\Psi(E_\rho)+\frac{T(E_\theta)}{\rho}=0$
8.	$\mathrm{div}(H)=0$	$\Psi(H_\rho)+\frac{T(H_\theta)}{\rho}=0$

Chapter 8a. Solution of Maxwell's Equations for Spherical Capacitor

Contents

1. Introduction

The electromagnetic wave in a capacitor in an alternating current or constant current circuit is investigated in главах 2 и 7. In this paper, a spherical capacitor in a sinusoidal current circuit or an constant current circuit is considered. The capacitor electrodes are two spheres having the same center and radii $R_2 > R_1$.

2. Solution of the Maxwell Equations in the Spherical Coordinate System

The solution of the Maxwell equations in spherical coordinates was obtained in Chapter 8 (second solution).

The radial coordinate changes within

$$R_1 < \rho < R_2. \tag{1}$$

For a bounded ϱ and a small value χ, Table 2 in Chapter 8 (second solution) takes the form of Table 1.

Next, we rewrite this table in a complex form - see T2-2 and T2-3, where $|E_\rho|$ is the strength module of intensities E_ρ (which includes the dependence on θ), ψ is the argument of intensities E_ρ, and so on.

Table 1.

1	2
	$E_\theta = e_\theta sin(\theta)cos(\omega t)$
	$E_\varphi = e_\varphi sin(\theta)sin(\omega t)$
	$E_\rho = cos(\theta)\left(e_\rho cos(\omega t) + \bar{\bar{e}}_\rho sin(\omega t)\right)$
	$J_\rho = cos(\theta)\left(j_\rho sin(\omega t) + \bar{\bar{j}}_\rho cos(\omega t)\right)$
	$H_\theta = h_\theta sin(\theta)sin(\omega t)$
	$H_\varphi = h_\varphi sin(\theta)cos(\omega t)$
	$H_\rho = cos(\theta)\left(h_\rho sin(\omega t) + \bar{\bar{h}}_\rho cos(\omega t)\right)$
	$M_\rho = cos(\theta)\left(m_\rho cos(\omega t) + \bar{\bar{m}}_\rho sin(\omega t)\right)$

Table 2.

1	2	
	$E_\theta = e_\theta sin(\theta)$	$E_\theta = \lvert E_\theta \rvert$
	$E_\varphi = ie_\varphi sin(\theta)$	$E_\varphi = i\lvert E_\varphi \rvert$
	$E_\rho = cos(\theta)\left(e_\rho + i\bar{\bar{e}}_\rho\right)$	$E_\rho = \lvert E_\rho \rvert cos(\psi)$
	$J_\rho = cos(\theta)\left(ij_\rho + \bar{\bar{j}}_\rho\right)$	$J_\rho = \lvert J_\rho \rvert cos(\psi)$
	$H_\theta = ih_\theta sin(\theta)$	$H_\theta = i\lvert H_\theta \rvert$
	$H_\varphi = h_\varphi sin(\theta)$	$H_\varphi = \lvert H_\varphi \rvert$
	$H_\rho = cos(\theta)\left(ih_\rho + \bar{\bar{h}}_\rho\right)$	$H_\rho = \lvert H_\rho \rvert cos(\psi)$
	$M_\rho = cos(\theta)\left(m_\rho + i\bar{\bar{m}}_\rho\right)$	$M_\rho = \lvert M_\rho \rvert cos(\psi)$

It is important to note that at the moment the potential on the sphere of a given radius changes as a function of $sin(\theta)$. The outer and inner metal surfaces are on a constant radius. Consequently, the potential on the metal plate of the spherical radius is different at different points of the sphere. Consequently, further, currents flow on the plates of the spherical capacitor.

An additional argument in favor of the existence of such currents is the existence of telluric currents [53]. There is no generally accepted explanation of their cause.

Next, we will refer to the formulas of Chapter 8 (second solution) in the form: (8. "room_ of the". "Formula_number").

From (8.2.16, 8.2.17) we find:

$$|E_\rho| = \sqrt{(e_\rho)^2 + (\bar{\bar{e}}_\rho)^2} = \sqrt{\left(\frac{1}{\rho}(G + 2A \cdot \ln(\rho))\right)^2 + \left(\frac{D}{\rho}\right)^2} =$$

$$\frac{1}{\rho}\sqrt{(G + 2A \cdot \ln(\rho))^2 + D^2}, \qquad (2)$$

$$\mathrm{tg}(\psi_{e\rho}) = \frac{\bar{\bar{e}}_\rho}{e_\rho} = D/(G + 2A \cdot \ln(\rho)). \qquad (3)$$

Completely analogous formulas exist for H_ρ, but for $\psi_{h\rho}$ the formula has the form

$$tg(\psi_{h\rho}) = \frac{h_\rho}{\bar{\bar{h}}_\rho} = (G + 2A \cdot ln(\rho))/D, \qquad (6)$$

which follows from Table **T2-2**. Consequently,,

$$tg(\psi_{h\rho}) = 1/tg(\psi_{e\rho}). \qquad (7)$$

Further from (8.2.18, 8.2.19) we find::

$$|J_\rho| = \sqrt{(j_\rho)^2 + (\bar{\bar{j}}_\rho)^2} =$$

$$\sqrt{\left(\frac{2A}{\rho^2} - \frac{\mu\omega}{c} \cdot \frac{D}{\rho}\right)^2 + \left(\frac{\mu\omega}{c} \cdot \frac{1}{\rho}(G + 2A \cdot ln(\rho))\right)^2}, \qquad (8)$$

$$tg(\psi_{j\rho}) = \frac{j_\rho}{\bar{\bar{j}}} = \left(\frac{2A}{\rho^2} - \frac{\mu\omega}{c} \cdot \frac{D}{\rho}\right) / \left(-\frac{\mu\omega}{c} \cdot \frac{1}{\rho}(G + 2A \cdot ln(\rho))\right). \qquad (9)$$

Finally, from (8.2.20, 8.2.21) we find:

$$|M_\rho| = \sqrt{(m_\rho)^2 + (\bar{\bar{m}}_\rho)^2} =$$

$$\sqrt{\left(-\frac{2B}{\rho^2} + \frac{\varepsilon\omega}{c} \cdot \frac{D}{\rho}\right)^2 + \left(\frac{\varepsilon\omega \cdot 1}{c \ \ \rho}(G + 2A \cdot ln(\rho))\right)^2}, \qquad (10)$$

$$tg(\psi_{m\rho}) = \frac{\bar{\bar{m}}_\rho}{m_\rho} = \left(-\frac{\varepsilon\omega \cdot 1}{c \ \ \rho}(G + 2A \cdot ln(\rho))\right) / \left(-\frac{2B}{\rho^2} + \frac{\varepsilon\omega}{c} \cdot \frac{D}{\rho}\right). \qquad (11)$$

From the formulas obtained it follows that the <u>spherical capacitor must have magnetic properties similar to its electrical properties.</u>

With the known voltage with the rms value U on the capacitor from (2), we find:

$$U = |E_\rho(R_2)| - |E_\rho(R_1)| = \frac{1}{R_2}\sqrt{(G + 2A \cdot ln(R_2))^2 + D^2} - \frac{1}{R_1}\sqrt{(G + 2A \cdot ln(R_1))^2 + D^2} \qquad (12)$$

In particular, with $ln(R_2) \approx ln(R_1)$ we get:

$$U = K\left(\frac{1}{R_2} - \frac{1}{R_1}\right) \qquad (13)$$

where K is a constant. Consequently, the amplitude of the potential on the outer sphere of the capacitor is smaller than the amplitude of the potential on the inner sphere of the capacitor.

3. Electric and magnetic intensities

Let us consider a point T with coordinates φ, θ on a sphere of radius ρ .Vectors H_φ and H_θ, going from this point are in plane P, tangent to this sphere at point $T(\varphi,\ \theta)$ - see Fig. 2. These vectors are perpendicular to each other. Hence, at each point $(\varphi,\ \theta)$ the sum vector

$$H_{\varphi\theta} = H_\varphi + H_\theta \tag{1}$$

is in plane P and has an angle of ψ to a parallel line. As it follows from the Table 2 and (8.2.14), the module of this vector $|\mathrm{H}_{\varphi\theta}|$ and the angle ψ defined by the following formulas:

$$H_{\varphi\theta} = |H_{\varphi\theta}| cos(\psi) \tag{2}$$

$$|H_{\varphi\theta}| = \frac{B}{\rho} sin(\theta) \tag{3}$$

$$\psi = arcctg(\chi\rho + \omega t) \tag{4}$$

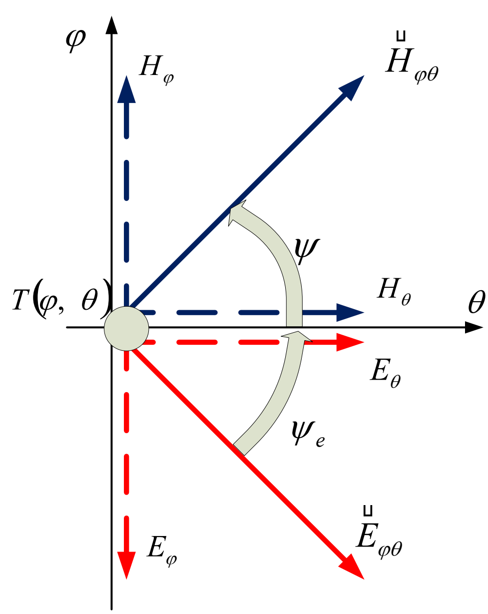


Fig. 2.

We find the intensities $\mathrm{H}_{\varphi\theta}$ at the poles of the sphere, where

$$\theta = \pm\frac{\pi}{2},\ \sin(\theta) = \pm 1,\ \rho = R. \tag{5}$$

It follows from (2-4) that at the poles

$$|H_{\varphi\theta}| = \pm\frac{B}{R} \tag{6}$$

and there is a magnetic intensities between the poles

$$H_{pp} = \frac{2B}{R}cos(\chi R + \omega t) \tag{7}$$

Similarly, the same relationships exist for the vectors E_{φ} and E_{θ}. At each point $(\varphi,\ \theta)$ the total vector

$$E_{\varphi\theta} = E_{\varphi} + E_{\theta} \tag{8}$$

lies in the plane P and is directed at an angle ψ_e to a line parallel (along the coordinate θ). It follows from Table 3 and (8.2.13), the module of this vector and the angle ψ_e defined by the following formulas:

$$E_{\varphi\theta} = |E_{\varphi\theta}|cos(\psi_e) \tag{9}$$

$$|E_{\varphi\theta}| = \frac{A}{\rho}sin(\theta) \tag{10}$$

$$\psi_e = arctg(\chi\rho + \omega t) \tag{11}$$

The angle between $H_{\varphi\theta}$ и $E_{\varphi\theta}$ in the plane P is straight.

Therefore, in a spherical capacitor we can consider only one vector of the electrical field intensities $E_{\varphi\theta}$ and only one vector of the magnetic field intensities $H_{\varphi\theta}$. As these vectors lie on the sphere, they will be called <u>spherical vectors</u>.

Angle ψ (30) is constant for all vectors $H_{\varphi\theta}$ for a given radius ρ. This means that the directions of all vectors $H_{\varphi\theta}$ constitute the same angle ψ with all parallels on a sphere with a radius of ρ. This implies in turn that there are the <u>magnetic equatorial plane</u> inclined to the mathematical equatorial plane at angle ψ, <u>magnetic axis</u>, <u>magnetic poles</u>, and <u>magnetic meridians</u>, along which vectors $H_{\varphi\theta}$ are directed – see Fig. 4, where thin lines mark the mathematical meridional grid, thick lines mark the magnetic meridional grid, the mathematical axis *mm*, and magnetic axis *aa* and electric axis *bb* are shown. It is important to note that the magnetic axis *aa*, electric axis *bb* and all vectors $E_{\varphi\theta}$ и $H_{\varphi\theta}$ are perpendicular.

When $\frac{\omega}{c} \approx 0$ the magnetic axis coincides with the mathematical axis.

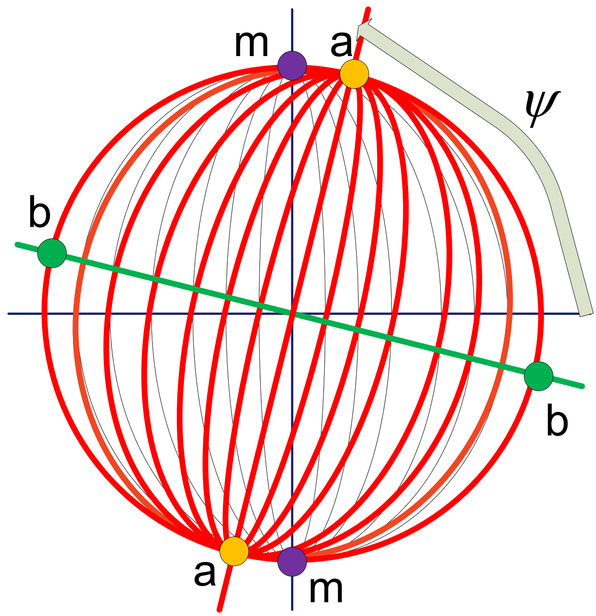


Fig. 4.

Spherical vectors depend on $\sin(\theta)$. Radial vectors depend on $\cos(\theta)$ – see Table 2. Therefore, there are the radial intensities only in locations where the spherical intensity is zero.

4. Electromagnetic Wave in a Charged Spherical Capacitor

A solution of the Maxwell equations for a parallel-plate capacitor being charged (see chapter 7) systems from a solution of these equations for a parallel-plate capacitor in a sinusoidal current circuit (see chapter 3). In this paper the method described in chapter 7 will be used in solving the Maxwell equations for a spherical capacitor being charged.

For a charged spherical capacitor, the system of Maxwell's equations presented in Tables 1A-2 of Chapter 8 (“The second solution”) must be changed, namely, instead of equation (4) the following equation is used:

$$\mathrm{div}(E) = Q(t), \tag{1}$$

where $Q(t)$ - charge on capacitor plate, which appears and accumulates during charging. The system of partial differential equations obtained in such a way has a solution represented by the sum of a particular solution of this system and a general solution of the corresponding homogeneous system of equations. Homogeneous system is shown in specified table, i.e. it only differs from this new system by the absence of term $Q(t)$. Particular solution with given t is a solution, which associates electric intensity $E_\rho(t)$ between the capacitor plates with electric charge $Q(t)$. If $E_\rho(t)$ varies with time, then a solution of the system of equations from specified table shall exist at given $E_\rho(t)$. Exactly this solution we're going to seek further on.

Table 6.

1	2
	$E_\theta = e_\theta sin(\theta)(1 - exp(\omega t))$
	$E_\varphi = e_\varphi sin(\theta)(exp(\omega t) - 1)$
	$E_\rho = cos(\theta)\left(e_\rho(1 - exp(\omega t)) + \bar{\bar{e}}_\rho(exp(\omega t) - 1)\right)$
	$J_\rho = cos(\theta)\left(j_\rho(exp(\omega t) - 1) + \bar{\bar{j}}_\rho(1 - exp(\omega t))\right)$
	$H_\theta = h_\theta sin(\theta)(exp(\omega t) - 1)$
	$H_\varphi = h_\varphi sin(\theta)(1 - exp(\omega t))$
	$H_\rho = cos(\theta)\left(h_\rho(exp(\omega t) - 1) + \bar{\bar{h}}_\rho(1 - exp(\omega t))\right)$
	$M_\rho = cos(\theta)\left(m_\rho(1 - exp(\omega t)) + \bar{\bar{m}}_\rho(exp(\omega t) - 1)\right)$

Let us consider the field intensities in the form of functions presented in Table 6. These functions differ from functions of Table 1 only by the type of time dependence: in Table 3, E and H functions depend on time as $\sin(\omega t)$, $\cos(\omega t)$, respectively, while in Table 6, E and H functions depend on time as $(exp(\omega t) - 1), (1 - exp(\omega t))$, respectively. Although the indicated substitution, the solution of Maxwell's equations remain unchanged. Here the constant $\omega = -1/\tau$, where τ is the time constant in the capacitor charge circuit.

Fig. 6 presents intensities components and their time derivatives as well as the bias current as a function of time for $\omega = -300$: H_ρ is shown with a solid line, with a dashed line, and J_ρ with dotted line. It is evident that with $t \Rightarrow \infty$ the amplitudes of all intensities components tend to a constant together, while the current amplitude approaches zero. This corresponds to the capacitor charging via a fixed resistor.

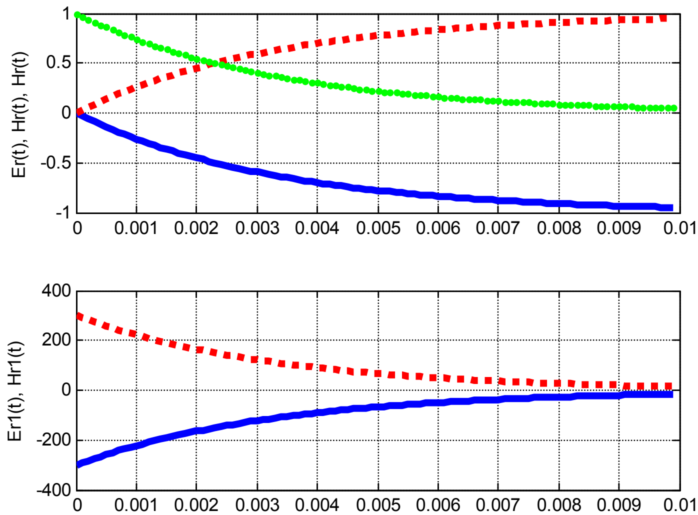


Fig.6. (SSMB6.1)

Thus, it's fare to say, that spherical capacitor is a device which is equivalent to both - magnet and, at the same time, electret which axes are perpendicular.

By analogy with Section 3 in Chapter 8 ("second solution"), we consider the flux of radial energy in a charged spherical capacitor. For this, in the formula (8.3.4a) it is necessary to make the following change of functions:

$$\sin(q) \Longrightarrow (\exp(\omega t) - 1), \tag{2}$$

$$\cos(q) \Longrightarrow \left(1 - \exp(\omega t)\right). \tag{3}$$

Then we get:

$$S_\rho = \frac{A}{\rho}\sin(\theta)(\exp(\omega t) - 1)\frac{B}{\rho}\sin(\theta)(\exp(\omega t) - 1)$$
$$- \frac{A}{\rho}\sin(\theta)\left(1 - \exp(\omega t)\right)\frac{-B}{\rho}\sin(\theta)\left(1 - \exp(\omega t)\right)$$

or

$$S_\rho = \frac{2AB}{\rho^2}\sin^2(\theta)\left(1 - \exp(\omega t)\right)^2 \Longrightarrow 0 \tag{4}$$

Thus, the solution of the Maxwell equations for a capacitor being charged and for a capacitor in a sinusoidal current circuit differs only in that the former includes exponential functions of time and the latter contains sinusoidal time-functions.

So, It was shown that electromagnetic wave propagation in charging spherical capacitor , and mathematical description of this wave is proved to be a solution of Maxwell's equations. It was shown that a charged spherical capacitor accommodates a stationary flux of electromagnetic energy, and the energy contained in the capacitor, which was considered to be electric potential energy, is, indeed, electromagnetic energy stored in the capacitor in the form of the stationary flux.

Chapter 8b. A new approach to antenna design

Contents

1. On the shortcomings of existing methods

The solution of the Maxwell equations for a spherical wave is necessary for the design of antennas. Such a problem arises in the solution of the equations of electrodynamics for an elementary electric dipole - a vibrator. The solution of this problem is known and it is on the basis of this solution that the antennas are constructed. At the same time, this solution has a number of shortcomings, in particular [107-110].

1. The energy conservation law is satisfied only on the average,
2. The solution is inhomogeneous and it is practically necessary to divide it into separate zones (as a rule, near, middle and far), in which the solutions turn out to be completely different,
3. In the near zone there is no flow of energy with the real value
4. The magnetic and electrical components are in phase,
5. In the near zone, the solution is not wave (i.s. the distance is not an argument of the trigonometric function),
6. The known solution does not satisfy Maxwell's system of equations (a solution that satisfies a single equation of the system can not be considered a solution of the system of equations).

In Fig. 1 [110] shows the picture of the lines of force of the electric field, constructed on the basis of the known solution. Obviously, such a picture can not exist in a spherical wave.

Far from the vibrator - in the so-called the far zone, where longitudinal (directed along the radius) the electric and magnetic intensities can be neglected by , the solution of the problem is simplified. But even there the well-known solution has a number of shortcomings

[107-110]. The main disadvantages of this solution (see Appendix 1) are that

1. the law of conservation of energy is fulfilled only on the average (in time),
2. the magnetic and electrical components are in phase,
3. in the Maxwell equations system, in the known solution, only one equation of eight is satisfied.

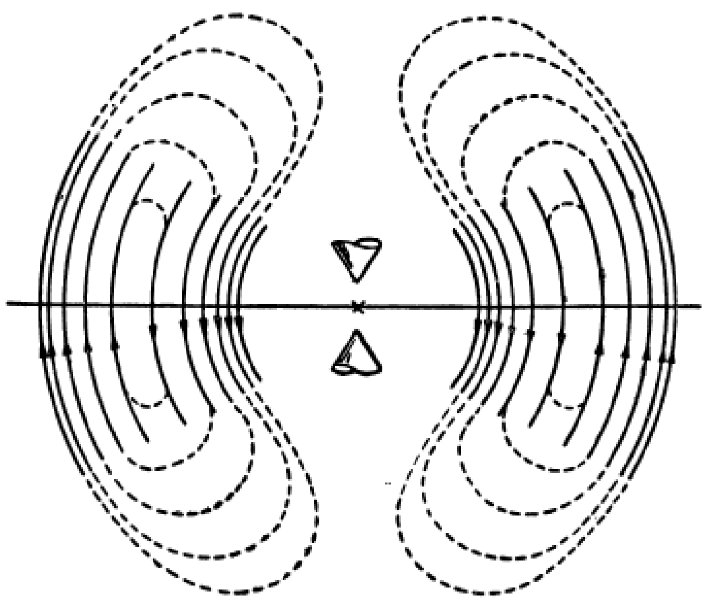


Fig. 1.

2. A new approach

These shortcomings are a consequence of the fact that until now Maxwell's equations for spherical coordinates could not be solved. A well-known solution is obtained after dividing the entire domain into so-called near, middle and far zones and after applying a variety of assumptions, different for each of these zones.

In practice, specified drawbacks of the known solution mean that they (mathematical solutions) do not strictly describe the real characteristics of technical devices. A more rigorous solution (see Chapter 8), when applied in the design systems of such devices, must certainly improve their quality.

Appendix 1

The known solution has the form [107, 108]:

$$E_\theta = e_\theta \frac{1}{\rho} \sin(\theta) \sin(\omega t - \chi\rho), \tag{1}$$

$$H_\varphi = h_\varphi \frac{1}{\rho} \sin(\theta) \sin(\omega t - \chi\rho), \tag{2}$$

$k_{e\theta} = \dfrac{\chi^2 lI}{4\pi\omega\varepsilon\varepsilon_o}$, $k_{h\varphi} = \dfrac{\chi lI}{4\pi}$, where l, I - length and current of the vibrator. We notice, that

$$\frac{e_\theta}{h_\varphi} = \frac{\chi}{\omega\varepsilon} \tag{3}$$

It should be noted that these tensions are in phase, which contradicts practical electrical engineering.

Table 2.

1	2
1.	$\mathrm{rot}_\rho H - \dfrac{\varepsilon}{c}\dfrac{\partial E_\rho}{\partial t} = 0$
2.	$\mathrm{rot}_\theta H - \dfrac{\varepsilon}{c}\dfrac{\partial E_\theta}{\partial t} = 0$
3.	$\mathrm{rot}_\varphi H - \dfrac{\varepsilon}{c}\dfrac{\partial E_\varphi}{\partial t} = 0$
4.	$\mathrm{rot}_\rho E + \dfrac{\mu}{c}\dfrac{\partial H_\rho}{\partial t} = 0$
5.	$\mathrm{rot}_\theta E + \dfrac{\mu}{c}\dfrac{\partial H_\theta}{\partial t} = 0$
6.	$\mathrm{rot}_\varphi E + \dfrac{\mu}{c}\dfrac{\partial H_\varphi}{\partial t} = 0$
7.	$\mathrm{div}(E) = 0$
8.	$\mathrm{div}(H) = 0$

Let us consider how equations (1, 2) relate to Maxwell's system of equations - see Table 2 (rewritten from Chapter 8, first solution). The intensities (1, 2) enter only in equation (6) from Table 2, which has the form

$$\mathrm{rot}_{\varphi} E + \frac{\mu}{c}\frac{\partial H_{\varphi}}{\partial t} = 0 \tag{4}$$

or

$$\frac{E_{\theta}}{\rho} + \frac{\partial E_{\theta}}{\partial \rho} + \frac{\mu}{c}\frac{\partial H_{\varphi}}{\partial t} = 0\,. \tag{5}$$

We substitute (1, 2) into (5) and obtain:

$$\begin{gathered} -e_{\theta}\frac{\chi}{\rho}\sin(\theta)\cos(\omega t - \chi\rho) - \\ -h_{\varphi}\frac{\chi}{\rho}\frac{\mu}{c}\sin(\theta)\cos(\omega t - \chi\rho) = 0 \end{gathered} \tag{6}$$

or

$$\frac{e_{\theta}}{h_{\varphi}} + \frac{\mu}{c} = 0\,. \tag{7}$$

From a comparison of (3) and (7) it follows that the intensities (1, 2) satisfy equation (4). The remaining 7 Maxwell equations are violated. In the equations (2, 3, 5) from Table 2 one of the terms differs from zero, and the other is equal to zero. The violation of equations (1, 4, 7, 8) from Table. 2 is shown – see Chapter 8, first solution, formula (2.20). So,

> **the known solution does not satisfy Maxwell's system of equations.**

Chapter 9. The Nature of Earth's Magnetism

It is known that the Earth electrical field can be considered as a field "between spherical capacitor electrodes" [51]. These electrodes are the Earth surface having a negative charge and the ionosphere having a positive charge. The charge of these electrodes is maintained by continuous atmospheric thunderstorm activities.

It is also known that there is the Earth magnetic field. However, in this case no generally accepted explanation of the source of this field is available. "The problem of the origin and retaining of the field has not been solved as yet." [52].

Next, we will consider the hypothesis that the **Earth's magnetic field is a consequence of the existence of the Earth's electric field**.

In Chapter 8a, a spherical capacitor is considered in a DC circuit and it is shown that after a capacitor charge, when the current practically ceases, the stationary flux of electromagnetic energy remains in the capacitor, and with it an electromagnetic wave is conserved. A magnetic field is present in the capacitor.

In Chapter 8a it was shown that in a spherical condenser are are the <u>magnetic equatorial plane</u>, <u>magnetic axis</u>, <u>magnetic poles</u> and <u>magnetic meridians</u>, along which vectors $\mathrm{H}_{\varphi\theta}$ are directed – see Fig. 4 in chapter 8. The angle between the magnetic axis and the axis of the mathematical model can not be determined from the mathematical model. Moreover, not determined angle between the magnetic axis and the Earth's physical axis of rotation.

Spherical vectors depend on $\sin(\theta)$. Radial vectors depend on $\cos(\theta)$ – see table 6 in chapter 8. Therefore, there are the radial intensities only in locations where the spherical intensity is zero.

It flows from the above mentioned that <u>**the Earth electrical field is responsible for the Earth magnetic field.**</u>

Let us consider this problem in more details.

The vector field $\mathrm{H}_{\varphi\theta}$ in a diametral plane passing through the magnetic axis is shown in Fig. 8. Here, $\left|\mathrm{H}_{\varphi\theta}\right| = 0.7;\ \rho = 1.$ The vector field H_ρ in a diametral plane passing through the magnetic axis is shown in Fig. 9. Here, $|H_\rho| = 0.4; \ \rho = 1$. The vector field $H = H_{\varphi\theta} + H_\rho$ in a diametral plane passing through the magnetic axis is shown in Fig. 10. Here, $|H_{\varphi\theta}| = 0.3; \ |H_\rho| = 0.2; \ \rho = 1$.

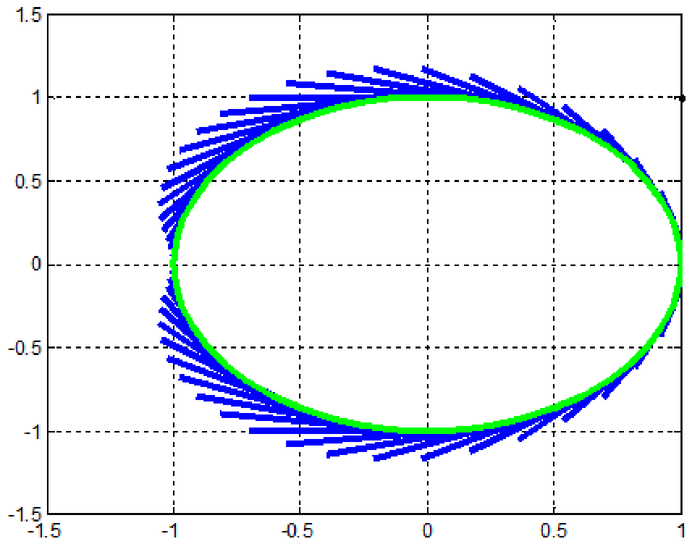


FIG. 8. (Sfera.88)

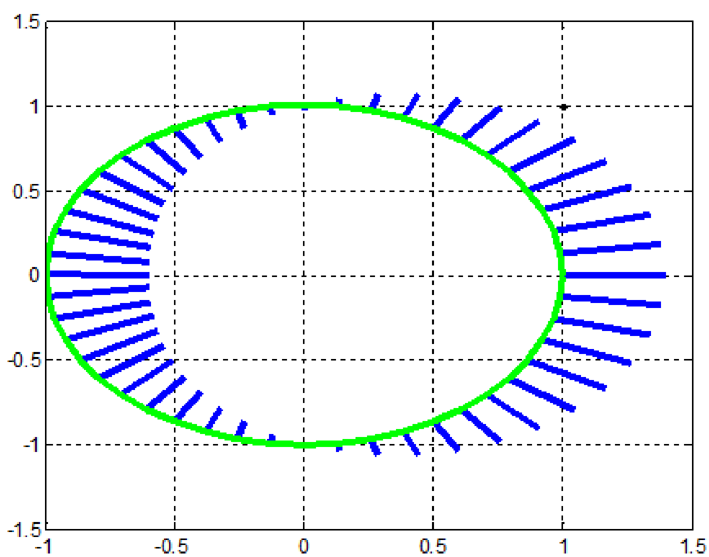


FIG. 9. (Sfera.88)

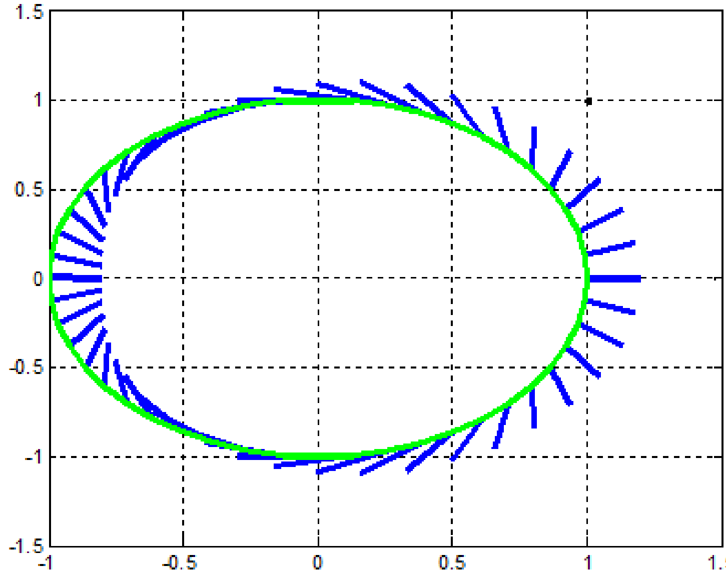


FIG. 10. (Sfera 88)

Similarly, can be described the electric field of the Earth. Importantly, the electric field and the magnetic field are perpendicularly.

Once again, the very existence of the electric field is not in doubt, and the charge of "Earth's spherical capacitor" is supported by the thunderstorm activity [51, 52].

Also consider the comparative quantitative estimates of magnetic and electric intensity of the Earth's field.

In a vacuum, where $\varepsilon = \mu = 1$, there is a relation between the magnetic and electric intensity in any direction in the GHS system [51]

$$E = H . \tag{9}$$

This relation is true if these intensities are measured in the GHS system at a given point in the same direction. To go to the SI system, one shall take into account that

for H: 1 GHS unit = 80 A/m

for E: 1 GHS unit = 30,000 B/m

Hence, the equation (9) takes the following form in the SI system:

$$3000E = 80H \tag{10}$$

or

$$E \approx 0.03H . \tag{11}$$

or

$$H \approx 30E \cdot \mathrm{tg}(\beta) . \tag{12}$$

An additional argument in favor of the existence of the electric field of the structure specified is the existence of the telluric currents [53]. There is no generally accepted explanation of their causes. On the basis of the foregoing, it shall be assumed that these currents must have the largest value in the direction of the parallels.

It is possible that the electric field of the Earth can be detected using a freely suspended electric dipole, made in the form of a long isolated rod with metal balls at the ends. It is also possible that oscillations of the rod will be recorded at the low frequency of changing in dipole charges.

Based on the hypothesis suggested, it can be assumed that the magnetic field shall be observed among planets with an atmosphere. Indeed, the Moon and Mars, free of the atmosphere, lack the magnetic field. However, there is no magnetic field at Venus. This may be due to the high density and conductivity of the atmosphere – it cannot be considered as an insulating layer of the spherical capacitor.

Chapter 10. Solution of Maxwell's Equations for Ball Lightning

Contents

1. Introduction

The hypotheses that were made about the nature of ball lightning are unacceptable because they are contrary to the law of energy conservation. This occurs because the luminescence of ball lightning is usually attributed to the energy released in any molecular or chemical transformation, and so it is suggested source of energy, due to which the ball lightning glows is located in it.

Kapitsa P.L. 1955 [41]

This assertion (as far as the author knows) is true also today. It is reinforced by the fact that the currently estimated typical ball lightning contains tens of kilojoules [42], released during its explosion.

It is generally accepted that ball lightning is somehow connected with the electromagnetic phenomena, but there is no rigorous description of these processes.

A mathematical model of a globe lightning based on the Maxwell equations, which enabled us to explain many properties of the globe lightning, is proposed in [55]. However, this model turned out be quite intricate as to the used mathematical description. Another model of the ball lightning which is substantiated to a greater extent and make is possible to obtain less intricate mathematical description is outlined below [56]. Moreover, this model agrees with the model of a spherical capacitor – see chapter 8.

When constructing the mathematical model, it will be assumed that the globe lighting is plasma, i.e. gas consisting of charged particles – electrons, and positive charged ions, i.e. the globe lightning plasma is fully ionized. In addition, it is assumed that the number of positive charges equal to the number of negative charges, and, hence, the total charge of the globe lightning is equal to zero. For the plasma, we usually consider charge and current densities averaged over an elementary volume. Electric and magnetic fields created by the average "charge" density and the "average" current density in the plasma obey the Maxwell equations [62]. The effect of particles collision in the plasma is usually described by the function of particle distribution in the plasma. These effects will be accounted for the Maxwell equations assuming that the plasma possesses some electric resistance or conductivity.

And so on based on the Maxwell's equations and on the understanding of the electrical conductivity of the body of ball lightning, a mathematical model of ball lightning is built; the structure of the electromagnetic field and of electric current in it is shown. Next it is shown (as a consequence of this model) that in a ball lightning the flow of electromagnetic energy can circulate and thus the energy obtained by a ball lightning when it occurs can be saved. Sustainability, luminescence, charge, time being, the mechanism of formation of ball lightning are briefly discussed.

2. The solution of Maxwell equations in spherical coordinates

In Chapter 8, third solution, a solution is obtained for Maxwell's equations for a sphere whose material has dielectric and magnetic permeability, and also has conductivity. This solution has been obtained under the following assumptions: the sphere is conductive and neutral (does not have any uncompensated charges). Its existence means only that in a conductive and neutral sphere, an electromagnetic wave <u>can</u> exist, and currents can circulate.

3. Energy

From the resulting solution follows that lightning contains the following energy components

- Active loss energy W_a – see the second term in the expression for the electric strength:

- Reactive electric energy W_e – see the first term in the expression for the electric strength:
- Reactive magnetic energy W_h – see the expression for the magnetic strength

4. About Ball Lightning Stability

The question of stability for bodies, in which a flow of electromagnetic energy is circulating, has been treated in [43]. Here we shall consider only such force that acts along the diameter and breaks the ball lightning along diameter plane perpendicular to this diameter. In the first moment it must perform work

$$A = F\frac{dR}{dt}. \tag{1}$$

This work changes the internal energy of the ball lightning, i.e.

$$A = \frac{dW}{dt}. \tag{2}$$

Considering (1, 2) together, we find:

$$F = \frac{dW}{dt} \bigg/ \frac{dR}{dt}. \tag{3}$$

If the energy of the global lightning is proportional to the volume, i.e.

$$W = aR^3. \tag{4}$$

where a – is the coefficient of proportionality, then

$$\frac{dW}{dt} = 3aR^2\frac{dR}{dt}. \tag{5}$$

Thus,

$$F = \frac{dW}{dt} \bigg/ \frac{dR}{dt} = 3aR^2 = \frac{3W}{R}. \tag{6}$$

Thus, <u>the internal energy of a ball lightning is equivalent to the force creating the stability of ball lightning.</u>

5. About Luminescence of the Ball Lightning

The problem was solved above considering the electric resistance of the globe lightning. Naturally, it is nor zero, and when current flows through it, thermal energy is released.

6. About the Time of Ball Lightning Existence

The energy of the ball lightning *W* and the power of the heat losses *P* can be found with the solution obtained above.

The existence time of the globe lightning is equal to the time the electrical energy transforms into the heat losses, i.e.

$$\tau = W/P \tag{1}$$

7. About a Possible Mechanism of Ball Lightning Formation

The leader of a linear lightning, meeting a certain obstacle, may alter the motion trajectory from linear to circular. This may become the cause of the emergence of the described above electromagnetic fields and currents.

In [44] this process was described as follows:

Another strong bolt of lightning, simultaneous with a bang, illuminated the entire space. I can see how a long and dazzling beam in the color of sun beam approaches to me right in the solar plexus. The end of it is sharp as a razor, but further it becomes thicker and thicker, and reaches something like 0,5 meter. Further I can't see, as I am staring at a downward angle.

Instant thought that it is the end. I see how the tip of the beam approaches. Suddenly it stopped and between the tip and the body began to swell a ball the size of a large grapefruit. There was a thump as if a cork popped from a bottle of champagne. The beam flew into a ball. I see the blindingly bright ball, color of the sun, which rotates at a breakneck pace, grinding the beam inside. But I do not feel any touch, any heat.

The ball grinds the ray and increases in size. ... The ball does not issue any sounds. At first it was bright and opaque, but then begins to fade, and I see that it is empty. Its shell has changed and it became like a soap bubble. The shell rotates, its diameter remained stable, but the surface was with metallic sheen.

Chapter 11. Mathematical model of a plasma crystal

Contents

1. Problem statement

Dusty plasma (see the [87]) is a set of charged particles. These "particles can arrange in space in a certain way and form the so-called plasma crystal" [88]. The mechanism of formation, behavior and form of such crystals is difficult to predict. Observation of these processes and forms under low gravity conditions sets at the gaze – see illustration (Fig 1.) of the experiments in space in the [89].

Therefore, they were simulated on computer in 2007. The results surprised even greater, which was reflected in the name of a corresponding article [90]: "From plasma crystals and helical structures towards inorganic living matter". The [91] gives a summary and discussion of the simulation results.

I like such comparisons too. But, nevertheless, it should be noted that the method used by the authors of the molecular dynamics simulations does not fully take into account all the features of the dusty plasma. To describe the motion of the particles this method uses classical mechanics and considers only electrostatic forces between the charged particles. In fact, the charged particles motion causes occurrence of charge currents – electrical currents and electromagnetic fields as a consequence. They should be considered during simulation.

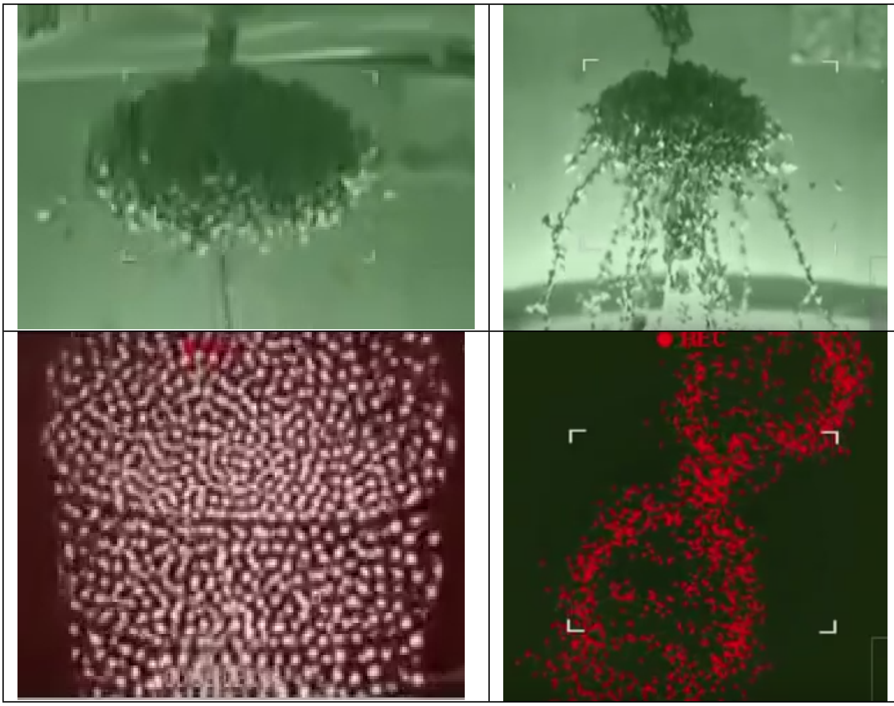


Fig. 1.

In absence of gravity the plasma particles are not affected by gravitational forces. If we exclude radiation energy, then it can be said that the dusty plasma is electric charges, electric currents and electromagnetic fields. Moreover, at its formation (filling a vessel with a set of charged particles) the plasma receives some energy. This energy may be only electromagnetic and kinetic energy of the particles, since there is no mechanical interaction between the particles: they are charged with like charges. Thus, the dusty plasma should meet the following conditions:

- to meet the Maxwell's equations,
- to maintain the total energy as a sum of electromagnetic and kinetic energy of the particles,
- to become stable in terms of the particles structure and motion in some time; it follows, for example, from the said experiments in space – see fig. 1.

The charged particles obviously push off from each other by Coulomb forces. However, the experiments show that these forces do not act on the periphery of a particles cloud. Consequently, they are compensated by other forces. It will be shown below that these forces are Lorentz forces arising during charged particles motion (although it seems strange at first sight that these forces direct into the cloud, opposing the Coulomb forces). The particles cannot be fixed, since then the Coulomb forces will prevail. But then these forces will move the particles, which causes the Lorentz forces, etc.

In the mathematical model shown below we will not take into account the Coulomb forces, believing that their role is only to ensure that the particles are isolated from each other (just as these forces are not considered in electrical engineering problems).

Thus, we will consider the dusty plasma as an area with flowing electrical currents and analyze it using the Maxwell's equations. Since the particles are in vacuum and are always isolated from each other, there is no ohmic resistance and no electrical voltage proportional to the current – it should not be taken into account in the Maxwell's equations. In addition, in the first stage, we will assume that the currents change slowly – they are constant currents. Considering these remarks, the Maxwell's equations are as follows:

$$\mathrm{rot}(H) - J = 0, \tag{1}$$

$$\mathrm{div}(J) = 0, \tag{2}$$

$$\mathrm{div}(H) = 0, \tag{3}$$

where the J, H is the current and magnetic intensity, respectively. In addition, we need to add to these equations an equation uniting the plasma energy W with the J, H:

$$W = f(J,\ H). \tag{4}$$

In this equation, the energy W is known since the plasma receives this energy at its formation.

In scalar form, the system of equations (1-4) is a system of 6 equations with 6 unknowns and should have only one solution. However, there is no regular algorithm for solving such a system. Therefore, below we propose another approach:

1. Search for analytical solutions of underdetermined system of equations (1-3) with this plasma cloud form. There can be multiple solutions.
2. Calculation of energy W using the (4). If the solution of the system (1-4) is the only one then this solves the system (1-4) with the data of the W and cloud form.

2. System of equations

In the cylindrical coordinates $r,\ \varphi,\ z$, as is well-known [4], the divergence and curl of the vector H are as follows:

$$\mathrm{div}(H)=\left(\frac{H_r}{r}+\frac{\partial H_r}{\partial r}+\frac{1}{r}\cdot\frac{\partial H_\varphi}{\partial \varphi}+\frac{\partial H_z}{\partial z}\right), \tag{a}$$

$$\mathrm{rot}_r(H)=\left(\frac{1}{r}\cdot\frac{\partial H_z}{\partial \varphi}-\frac{\partial H_\varphi}{\partial z}\right), \tag{b}$$

$$\mathrm{rot}_\varphi(H)=\left(\frac{\partial H_r}{\partial z}-\frac{\partial H_z}{\partial r}\right), \tag{c}$$

$$\mathrm{rot}_z(H)=\left(\frac{H_\varphi}{r}+\frac{\partial H_\varphi}{\partial r}-\frac{1}{r}\cdot\frac{\partial H_r}{\partial \varphi}\right). \tag{d}$$

Considering the equations (a-d) we rewrite the equations (1.1-1.3) as follows:

$$\frac{H_r}{r}+\frac{\partial H_r}{\partial r}+\frac{1}{r}\cdot\frac{\partial H_\varphi}{\partial \varphi}+\frac{\partial H_z}{\partial z}=0, \tag{1}$$

$$\frac{1}{r}\cdot\frac{\partial H_z}{\partial \varphi}-\frac{\partial H_\varphi}{\partial z}=J_r, \tag{2}$$

$$\frac{\partial H_r}{\partial z}-\frac{\partial H_z}{\partial r}=J_\varphi, \tag{3}$$

$$\frac{H_\varphi}{r}+\frac{\partial H_\varphi}{\partial r}-\frac{1}{r}\cdot\frac{\partial H_r}{\partial \varphi}=J_z, \tag{4}$$

$$\frac{J_r}{r}+\frac{\partial J_r}{\partial r}+\frac{1}{r}\cdot\frac{\partial J_\varphi}{\partial \varphi}+\frac{\partial J_z}{\partial z}=0 \tag{5}$$

The system of 5 equations (1-5) with respect to the 6 unknowns $(H_r,\ H_\varphi,\ H_z,\ J_r,\ J_\varphi,\ J_z)$ is overdetermined and may have multiple solutions. It is shown below that such solutions exist and for different cases some of possible solutions can be identified.

We will first look for a solution for this system of equations (1-5) as functions separable relative to the coordinates. These functions are as follows:

$$H_r.=h_r(r)\cdot\cos(\chi z), \tag{6}$$

$$H_\varphi.=h_\varphi(r)\cdot\sin(\chi z), \tag{7}$$

$$H_z.=h_z(r)\cdot\sin(\chi z), \tag{8}$$

$$J_{r}. = j_r(r)\cdot\cos(\chi z), \qquad (9)$$

$$J_{\varphi}. = j_\varphi(r)\cdot\sin(\chi z), \qquad (10)$$

$$J_z = j_z(r)\cdot\sin(\chi z), \qquad (11)$$

where the χ is a constant, while the $h_r(r),\ h_\varphi(r),\ h_z(r),\ j_r(r),\ j_\varphi(r),\ j_z(r)$ are the functions of the coordinate r; derivatives of these functions will be denoted by strokes.

By putting the (6-11) into the (1-5) we get:

$$\frac{h_r}{r} + h_r' + \chi h_z = 0, \qquad (12)$$

$$-\chi h_\varphi = j_r, \qquad (13)$$

$$-\chi h_r - h_z' = j_\varphi \qquad (14)$$

$$\frac{h_\varphi}{r} + h_\varphi' = j_z, \qquad (15)$$

$$\frac{j_r}{r} + j_r' + \chi j_z = 0. \qquad (16)$$

Let's put the (13) and (15) into the (16). Then we get:

$$\frac{-\chi h_\varphi}{r} - \chi h_\varphi' + \chi\left(\frac{h_\varphi}{r} + h_\varphi'\right) = 0. \qquad (17)$$

The expression (17) is an identity 0=0. Therefore, the (16) follows from the (13, 15) and can be excluded from the system of equations (12-16). The rest of the equations can be rewritten as:

$$h_z = -\frac{1}{\chi}\left(\frac{h_r}{r} + h_r'\right), \qquad (18)$$

$$j_z = \frac{h_\varphi}{r} + h_\varphi', \qquad (19)$$

$$j_r = -\chi h_\varphi, \qquad (20)$$

$$j_\varphi = -\chi h_r - h_z' \qquad (21)$$

3. The first mathematical model

In this system of 4 differential equations (18-21) with 6 unknown functions we can define two functions arbitrarily. For further study we define the following two functions:

$$h_\varphi = q\cdot r\cdot\sin(\pi\cdot r/\chi), \qquad (22)$$

$$h_r = h\cdot r\cdot\sin(\pi\cdot r/\chi), \qquad (23)$$

where the $q,\ h$ are some constants. Then using the (18-23) we find:

$$h_z = -\frac{h}{\chi}\left(2\sin(\pi\cdot r/\chi)+\frac{\pi\cdot r}{\chi}\cos(\pi\cdot r/\chi)\right), \tag{24}$$

$$j_z = q\left(2\sin(\pi\cdot r/\chi)+\frac{\pi\cdot r}{\chi}\cdot\cos(\pi\cdot r/\chi)\right), \tag{25}$$

$$j_r = -\chi\cdot q\cdot r\cdot\sin(\pi\cdot r/\chi) \tag{26}$$

$$j_\varphi = h\cdot\left(\frac{\pi^2}{\chi R^2}-\chi\right)\cdot r\cdot\sin(\pi\cdot r/\chi)+\frac{h}{\chi}\left(2-\frac{\pi}{\chi}\right)\cdot\cos(\pi\cdot r/\chi). \tag{27}$$

Thus, the functions $j_r(r)$, $j_\varphi(r)$, $j_z(r)$, $h_r(r)$, $h_\varphi(r)$, $h_z(r)$ can be defined using the (26, 27, 25, 23, 22, 24), respectively.

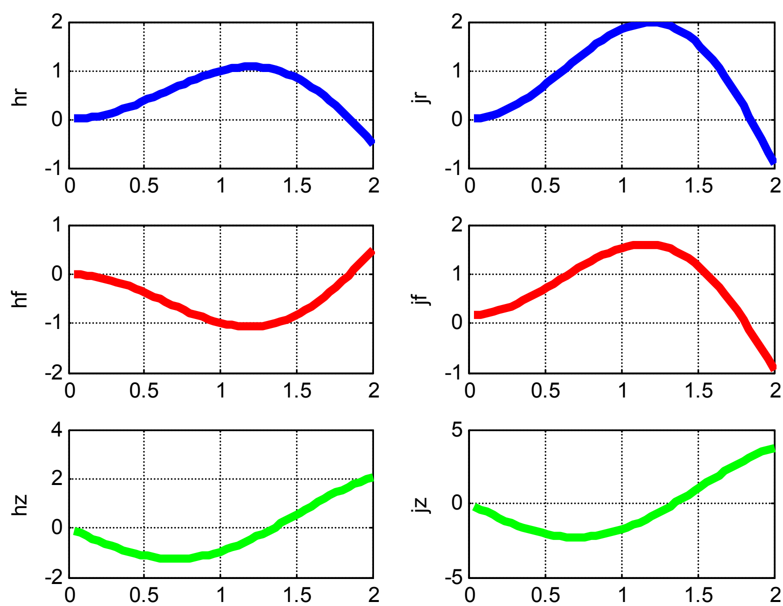


FIG. 2 (figPlazma.m)

Example 1.

Fig. 2 shows function graphs $j_r(r)$, $j_\varphi(r)$, $j_z(r)$, $h_r(r)$, $h_\varphi(r)$, $h_z(r)$. These functions can be calculated with data $\chi = 2$, $h = 1$, $q = -1$. The first column shows the functions $h_r(r)$, $h_\varphi(r)$, $h_z(r)$, the second column shows the functions $j_r(r)$, $j_\varphi(r)$, $j_z(r)$.

It is important to note that there is a point in the function graph $j_r(r)$, $j_\varphi(r)$ where $j_r(r)=0$ and $j_\varphi(r)=0$. Physically, this means that there are radial currents $J_r(r)$ in the area $r < \chi$ directed from the center (with $\chi q < 0$). There are no currents $J_r(r)$, $J_\varphi(r)$, in the point $r = \chi$. Therefore, the value $R = \chi$ is the radius of a crystal. The specks of dust outside this radius experience radial currents $J_r(r)$ directed towards the center. <u>This creates a stable boundary of the crystal.</u>

The built model describes a cylindrical crystal of infinite length, which, of course, is inconsistent with reality. Let's now consider a more complex model.

4. The second mathematical model

The root of the equation $j_r(r) = 0$ determines the value $R = \chi$ of the cylindrical crystal radius. Let's now change the value χ. If the value χ is dependent on the z, then the radius R will depend on the z. But this very dependence is observed in the experiments – see, for example, the first fragment in Fig. 1.

With this in mind, let's consider the mathematical model which differs from the above used by the fact that the function $\chi(z)$ is used instead of the constant χ. Let's rewrite the (6-11) with this in mind:

$$H_r. = h_r(r) \cdot \cos(\chi(z)), \tag{28}$$

$$H_\varphi. = h_\varphi(r) \cdot \sin(\chi(z)), \tag{29}$$

$$H_z. = h_z(r) \cdot \sin(\chi(z)), \tag{30}$$

$$J_r. = j_r(r) \cdot \cos(\chi(z)), \tag{31}$$

$$J_\varphi. = j_\varphi(r) \cdot \sin(\chi(z)), \tag{32}$$

$$J_z = j_z(r) \cdot \sin(\chi(z)). \tag{33}$$

The system of equations (1-6) differs from the system (2.9-2.14) only by the fact that instead of the constant χ we use the derivative $\chi'(z)$ along the z of the function $\chi(z)$. Consequently, the solution of the system (28-33) will be different from that of the previous system only by using the derivative $\chi'(z)$ in instead of the constant χ. Thus, the solution in this case will be as follows:

$$j_r = -\chi'(z) \cdot q \cdot r \cdot \sin(\pi \cdot r / \chi'(z)), \tag{34}$$

$$j_\varphi = \begin{pmatrix} h \cdot \left(\dfrac{\pi^2}{\chi'(z) R^2} - \chi'(z) \right) \cdot r \cdot \sin(\pi \cdot r / \chi'(z)) + \\ + \dfrac{h}{\chi'(z)} \left(2 - \dfrac{\pi}{\chi'(z)} \right) \cdot \cos(\pi \cdot r / \chi'(z)) \end{pmatrix}, \tag{35}$$

$$j_z = q\left(2\sin(\pi \cdot r/\chi'(z)) + \frac{\pi \cdot r}{R} \cdot \cos(\pi \cdot r/\chi'(z))\right), \tag{36}$$

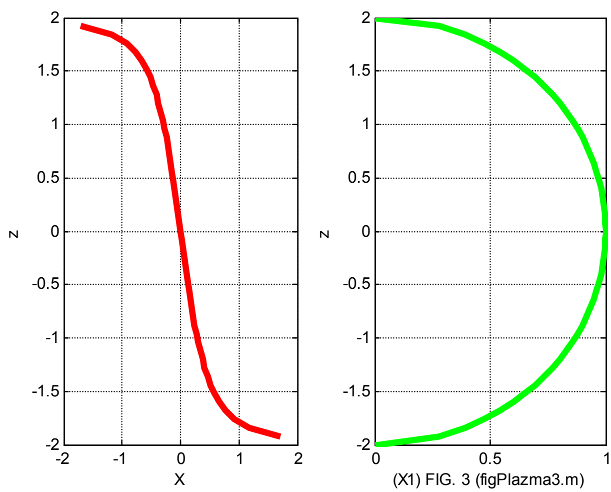
$$h_r = h \cdot r \cdot \sin(\pi \cdot r/\chi'(z)), \tag{37}$$

$$h_\varphi = q \cdot r \cdot \sin(\pi \cdot r/\chi'(z)), \tag{38}$$

$$h_z = -\frac{h}{\chi'(z)}\left(2\sin(\pi \cdot r/\chi'(z)) + \frac{\pi \cdot r}{R}\cos(\pi \cdot r/\chi'(z))\right). \tag{39}$$

The said functions will depend on the $\chi'(z)$. With the $\chi(z) = \eta z$ the equations (34-39) are transformed into the equations (22-27).

For example, Fig. 3 shows the functions $\chi(z)$ and $\chi'(z)$ where the $\chi'(z)$ is an equation of ellipse.



(X1) FIG. 3 (figPlazma3.m)

We can suggest that the current of the specks of dust is such that their average speed does not depend on the current direction. In particular, the path covered by a speck of dust per a unit of time in a circumferential direction and the path covered by it in a vertical direction are equal with a fixed radius. Consequently, in this case with a fixed radius we may assume that

$$\Delta\varphi \equiv \Delta z\,. \tag{40}$$

The dust trajectory in the above considered system is described by the following formulas

$$co = \cos(\chi(z)), \tag{41}$$

$$si = \sin(\chi(z)). \tag{42}$$

Thus, there is a point trajectory described by the formulas (40-42) in such system on the rotation figure with a radius of $r = \chi'(z)$. This trajectory is a helix. All the tensions and densities of currents do not depend on the φ in this trajectory.

Based on this assumption, we can construct a movement trajectory for specks of dust in accordance with the functions (1-3). Fig. 4 shows the two helices described by the current functions $j_r(r)$ and $j_z(r)$: with $r_1 = \chi'(z)$ with $r_2 = 0.5\chi'(z)$, where the $\chi'(z)$ is defined in Fig. 3.

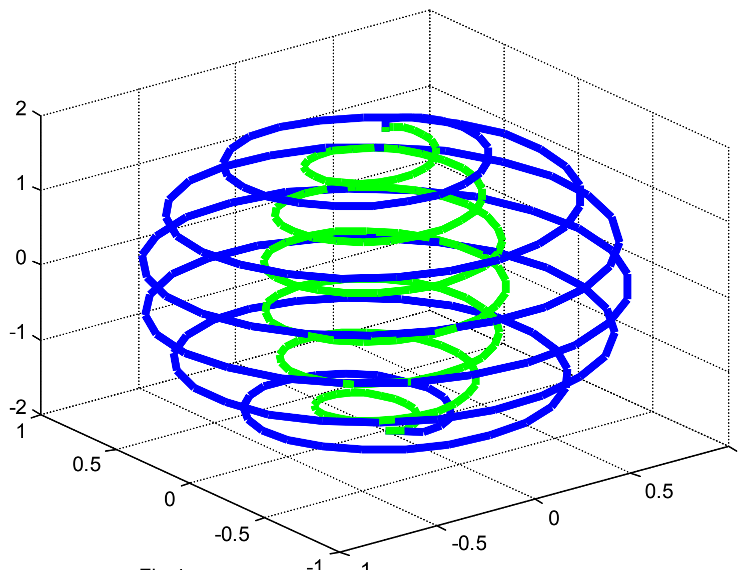


Fig 4 (Plazma4.m)

5. The plasma crystal energy

Under certain magnetic strengths and current densities we can find the plasma crystal energy. The magnetic field energy density

$$W_H = \frac{\mu}{2}\left(H_r^2 + H_\varphi^2 + H_z^2\right). \tag{43}$$

The specks of dust kinetic energy density W_J can be found in the assumption that all the specks of dust have equal mass m. Then

$$W_J = \frac{1}{m}\left(J_\varphi^2 + J_\varphi^2 + J_\varphi^2\right). \tag{44}$$

To determine the full crystal energy we need to integrate the (43, 44) by the volume of the crystal, which form is defined. Thus, with a defined form of the crystal and assumed mathematical model we can find all the characteristics of the crystal.

Chapter 12. Work of Lorentz force

It is proved that the Lorentz force does the work, and the relations that determine the magnitude of this work are derived.

The magnetic Lorentz force is determined by a formula of the form

$$F = qQ(V \times B), \tag{1}$$

where

q - the density of electric charge,

Q - the volume of a charged body,

V - velocity of the charged body (vector),

B - magnetic induction (vector).

The work of the Lorentz force is zero, since the force and velocity vectors are always orthogonal.

The Ampere force is determined by a formula of the form

$$A = Q(j \times B), \tag{2}$$

where j is the electric current density (vector). Because the

$$j = qV, \tag{3}$$

then formula (2) can be written in the form

$$A = qQ(V \times B). \tag{4}$$

It can be seen that formulas (1, 4) coincide. Meanwhile, the work of the Ampère force is NOT zero, as evidenced by the existence of electric motors. Consequently, the **work of the Lorentz force is NOT zero**. Thus, the definition of mechanical force through work can not be extended to the Lorentz force.

Let us consider **how the Lorentz force performs its work**.

The density of the flow of electromagnetic energy - the Poynting vector is determined by the formula:

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

where

E - electric field intensities (vector),

H - magnetic field intensities (vector).

The currents densities correspond to electrical intensities, i.e.

$$E = \rho j, \tag{6}$$

where ρ is the electrical resistance. Combining (5, 6), as in Chapter 5, we obtain:

$$S = \rho j \times H = \frac{\rho}{\mu} j \times B. \tag{7}$$

where μ is absolute magnetic permeability. The magnetic Lorentz force acting on all charges of the conductor in a unit volume - the volume density of the Lorentz force is (as follows from (1))

$$f = qV \times B. \tag{8}$$

From (3, 8) we find:

$$f = qV \times B = j \times B. \tag{9}$$

From (7, 9) we find:

$$f = \mu S / \rho. \tag{10}$$

The density of the magnetic force of Lorentz is proportional to the density of electromagnetic energy - the Poynting vector.

The energy flux with density S is equivalent to the power density p, i.e.

$$p = S. \tag{11}$$

Consequently, the density of the magnetic force of Lorentz is proportional to the power density p.

Example 1. For verification, let us consider the dimensions of the quantities in the above formulas in the SI system - see Table. 1.

Table 1.

Parameter		Dimension
Energy		kg m^2·sec^{-2}
Density of energy		kg m^{-1}·sec^{-2}
Power	**P**	kg m^2·sec^{-3}
Density of energy flow, power density	S	kg sec^{-3}
Current density	j	A·m^{-2}
Induction	B	kg sec^{-2}·A
The volume density of the Lorentz force	f	kg sec^{-3}·m^{-2}
Magnetic permeability	μ	kg sec^{-2}·m·A^{-2}
Resistivity	ρ	kg·sec^{-3}·m^3·A^{-2}
μ/ρ	μ/ρ	sec·m^{-2}

So, a current with density j and a magnetic field with induction B create an energy flow with density S (or power with density p), which is identical to the magnetic force of Lorentz with density f - see (11) or

$$f = \mu p/\rho . \tag{12}$$

Thus, the Lorentz force with density f through energy flux with density S (or power with density p), acts on charges moving in a current J in a direction perpendicular to this current. Consequently, it can be argued that the Poynting vector (or power with density p) creates an emf in the conductor. This question, on the other hand, was considered in [19, 17], where such an emf is called the fourth kind of electromagnetic induction.

Consider the emf created by the Lorentz force. The intensity, equivalent to the Lorentz force acting on a unit charge, is

$$e_f = \frac{f}{q} = \frac{p\mu}{q\rho}, \tag{13}$$

and the current produced by the Lorentz force in the direction of this force has a density

$$i = e_f \rho = \frac{p\mu}{q}. \tag{14}$$

If the current I produced by the Lorentz force in resistance R is known, then

$$U = e_f \rho = I\left(R + \rho\frac{l}{s}\right), \tag{15}$$

where l, s is the length and cross-section of the conductor in which the Lorentz force acts. From (15) we find:

$$I = e_f \rho \Big/ \left(R + \rho\frac{l}{s}\right) = e_f \Big/ \left(\frac{R}{\rho} + \frac{l}{s}\right). \tag{16}$$

Full power

$$P = pls . \tag{17}$$

Finally, from (13, 16, 17) we obtain:

$$I = \frac{P\mu}{qls} \Big/ \left(R + \rho\frac{l}{s}\right) = \frac{P\mu}{ql} \Big/ (sR + \rho l), \tag{18}$$

$$U = \frac{P}{I} = \frac{ql}{\mu}(sR + \rho l). \tag{19}$$

From these formulas, according to the measurement U and I results, the density of charges under the action of the Lorentz force can be found.

Chapter 13. Electromagnetic momentum

Contents

1. Preface

Umov in 1874 introduced to physics the idea of energy motion, the energy flow and the velocity of energy motion. In this case, the energy flux density S, energy density W and velocity of energy motion v are related by the formula $S = W \cdot v$.

This statement is universal. In electrodynamics, the flux density vector of electromagnetic energy is called the Umov – Poynting vector. The velocity of electromagnetic energy in electrodynamics is assumed to be equal to the velocity of light: $v = c$. This statement forced out cases from scientific use, where the velocity of movement of electromagnetic energy is less than the velocity of light. And such cases are known. For example, the velocity of energy in a wave packet is less than the velocity of light. In a **stationary** electromagnetic field there is no electromagnetic wave, but there is a flow of electromagnetic energy. In this case there is no reason to associate the velocity of electromagnetic energy in static fields with the velocity of light.

It is known that the density of the electromagnetic momentum p is related to the density of the flow of electromagnetic energy by the formula $p = S/c^2$. It is also known that the density of an electromagnetic momentum propagating in the body is (numerically) the density of the mechanical momentum m in this body: $m = p$. And this fact also somehow fell out of scientific use. Indeed, is it worth paying attention to the meager value resulting from dividing by the square the velocity of light.

And, meanwhile, the mechanical momentum of the electromagnetic field in the body appealed to attention. Experiments are known (they will be discussed in more detail below), which prove the existence of a momentum, the magnitude of which is 100 times greater than the theoretical value. Researchers searched for an explanation in the existence of a substance other than matter and field.

It is enough to assume that the velocity of movement of electromagnetic energy **is not equal** to the velocity of light (in general), and then all the situations described above become explainable. This velocity can be calculated. In the previous chapters of this book, various processes of electromagnetic energy propagation (battery discharge, capacitor discharge, magnet demagnetization, energy movement in a DC wire) are considered and it is shown that in these cases the energy velocity is much less than the velocity of light.

Thus, the electromagnetic momentum and the mechanical momentum enter quantitatively in an equitable manner into the law of conservation of momentum.

2. Basic ratios

There are known interdependencies between the densities of energy W, energy flux S, momentum flux p, momentum density f, which have the following form (in the SI system):

$$S = W \cdot c, \tag{1}$$

$$p = W/c, \tag{2}$$

$$p = S/c^2. \tag{3}$$

$$f = p \cdot c. \tag{3a}$$

2.1. It was shown in Chapter 1 that for a monochromatic wave there is a solution for which condition (1) is satisfied, i.e. for a monochromatic wave the **velocity of energy motion** is equal to the propagation velocity of a monochromatic wave, i.e. velocity of light. The solution found in Chapter 1 is such that it the constancy of the energy and energy flux of the electromagnetic wave **in time** is establishes (in contrast to the known solution, where the constancy of these quantities **on the average in time** is established, which, of course, is not the actual constancy required by the energy conservation law).

2.2. Thus, equation (1) is valid for a monochromatic wave. The velocity of energy motion in a wave packet is generally considered equal to the group velocity. In [94] it is strictly shown that velocity of energy motion depends on the phase velocity and the velocity of light. In any case, the velocity of energy motion in the wave packet is less than the velocity of light.

2.3. In a **stationary** electromagnetic field there is no electromagnetic wave, but there is a flux of electromagnetic energy. Along with this flow there is also an electromagnetic momentum - see (2, 3). This statement is not universally accepted. However, G.P. Ivanov in [97] proves the existence of a momentum, by analyzing known experiments by direct calculations. In these experiments there are quasistationary electromagnetic fields, where there is no emission of electromagnetic waves. Among these experiments there are speculative (their authors are Tamm and Feynman see appendix 1a), but there is also a real experiment of G.M. Graham and D.G. Lahoza [95] - see appendix 1b.

The experiments of Tamm, Graham and Lahoz discuss Ivanov in [144] (from where the illustrations and translation of the article [95] come from). From them, in his opinion, it follows that "the angular momentum of the substance and field is not preserved." Later in [147], he proposes a construction — see Appendix 1c. He believes that his design will move only at alternating voltage. His proof is built "on the basis of the laws of conservation of momentum, energy and the principle of relativity, according to which such a movement is carried out thanks to the force and energy interaction with the physical vacuum (ether)".

So, the electromagnetic momentum exists in stationary fields. However, using the same analysis G.P. Ivanov in [97] proves that the magnitude of this momentum is extremely small (in essence, this follows from (1, 2), where there is a division by the velocity of light). Nevertheless, the experiment of G.M. Graham and D.G. Lahoza detects a large value of momentum. G.P. Ivanov proves that the experimental value of the momentum is 100 times higher than the theoretical value (and otherwise this experiment could not have taken place, since the experimenters measured the electromagnetic momentum as the value of the mechanical momentum, based on the law of conservation of momentum).

So, the electromagnetic momentum exists in stationary fields, but does not satisfy equations (1-3), because has a significant value.

G.M. Graham and D.G. Lahoz see the explanation for this in the fact that electromagnetic energy circulates in a vacuum like a flywheel.

G.P. Ivanov see the explanation for this in the "existence of a kind of matter (electrovacuum) that is different from matter and the field, that fills the entire physical space and is capable of entering into impulsive (force) and energy interaction with matter."

2.4. The above experiments were performed in stationary fields, but with a variable intensity E. If we assume that the energy flow exists in static fields, then we can offer other experiments. For example, you can repeat the experiments of Tamm, Feynman, Graham and Lakhoz, replacing the source of an alternating voltage to the source of constant voltage. This voltage can be high-voltage and then the observed pulse should increase significantly.

Another theoretical experiment, which proves the possibility of unsupported movement in the system due to the interaction of moving electric charges, is discussed in Chapter 13a.

In Chapter 18 proves that the Ampere and Lorentz forces are a consequence of the observance of the law.

2.5. Theory and experiments Sigalov.

R.G. Sigalov in [156], as far back as 1965, showed for the first time that **“the magnetic interaction of currents flowing in a solid can bring this body into translational and rotational motion”**. For a theoretical proof of this phenomenon, Sigalov used electronic theory. At the same time, he had to perform complex and cumbersome calculations for almost every configuration. He accompanied all theoretical conclusions with original experiments. All this was convincing evidence of a violation of Newton's third law. Therefore, Sigalov’s theory was not widely accepted.

Рис. 1.

Now his experiments are repeated without mentioning the author. In fig. 1 shows an experiment from [157] - a rotating spiral through which direct current flows. A similar experiment is shown on page 49 in [156] - see there fig. 28 and fig. 29. Interestingly, the rotation of the helix depends on the direction of winding.

Chapter 5 shows that an electromagnetic wave propagates in the dc wire. Together with the electromagnetic wave propagates electromagnetic pulse. In clause 2.10 below, it is shown that a mechanical pulse is present in the wire along with an electromagnetic pulse. This impulse causes the shown spiral to rotate. The existence of this pulse explains all of Sigalov's experiments.

2.6. Umov [81] introduced to physics the idea of energy motion, the energy flow and the velocity of energy motion. In this case, the energy flux density S, energy density W and velocity of energy motion v are related by the formula

$$S = W \cdot v . \tag{4}$$

This statement is universal in nature. However it is sufficient to assume that the velocity of electromagnetic energy motion is **not equal** to the velocity light (in the general case), and then all the above-described situations become understandable.

Indeed, there is no reason to associate, for example, the velocity of electromagnetic energy motion in static fields with the velocity light.

2.7. In the previous chapters various processes of propagation of electromagnetic energy (battery discharge (Chapter 5), condenser discharge (Chapter 7), demagnetization of a magnet (Chapter 7a), movement of energy in a DC wire (Chapter 5)) are considered and it is shown that in these cases condition (4) is fulfilled and the velocity of electromagnetic energy motion is significantly less than the velocity light.

2.8. So, in general, we need to use formulas (1-3), where instead of the velocity of light set the velocity of electromagnetic energy motion:

$$S = W \cdot v , \tag{4}$$

$$p = W/v , \tag{5}$$

$$p = S/v^2 , \tag{6}$$

$$p = W^2/S . \tag{7}$$

So,

the electromagnetic momentum and the mechanical momentum enter the law of conservation of momentum in an equal manner. This statement opens up wide scope for the design of unsupported engines.	(8)

2.9. Electromagnetic mass

$$m = \frac{p}{v} = \frac{W}{v^2} = \frac{S}{v^3} = \frac{W^3}{S^2} \tag{9}$$

2.10. If at a certain part of the boundary of the body a flow of energy $\overline{S}$ with a density S directed outwards arises, then an electromagnetic momentum with a density $\overline{p}$ directed outward arises. According to the law of conservation of momentum, a mechanical momentum equal to it and directed towards the body is created

$$\overline{M} = -\left(\overline{p}\right). \tag{10}$$

Let the surface of this area is equal q, and its volume is equal g. Then

$$\overline{S} = qS, \tag{11}$$

$$\overline{p} = gp. \tag{12}$$

From (7, 10, 12) we find:

$$\overline{M} = -gp. \tag{13}$$

So, if electromagnetic energy is present in the body and a stream of electromagnetic energy leaves the body, then, according to (13), a mechanical momentum acting on the body can be found.

2.11. Naturally, the designers of unsupported engines did not wait for my approval (8) and have long been engaged in this ungrateful business.

In [99] a method is proposed for "ensuring the translational momentum of transport, including space vehicles." However, the author himself points out that, in accordance with his theory, the tractive effort in the proposed constructions will be very small.

Known Biefeld-Brown effect [101]. There is no reliable information on the implementation of the patent. This effect has not received a generally accepted explanation to date. It can be assumed that this effect is due to the appearance of an electromagnetic momentum.

In [102] describes a device intended for flights in an airless environment. In it also implements the Biefeld-Brown effect and explains this effect with the use of an electrodynamic momentum.

In [106] describes a hypothetical experiment with electric charges and currents, which demonstrates the violation of Newton's third law, but the fulfillment of the law of conservation of momentum, i.e. the possibility of unsupported movement.

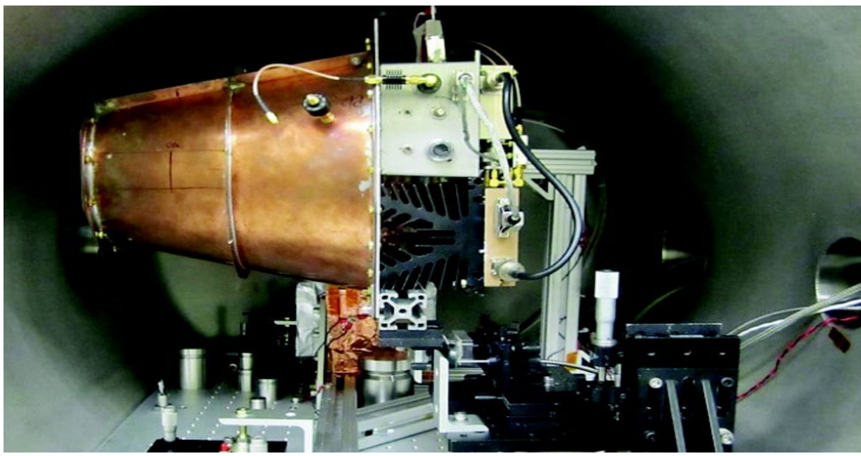


Fig. 1.

Recently, there has a patent [103], an experiment by NASA based on this patent [104], and a similar Chinese experiment [105] - see fig. 1. They cause the same doubts and disputes in the scientific world, because they violate the law of conservation of momentum. This experiments clearly demonstrates the creation of thrust force due to electrodynamic effects. But these are experiments and you can't argue with them! In my opinion, they confirm the above theory.

But the most indisputable is the “High voltage electric engine - HVE” Lavrinenko [131], which is a high-voltage air condenser. In it, one plates is made in the form of a wire, and the second in the form of a strip of foil - see fig. 2. With a high voltage between the plates, an ion current and an ion wind arise. The device takes off. This effect was first explained by the action of ion current and ion wind. More careful measurements show that ion wind generates about 60% of the lift. The source of 40% of the lifting force is not revealed.

Based on the above, the author has developed a theory that, in particular, explains the functioning of the HVE and predicts the results of experiments. According to the known parameters of HVE (dimensions, mass, current, voltage, electrical capacity), the lifting rate is calculated. If it is equal to the measured one, then the theory is valid - see Appendix 2.

Fig. 2 (from [131b], time 6:37)

> *The author is ready to compare this theory with various versions of the HVE designs available to the reader.*
> *The author also developed a different design of a unsupported engine and invites those interested in joint patenting.*

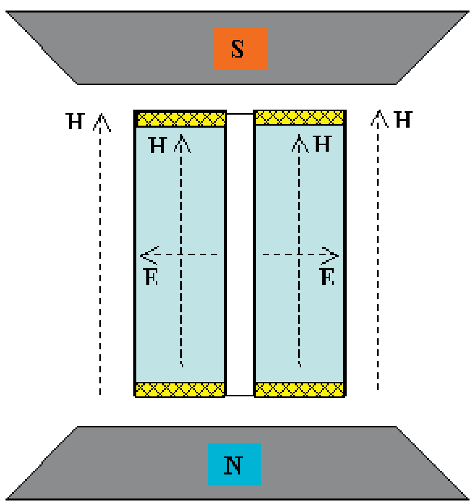


Fig. 3a.

Appendix 1a. Tamm's experiment.

In [22], Tamm describes the following thought experiment - see fig. 3a of [144]. A cylindrical capacitor placed in a uniform magnetic field H parallel to its axis is considered. In the space between the plates of the capacitor, in addition to the magnetic, there is also a radial electric field of intensity E, created by a charged capacitor. In the space between the capacitor plates in a static electromagnetic field, there is a Pointing vector. Poynting vector lines, i.e. energy flow lines, are concentric circles whose planes are perpendicular to the axis of the capacitor.

Appendix 1b. Experiment of Graham and Lahoza

The scheme of the experiment is shown in Fig. 3 from [144], where
1 - cylindrical capacitor,
2 - torsion-oscillator suspension,
3 - a mirror,
4 - radially located wires for supplying alternating voltage to the plates,
5 - superconducting solenoid.

The authors write: "Our program for measuring the forces associated with the electromagnetic momentum at low frequencies in matter, has culminated in the first direct observation of the free electromagnetic angular momentum produced by the quasistatic (non-wave) independent fields E and B in the vacuum gap of a cylindrical capacitor. To record condenser motion, a resonance suspension was used."

Thus, in this experiment, the electromagnetic momentum was detected by measuring the mechanical momentum during torsional vibrations of the capacitor. This means that the electromagnetic momentum exists in stationary electromagnetic fields and has a significant value.

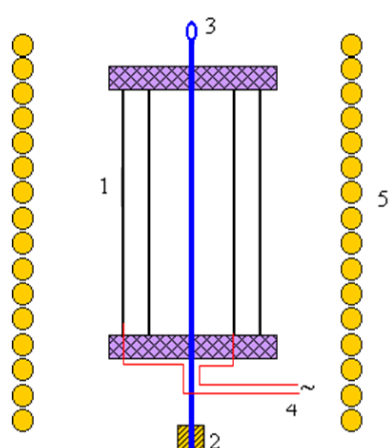


Fig. 3.

Appendix 1c. Ivanov's experiment.

Ivanov G.P. in [147] offers the construction shown in fig. 3c.

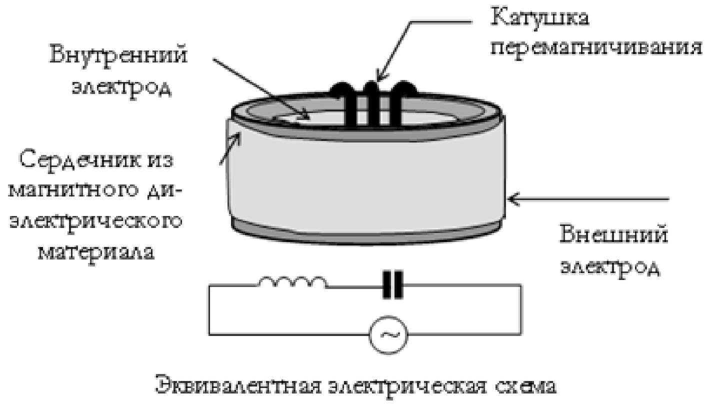


Fig. 3c.

Appendix 2. Experiment with HVEM.

In tab. 1 shows the technical parameters of one of the HVEM designs obtained from the author of this design M. Lavrinenko - see lines 1-7. The same table shows the values of the parameters, which are calculated on the basis of the proposed theory. It is seen that the mechanical moment and the theoretical electromagnetic moment coincide (see lines 13 and 14), the measured and calculated lifting velocities coincide (see lines 3 and 16), velocity of energy flow is 4444 m/s (see line 21).

Table 1.

№	Parameter	Formula	Measurement	Calculation
1	voltage, kV	U	45	
2	lifting time, sec	t	2	
3	lifting height, m	h	4	
4	weight, H	G	0.5	
5	capacitor capacitance 15 pf	C	15*10^-12	
6	distance between electrodes	d	0.03	
7	air dielectric constant	ε	9*10^-12	
8	weight, kg	m	0.05	
9	ionized air resistivity	ρ		7*10^9
10	dielectric resistance	R=ρb/d		10^10

11	capacitor plate area, m ^ 2	b=Cd/ε		0.05
12	capacitor energy, Wt * s	W		0.015
13	lifting speed, m / s	v	2	0.89
14	lift force, N	F	0.51	0.19
15	impulse, kg * m / s	M	0.1	0.044
16	driving power, Wt	P	1	0.17
17	the flow rate of electromagnetic energy in a capacitor, m / s	v_e		0.14

Chapter 13a. Unsupported Motion Without Violating the Laws of Physics

Contents

1. Introduction

We are considering some speculative experiments with charges and currents, which demonstrate a breach of Newton's third law, i.e. an opportunity of unsupported movement. It is shown that these experiments do not violate the Law of momentum conservation. We describe a structure in which electric charges are driven into rotation. We show that this structure performs translational unsupported motion. We describe the mathematical model and the experimental results with a mathematical model of this structure. Some recommendations are given for the implementation of the design.

Unsupported motion is usually considered to be impossible due to the fact that it violates Newton's third law, and following from it (in mechanics) the law of momentum conservation. The latter is more general law of the laws of physics. In electrodynamics, the law takes into account also the momentum of electromagnetic waves and therefore the impulses of material objects that interact with the wave, in total turn out to be not equal to zero [13].

In [161] the interaction of electric charges is considered, and it is proved that in this case there may be cases when the law of momentum conservation in mechanics is violated. Described below based on this experiments that demonstrate unsupported motion (see also [106]).

2. The Interaction of Moving Electric Charges

Let us consider two charges q_1 and q_2, moving with the speeds v_1 and v_2 accordingly. It is known [161], that the induction of the field created by the charge q_1 in the point where at this moment the charge is located, is equal to (here and further the system GHS is used)

$$\overline{B_1} = q_1\left(\overline{v_1} \times \overline{r}\right)/cr^3 . \tag{1}$$

The vector $\overline{r}$ is directed from the point where the moving charge q_1 is located. The Lorentz force acting on the charge q_2 is

$$\overline{F_{12}} = q_2\left(\overline{v_2} \times \overline{B_1}\right)/c . \tag{2}$$

or

$$\overline{F_{12}} = q_1 q_2\left(\overline{v_2} \times \left(\overline{v_1} \times \overline{r}\right)\right)/\left(c^2 r^3\right). \tag{3}$$

Similarly,

$$\overline{B_2} = -q_2\left(\overline{v_2} \times \overline{r}\right)/cr^3 , \tag{4}$$

$$\overline{F_{21}} = q_1\left(\overline{v_1} \times \overline{B_2}\right)/c \tag{5}$$

or

$$\overline{F_{21}} = -q_1 q_2\left(\overline{v_1} \times \left(\overline{v_2} \times \overline{r}\right)\right)/\left(c^2 r^3\right). \tag{6}$$

Here the minus sign appears because the vector remained the same.

In the general case $\overline{F_{12}} \neq \overline{F_{21}}$ i.e. the Newton's third law is not observed – there appear unbalanced forces acting on the charges q_1 and q_2 and contorting the trajectories of these charges motion.

If the charges q_1 and q_2 <u>in the process of moving do not leave a certain general construction</u>, then there is a force acting on this construction

$$\overline{F} = \overline{F_{12}} + \overline{F_{21}} \tag{7}$$

or

$$\overline{F} = \frac{q_1 q_2}{c^2 r^3}\left(\left(\overline{v_2} \times \left(\overline{v_1} \times \overline{r}\right)\right) - \left(\overline{v_1} \times \left(\overline{v_2} \times \overline{r}\right)\right)\right). \tag{8}$$

This force is capable of moving the construction. It can be assumed that such forces provide the flight of ball lightning.

3. The First Experiment

Let us consider two charges q_1 and q_2, rotating with a constant speed $v_1 = v_2$ along mutually perpendicular circular orbits - see Fig. 1. The rotation begins from a position shown on Fig. 1, and is provided by mechanical forces within the construction.

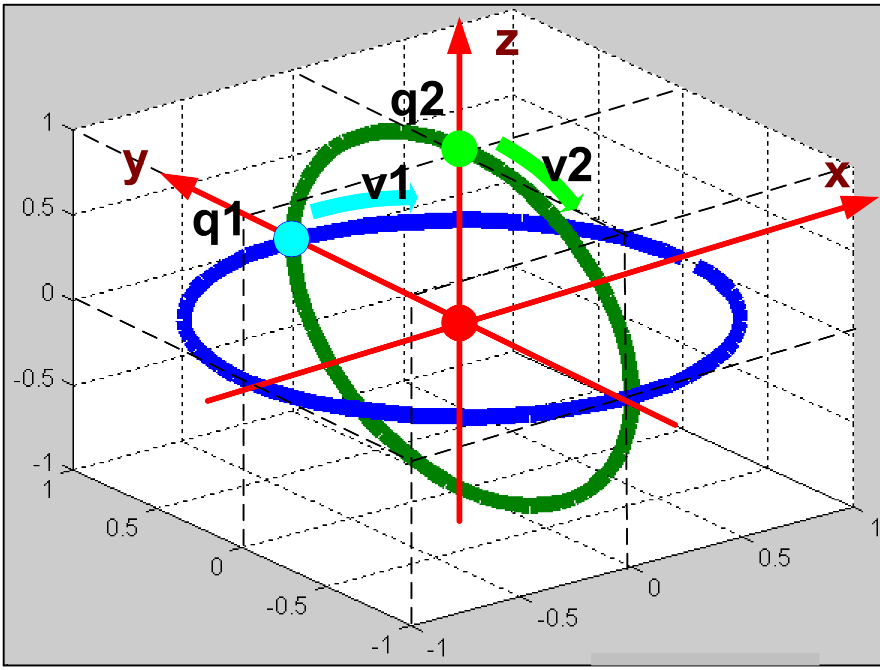
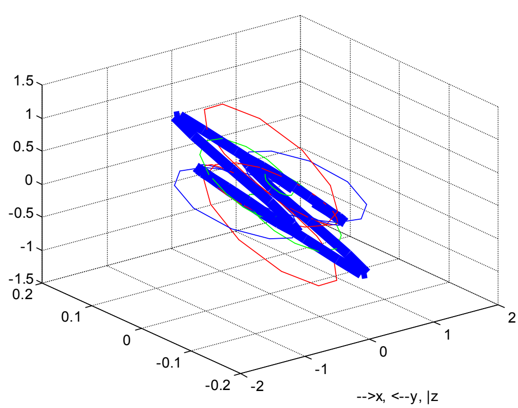

z
q2
y
v2
x
v1
q1
1
0.5
0
-0.5
-1
1
0.5
0
-0.5
-1
-1
-0.5
0
0.5
1

Fig. 1.


1.5
1
0.5
0
-0.5
-1
-1.5
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-->x, <--y, |z

Fig. 2.

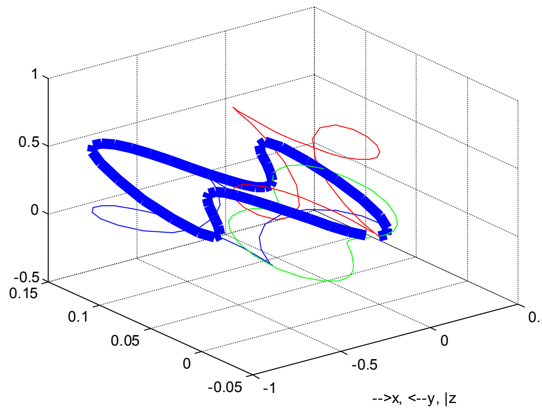

Fig. 3.

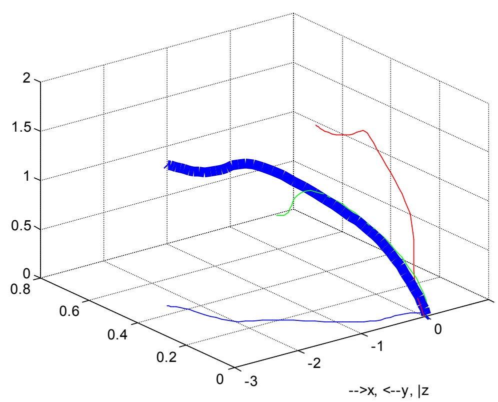

Fig. 4.

Using formula (8) we can find the force acting on the whole construction. Fig. 2 shows the special graph of this force's change during one revolution of the charges (the thick line) and the projection of this graph on the coordinate planes (thin lines). Here and further the projection lines are depicted so: the green one is xz, the blue one - xy, the red one –yz; the axes direction is shown under the graph.

For a known force and given zero initial conditions we find the speed and the trajectory of the construction for the given period –- see Fig. 3 and Fig. 4 accordingly. For this period the construction is shifted to the following distance `Rmax=2.8.` Fig. 5 shows the trajectory of the construction during two periods, when it has shifted to the distance `Rmax=5.6.`

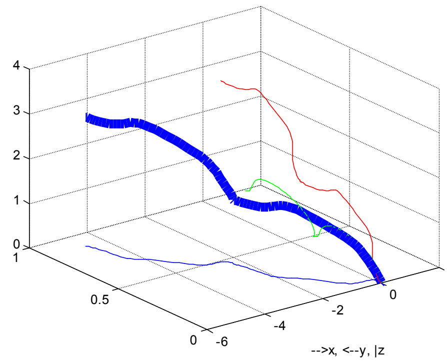

Fig. 5.

4. The Second Experiment

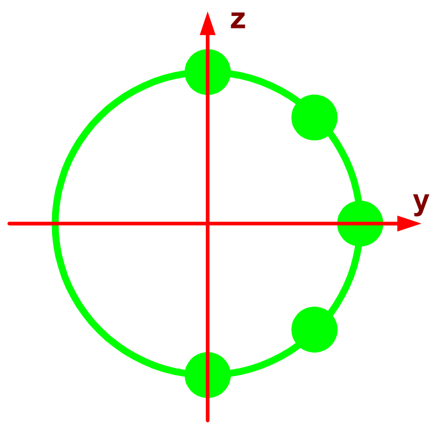

Fig. 5a.

In the construction depicted of Fig. 1, one charge was located on each circle. Now we shall consider a construction where several charges are located on each circle, but all of them are concentrated and are distributed uniformly along the half-circle – Fig, 5a. Here also with the formula (8) we may find the force acting on the construction as a whole. We find that the vector of this force lies on the plane xoz for any number of charges $a > 1$. The vector of speed and the trajectory are also on the plane xoz. Fig. 6 shows as an example the construction's trajectory for one period for the case when the construction contains 5 charges on each circle.

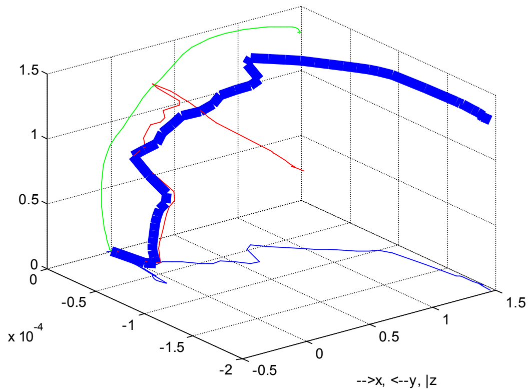

Fig. 6.

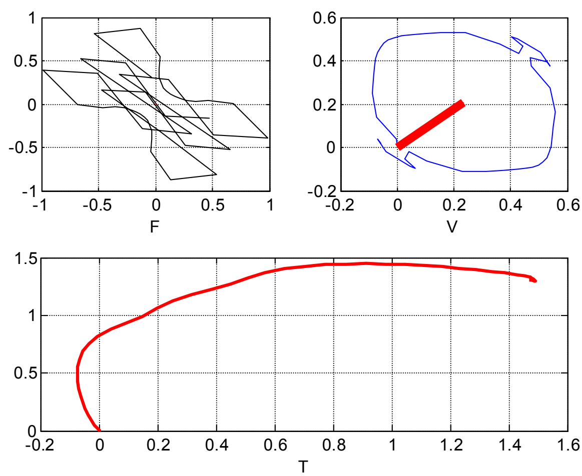

Fig. 7.

Fig. 7 shows for this same case the graphs of force change (window F) и скорости (window V) daring the time of one revolution of the charges and the trajectory of the construction (window T) in xoz coordinates. In this and in the following figures it is assumed that the ox axis is directed horizontally, and the oz axis– vertically.

On Fig. 7 we may see that during one period the construction is shifted by a certain distance `Rmax=2`. Fig. 8 shows the similar graphs for the same construction during two periods. Apparently, the construction shifts on the distance `Rmax=4`.

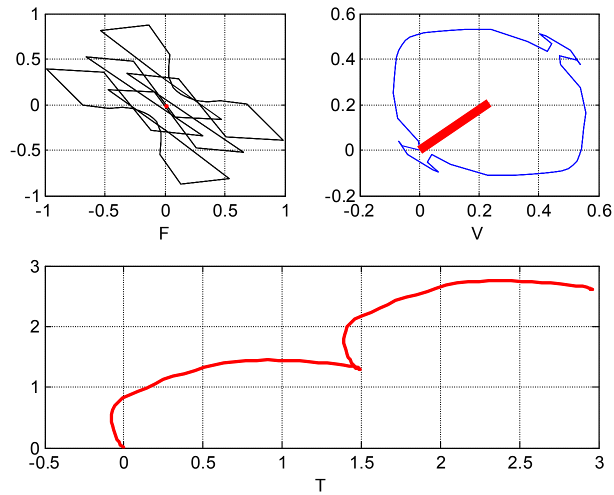

Fig. 8.

Fig. 9 and Fig. 10 show the same graphs for two periods for constructions containing 15 and 25 charges accordingly. For all constructions the magnitude of charge is chosen to be $q = 1/a$. Apparently, that in this case the graphs of force and speed change do not depend on the number of charges, and the trajectories are also independent from the charges number. Thus, such construction on increasing the number of charges "aims" to a construction with infinite number of charges. In it the linear distribution density of charges by the length l of charged half-circle is $\frac{dq}{dl} = \frac{1}{\pi R}$. As concerning the realization of such a construction, the charges in it must contact, but not merge into a single strip; for the functions of distribution density of the charges along the lane are not uniform (the charges are accumulated at the strip's edges). The charges of such construction may permanently recover from a source of DC voltage through brush contacts.

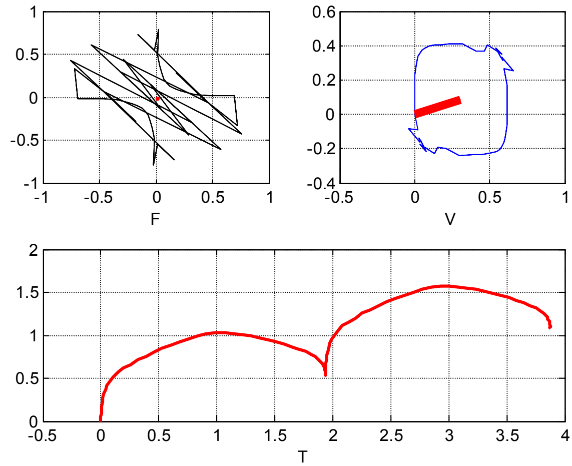

Fig. 9.

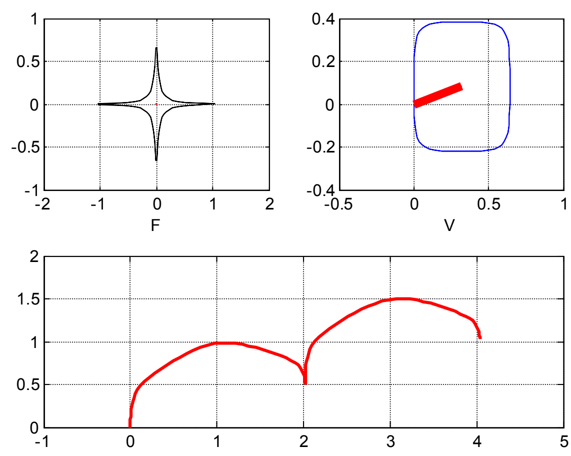

Fig. 10.

In conclusion let us consider the results of calculation for the same conditions that were used for calculation for Fig. 9, but for 20 periods– see Fig. 12. On this figure the red vector on the hodograph of speed depicts the average speed $V_s \approx 0.32$ of the construction's motion. After 20 periods the construction has shifted on $R \approx 40$.

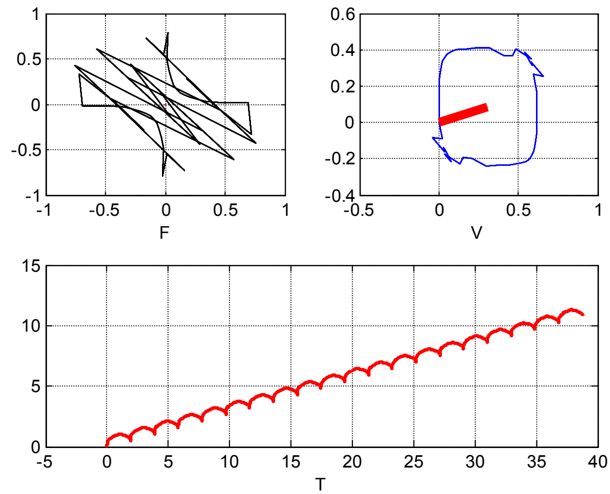

Fig. 12.

5. The Parameters of Motion

Let us consider in detail some characteristics of such motion. We shall not take into account the energy necessary for the construction's rotation with a permanent speed. The factors affecting the kinetic power P, expended by the construction for its motion, the average speed V_s and the construction's displacement, are :

- the speed of the construction as a whole $v = (v1, v2, v3)$,
- propulsive force $F = (f1, f2, f3)$, developed by the construction,
- the number of revolutions N,
- rotation frequency f or the angular rotation frequency $\omega = 2\pi f$,
- the construction's radius R_k ,
- linear speed of the charges $v_o = R_k \omega$,
- summary charge q_o ,
- the number a of charges, each of them having magnitude q_o / a ,
- the mass of construction m .

We can prove that for $a > 4$ the number a of charges does not affect the motion parameters, and

$$P = (v, F), \tag{1}$$

$$V_s = (v_o, m, q, \omega), \tag{2}$$

$$R = (N, v_o, m, q, \omega). \tag{3}$$

Fig. 13 shows the graphs of instant motion parameters for $a = 5, N = 5, \omega = 1, v_o = 1, q_o = 1$. Here

T - the motion trajectory,

$x1, x3$ - coordinates x, z depending on time,

V - hodograph of overall speed and average speed vector,

F - hodograph of the force,

$f1, f3$ the force projections f_x, f_z depending on time,

P - instant power depending on time,

P_s - average power,

$v1, v3$ - speed projections v_x, v_z depending on time,

vm - the speed amplitude.

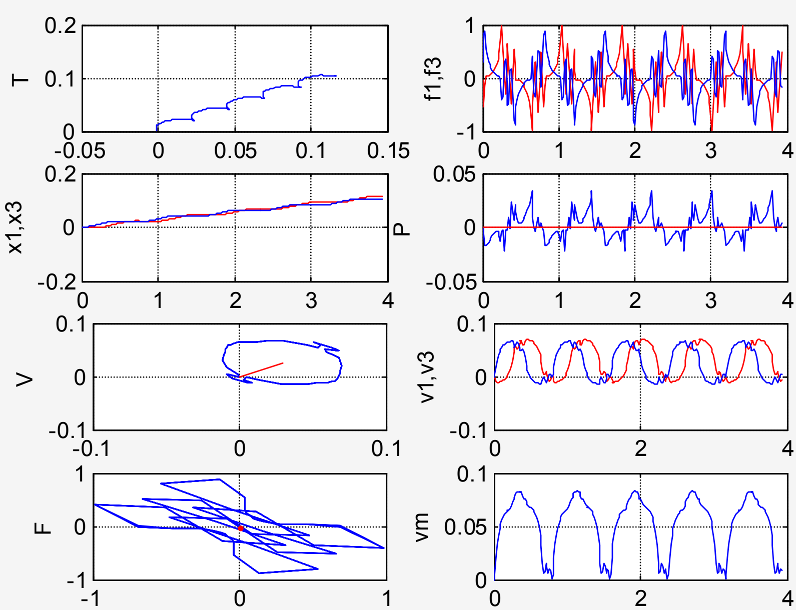

Fig. 13.

6. Resistance to Motion

The construction is always affected by the force F_T of resistance to motion – friction or useful load. Usually such force is proportional to the instant speed V, i.e.

$$F_T \approx F_t \cdot V, \tag{4}$$

where F_t is a known coefficient. The instant power f resistance to motion is

$$P_T = (F_T \cdot V) = F_t \cdot V^2, \tag{5}$$

Fig. 14 shows the graphs of instant values of the motion parameters for $F_t = -0.75$ и $a = 5, N = 5, \omega = 1, v_o = 1, q_o = 1$. In the window "P" the horizontal line is the graph of power (5). We may note that

- the trajectory gradually turns into circular motion of all the construction "on the spot",
- the instant amplitude of speed aims to a certain constant value (as the motion turns into rotation "on the spot"),

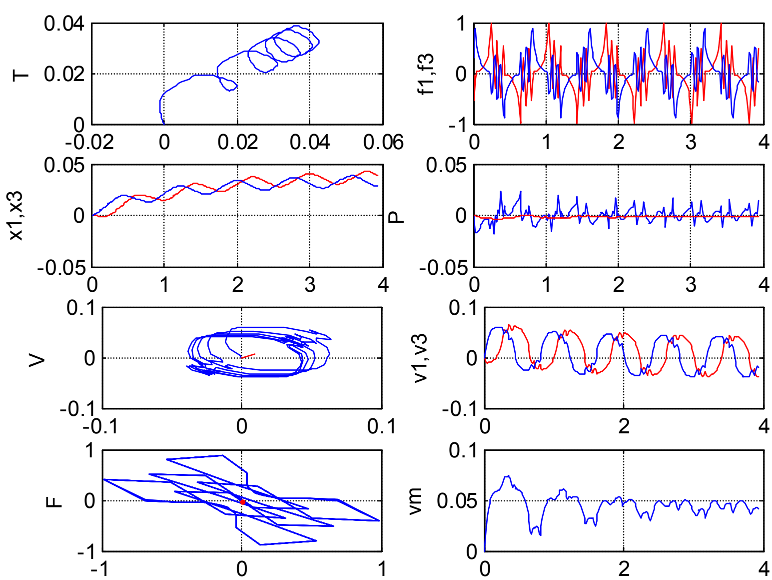

Fig. 14.

Thus, the considered construction performs unsupported motion also with the resistance. The power of the construction's motor is expended on the rotation of charges and on overcoming the resistance.

Chapter 14. The structure of the electromagnetic field in the body of a permanent magnet

Contents

1. Introduction

Below being considered a permanent magnet. The solution of Maxwell's equations for a system with magnetic dipoles is proposed. Based on this solution, a formal model of the distribution of magnetic dipoles in the body of a permanent magnet is built.

The study of the magnetic microstructure of permanent magnets is necessary to improve their technical characteristics. For this purpose, in well-known works, the structure of the distribution of magnetic dipoles in the body of a permanent magnet is studied. However, only experimental methods are used to study the domain structure - direct observations using various techniques. As far as the author knows, there is no formal model for the distribution of magnetic dipoles in the body of a permanent magnet. Obviously, such a model should be based on a formal model of the structure of the electromagnetic field of a permanent magnet, which is also absent.

Currently, the most common in modern technology received permanent magnets of the alloy NdFeB, a distinctive feature of which is conductivity. Therefore, a conductive permanent magnet is considered below. A solution is proposed Maxwell equations for such a magnet and on the basis of this solution, a formal model is constructed for the distribution of magnetic dipoles in the body of a permanent magnet.

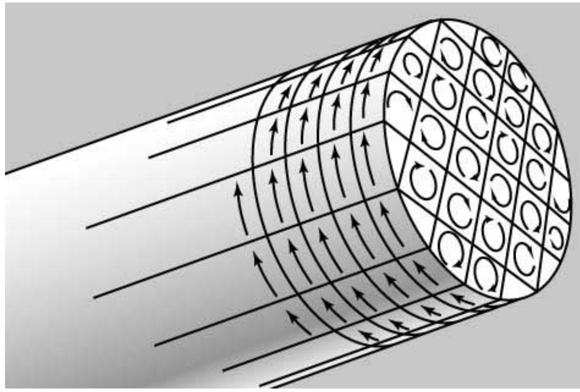

Fig. 1.

The solution found makes it necessary to reconsider the well-established ideas about the structure of magnetic intensities and currents in the body of a permanent magnet. It is known, for example, the idea that the magnetic field of a permanent magnet is formed only by currents on the surface of the magnet since the currents inside the magnet cancel each other out - see fig. 1. However, it is difficult to assume that significant currents flow in the surface layer, creating a large induction in modern magnets. And with this explanation, the role of domains in the body of the magnet becomes unnecessary. In reality, there are currents in the body of the magnet (as shown below) that flow along three coordinate axes, and there are also magnetic intensities directed along the three coordinate axes. In particular, there are currents flowing in all circles of the cylinder. Intensity is created by all the domains of the magnet (i.e., the currents forming the domains), and not just the surface domains.

In [152], an experiment of 1839 was described in which a sewing needle was inserted into a solenoid and a hollow cylindrical magnet. In the solenoid, the needle was installed in the center of the solenoid, and in a magnet, it was installed at the pole. This was explained by the fact that in the center and outside the magnetic strengths of the solenoid are opposite, and for the magnet, they coincide, since they are determined by the surface currents in the magnet. However, the sewing needle "does not know what is outside." If it behaves as described, then this means that 1) the field is uniform in the solenoid, 2) and in the magnet, the field in the center is zero. And this contradicts the theory of the equivalence of a solenoid and a magnet. However, it is this assumption that is used today in the modeling and design of magnets.

Erroneous ideas arise due to the fact that when analyzing a phenomenon, **not all** laws of electromagnetism are taken into account. All laws are combined in the system of Maxwell equations. Consequently, a full analysis of the phenomenon can be done only after the system of Maxwell equations has been formulated and solved for the object under study. Meanwhile, this system is not solved even for copper wire with a current, is not solved for a magnetized iron rod and, especially, is not solved for a permanent magnet. This gap is eliminated in the proposed work.

Practically the absence of this solution means that the real characteristics of the permanent magnets are described loosely. The rigorous solution obtained here, being applied in the design of permanent magnets, should certainly improve their quality.

A permanent magnet is usually considered as a ferromagnetic material consisting of a multitude of **domains**, each of which consists of a large number of atoms and therefore has dimensions of the order of 10^{-2} cm. However, the magnetic properties of the basic forms of carbon (diamond, graphite, nanographite, nanotubes, fullerenes) are known [158]. Organic substances with magnetic properties are also known [159]. In these cases, the magnetic properties manifest individual **molecules**, and not their conglomerates - domains.

In connection with the existence of such compounds, permanent magnets can be part of nanostructures and, possibly, in the composition of organisms. The latter is of interest for nanomedicine and nanotechnology. In this connection, it is important to build a mathematical model of a permanent magnet in the general case (and not only for domain structures). However, even to study the domain structure, only experimental methods are used - direct observations using various techniques. As far as the author knows, there is no formal model for the distribution of magnetic dipoles in the body of a permanent magnet. Obviously, such a model should be based on a formal model of the structure of the electromagnetic field of a permanent magnet, which is also absent.

At present, the idea of the absence of magnetic monopoles is accepted. Therefore, the mathematical model must operate with magnetic dipoles and take into account that the size of the dipole can be arbitrarily small. Below is a solution to the Maxwell equations for a permanent magnet that satisfies these conditions. Based on this solution, a formal model of the distribution of magnetic dipoles in the body of a permanent magnet is built.

2. Maxwell's equations for a system with magnetic monopoles

Maxwell's equations in the case when there is a constant magnetic field with magnetic intensity H and constant currents of density J have the form

$$\mathrm{rot}(J) = 0, \tag{1}$$
$$rot(H) - J = 0, \tag{2}$$
$$\mathrm{div}(J) = 0, \tag{3}$$
$$\mathrm{div}(H) = 0. \tag{4}$$

In the case when there are magnetic monopoles with density M, the last equation takes the form:

$$div(H) - M = 0. \tag{5}$$

If there are magnetic monopoles of different polarity, then the system of equations can be replaced (by virtue of the linearity of these equations) with two systems of the type

$$rot(J_1) = 0, \tag{6}$$
$$rot(H_1) - J_1 = 0, \tag{7}$$
$$div(J_1) = 0, \tag{8}$$
$$div(H_1) - M_1 = 0 \tag{9}$$

and

$$rot(J_2) = 0, \tag{10}$$
$$rot(H_2) - J_2 = 0, \tag{11}$$
$$div(J_2) = 0, \tag{12}$$
$$div(H_2) - M_2 = 0. \tag{13}$$

Suppose that all magnetic monopoles are combined in pairs - magnetic dipoles. Then

$$M_1 = -M_2 = M. \tag{14}$$

Suppose further that all magnetic dipoles have a size δ and are oriented along the z coordinate. Then

$$M_2(z) = -M_1(z + \delta), \tag{15}$$
$$H_2(z) = -H_1(z + \delta), \tag{16}$$
$$J_2(z) = -J_1(z + \delta). \tag{17}$$

So, the <u>system of Maxwell equations for a system with magnetic</u> <u>**monopoles**</u> takes the form of equations (6-9, 10-13, 15-17). Then the **algorithm for calculating the electromagnetic system with magnetic dipoles** takes the following form:

1. Calculation of magnetic intensities H_1 and current densities J_1 (the method of this calculation is described in chapter 5);

2. Calculation of the distribution of monopoles M_1; It is important to note that the values of monopoles found here have different signs;
3. Then, for data M_1, J_1, H_1 by (15-17), M_2, J_2, H_2 can be found.
4. Neglecting δ, for the system as a whole we get:

$$H = H_2 - H_1, \tag{18}$$

$$J = J_2 - J_1. \tag{19}$$

3. The solution of Maxwell's equations (2.6-2.9).

Consider equations (2.6-2.9), which in cylindrical coordinates are of the form:

$$\frac{1}{r}\cdot\frac{\partial H_z}{\partial \varphi} - \frac{\partial H_\varphi}{\partial z} = J_r, \quad \text{see (2.7)} \qquad (2)$$

$$\frac{\partial H_r}{\partial z} - \frac{\partial H_z}{\partial r} = J_\varphi, \quad \text{see (2.7)} \qquad (3)$$

$$\frac{H_\varphi}{r} + \frac{\partial H_\varphi}{\partial r} - \frac{1}{r}\cdot\frac{\partial H_r}{\partial \varphi} = J_z, \quad \text{see (2.7)} \qquad (4)$$

$$\frac{J_r}{r} + \frac{\partial J_r}{\partial r} + \frac{1}{r}\cdot\frac{\partial J_\varphi}{\partial \varphi} + \frac{\partial J_z}{\partial z} = 0, \quad \text{see (2.8)} \qquad (5)$$

$$\frac{1}{r}\cdot\frac{\partial J_z}{\partial \varphi} - \frac{\partial J_\varphi}{\partial z} = 0, \quad \text{see (2.6)} \qquad (6)$$

$$\frac{\partial J_r}{\partial z} - \frac{\partial J_z}{\partial r} = 0, \quad \text{see (2.6)} \qquad (7)$$

$$\frac{J_\varphi}{r} + \frac{\partial J_\varphi}{\partial r} - \frac{1}{r}\cdot\frac{\partial J_r}{\partial \varphi} = 0, \quad \text{see (2.6)} \qquad (8)$$

$$\frac{H_r}{r} + \frac{\partial H_r}{\partial r} + \frac{1}{r}\frac{\partial H_\varphi}{\partial \varphi} + \frac{\partial H_z}{\partial z} = M. \quad \text{see (2.9)} \qquad (9)$$

To shorten the record, we will further apply the following notation:

$$\mathrm{co} = \cos(\alpha\varphi + \chi z), \tag{10}$$

$$\mathrm{si} = \sin(\alpha\varphi + \chi z), \tag{11}$$

where α, χ are some constants. In Appendix 1 it is shown that there is a solution that has the following form:

$$J_r. = j_r(r)\cdot \mathrm{co}, \tag{12}$$

$$J_\varphi. = j_\varphi(r)\cdot \mathrm{si}, \tag{13}$$

$$J_z. = j_z(r)\cdot \mathrm{si}, \tag{14}$$

$$H_r. = h_r(r) \cdot \mathrm{co}, \tag{15}$$

$$H_\varphi. = h_\varphi(r) \cdot \mathrm{si}, \tag{16}$$

$$H_z. = h_z(r) \cdot \mathrm{si}, \tag{17}$$

$$M = m(r) \cdot si, \tag{18}$$

where $j(r)$, $h(r)$, $m(r)$ are some functions of coordinate r.

In Appendix 1, it was shown that there exists a modified Bessel function, denoted here as $F_\alpha(r)$, on which the functions of intensity $h(r)$ and current density $j(r)$ depend, namely

$$j_\varphi(r) = F_\alpha(r), \tag{25}$$

$$j_r(r) = \frac{-1}{\alpha}\left(j_\varphi(r) + r \cdot j'_\varphi(r)\right), \tag{26}$$

$$j_z(r) = \frac{\chi}{\alpha} r \cdot j_\varphi(r), \tag{27}$$

$$h_z(r) = \psi(j_r(r), j_\varphi(r), j_z(r)), \tag{28}$$

$$h_\varphi(r) = \frac{1}{\chi}\left(\frac{h_z(r)}{r}\alpha - j_r(r)\right), \tag{29}$$

$$h_r(r) = \frac{-1}{\chi}\left(j_\varphi(r) + h'_z(r)\right), \tag{30}$$

4. Calculation of the domain structure

In Appendix 1 shows that there is the following formula (see formula (A18)):

$$m(r) = -\frac{h_r(r)}{r} - \dot{h}_r(r) - \frac{h_\varphi(r)}{r}\alpha + \chi h_z(r). \tag{1}$$

This formula allows you to calculate the function $m(r)$. Given the formulas (3.11, 2.18), we find that

$$M_1(r,\varphi,z) = m(r) \cdot sin(\propto \varphi + \chi z). \tag{2}$$

In fig. 1, for example, shows the functions $h(r), j(r), m(r)$ for $\chi = 0.9,\ \propto = 0.005$. In the lower windows, the dipole distribution function along the circles of a given radius $q(r) = r \cdot m(r)$. is shown. At the same time in the left window shows the initial part of this function.

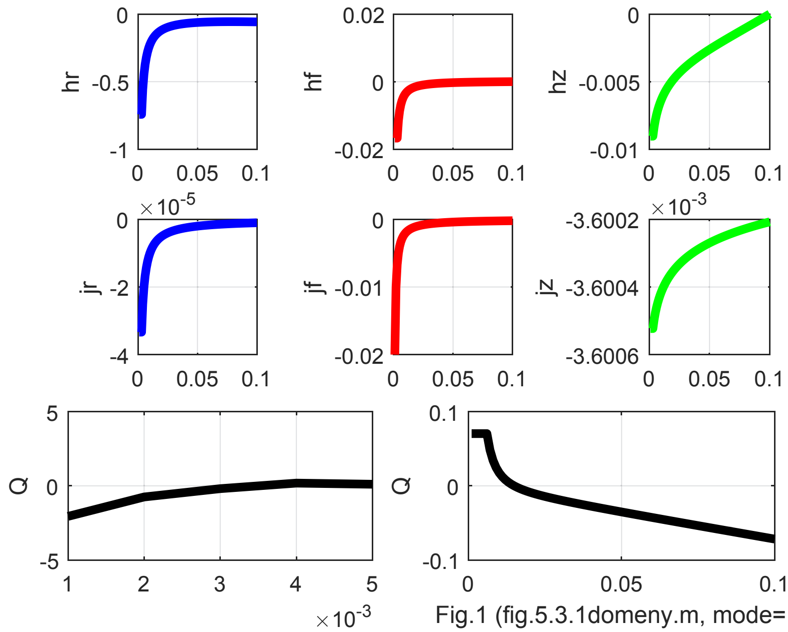

Fig.1 (fig.5.3.1domeny.m, mode=1)

The magnetic charge (2) is at the level of z and belongs to a certain dipole. The opposite charge of the same dipole is at the level (z + δ) and has the value

$$M_2(r,\varphi,z) = -m(r)\cdot sin(\propto \varphi + \chi(z+\delta)). \quad (3)$$

Note that for small δ the following relations hold:

$$sin(\varphi) - sin(\varphi+\delta) = -\delta\cdot cos(\varphi), \quad (4)$$

$$cos(\varphi) - cos(\varphi+\delta) = \delta\cdot sin(\varphi). \quad (5)$$

In this case, from (2.18, 2.19, 2.16, 2.17, 3.10-3.17) we get:

$$H_r = \delta h_r si, \quad (6)$$

$$H_\varphi = -\delta h_\varphi co, \quad (7)$$

$$H_z = -\delta h_z co, \quad (8)$$

$$J_r = \delta j_r si, \quad (9)$$

$$J_\varphi = -\delta j_\varphi co, \quad (10)$$

$$J_z = -\delta j_z co. \quad (11)$$

Thus, the following algorithm can be used to calculate the electromagnetic field of a permanent magnet:

1. Solving Maxwell's equations (3.2-3.8) to calculate functions (3.12-3.17).

2. Calculation of the function (2) taking into account (1). The resulting function is, in fact, a function of the distribution of magnetic domains. Thus domains
    a. located along the longitudinal axis z of the magnet,
    b. have length δ,
    c. they have magnetic monopole M_1 at level z, and magnetic monopole $(-M_1)$ at level (z+δ).
3. Calculation of functions (6-11).

The real domain structure should be decomposed into a series of functions (2). The resulting graphical distribution of dipoles can be compared with real observations, which will make it possible to do various extrapolations.

5. Domain structure (DS) in an external magnetic field

The proposed method for calculating the DS extends to the calculation of the DS of a magnetically soft material in an external magnetic field. This field may be variable. As shown in [128], the behavior of the DS in alternating magnetic fields of low frequency (0.1–10 kHz) largely determines the magnetic properties of soft magnetic materials. The proposed method for calculating the DS allows analytically studying

1. the phenomenon of dynamic self-organization of DS in alternating magnetic fields of low frequency,
2. translational motion of the domain structure as a whole often observed in the process of dynamic magnetization reversal,
3. controlled (by external influences) the movement of the domain structure as a whole.

Appendix 1.

The solution of equations (3.2-3.9) in the form of functions (3.10-3.18) is considered. Further, we will denote the derivatives with respect to strokes. In this case, we rewrite equations (3.2–3.9) in the following order (3.5, 3.2, 3.3, 3.4, 3.6, 3.7, 3.8, 3.9) and renumber them:

$$\frac{j_r(r)}{r} + j_r'(r) + \frac{j_\varphi(r)}{r}\alpha + \chi \cdot j_z(r) = 0, \qquad (3.5) \qquad (1)$$

$$\frac{h_z(r)}{r}\alpha - \chi h_\varphi(r) = j_r(r), \qquad (3.2) \qquad (3)$$

$$-h_r(r)\chi - h_z'(r) = j_\varphi(r), \qquad (3.3) \qquad (4)$$

$$\frac{h_\varphi(r)}{r}+h'_\varphi(r)+\frac{h_r(r)}{r}\cdot\alpha=j_z(r), \qquad (3.4) \qquad (5)$$

$$\frac{1}{r}\cdot j_z(r)\alpha-j_\varphi(r)\chi=0, \qquad (3.6) \qquad (6)$$

$$-j_r(r)\chi-j'_z(r)=0, \qquad (3.7) \qquad (7)$$

$$\frac{j_\varphi(r)}{r}+j'_\varphi(r)+\frac{j_r(r)}{r}\cdot\alpha=0, \qquad (3.8) \qquad (8)$$

$$\frac{h_r(r)}{r}+h'_r(r)+\frac{h_\varphi(r)}{r}\alpha+\chi h_z(r)=m(r). \qquad (3.9) \qquad (9)$$

The system of equations (1-8) is solved in Appendix 1 of Chapter 5 and has the following form:

$$j_\varphi(r)=F_\alpha(r), \qquad (25)$$

$$j_r(r)=\frac{-1}{\alpha}\left(j_\varphi(r)+r\cdot j'_\varphi(r)\right), \qquad (26)$$

$$j_z(r)=\frac{\chi}{\alpha}r\cdot j_\varphi(r), \qquad (27)$$

$$h_z(r)=\psi\left(j_r(r),j_\varphi(r),j_z(r)\right), \qquad (28)$$

$$h_\varphi(r)=\frac{1}{\chi}\left(\frac{h_z(r)}{r}\alpha-j_r(r)\right) \qquad (29)$$

$$h_r(r)=\frac{-1}{\chi}\left(j_\varphi(r)+h'_z(r)\right). \qquad (30)$$

The function $F_\alpha(r)$ is defined in the specified application. For small r, function (25) takes the form

$$y=Ax^\beta, \qquad (31)$$

where A is a constant, and

$$\beta=\frac{1}{2}\left(-3\pm\sqrt{3+4\chi^2}\right),\ \ \beta<0. \qquad (32)$$

At the same time, for calculating by equations (25-30), the quantities A, ∝, χ should be known.

Chapter 15. Fourth Electromagnetic Induction

Contents

1. Introduction

Below are different options for electromagnetic induction. Induction stand out, which depends on the change of the electromagnetic energy flow - the so-called fourth electromagnetic induction [19]. The dependence of the emf of this induction on the density of electromagnetic energy flux density and wire parameters is determined. The mechanism of the flow of energy entering the wire and compensating for heat loss is considered.

2. Forces and streams of electromagnetic energy in a conductive body

The law of conservation of momentum for a body interacting with an electromagnetic field can be written in the following form [13]:

$$-\frac{\partial}{\partial t}(J)=\frac{\partial}{\partial t}(pV)+gV, \tag{1}$$

where

J is mechanical momentum of the device,
p is the density of the electromagnetic momentum,
g is the flux density of the electromagnetic momentum,
V is the volume of the body in which the electromagnetic field momentum interacts with the body, i.e. with charges in this volume.

It is important that this formula be applicable only to a body in which there are free charges. Such a body is electrically conductive.

Equation (1) means that the total momentum flux in the entire volume of the field is zero.

It is known that the force acting on the body,

$$F = -\frac{\partial}{\partial t}(J). \tag{2}$$

Consequently,

$$\frac{F}{V} = \frac{\partial p}{\partial t} + g. \tag{3}$$

It is known [13] that

$$p = \frac{S}{c^2}, \tag{4}$$

$$g = \frac{S}{c}, \tag{5}$$

where S is the electromagnetic energy flux density. Combining (3-5), we find:

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

Thus, <u>if the electrically conductive body is in the flow of electromagnetic energy S, then a force (6) acts on it, depending only on the flow of electromagnetic energy S. This force also exists at a constant flow</u> S, and then

$$\frac{F}{V} = \frac{S}{c}. \tag{7}$$

In the event that the flow of electromagnetic energy propagates in the body with relative dielectric ε and magnetic μ permeability, in the previous formulas, instead of the speed of light in vacuum, it is necessary to substitute the speed of light in the substance

$$c_s = \frac{c}{\sqrt{\varepsilon\mu}}. \tag{8}$$

Consider the case when the vectors of electric and magnetic strengths are perpendicular. Then instead of formula (6) we get:

$$\frac{F}{V} = \frac{\partial}{\partial t}\left(\frac{S\varepsilon\mu}{c^2}\right) + \frac{S\sqrt{\varepsilon\mu}}{c}. \tag{9}$$

If, moreover, the field is constant, then

$$\frac{F}{V}=\frac{S\sqrt{\varepsilon\mu}}{c}. \qquad (10)$$

3. Types of electromagnetic induction

The law of electromagnetic induction is known.

$$e=\frac{\partial\Phi}{\partial t}, \qquad (1)$$

where Φ is the magnetic flux, e is the emf. It is also known [13] that this electromagnetic induction - the appearance of emf in the conductor may occur as a consequence of the fulfillment of two laws:

$$F=q(v\times B), \qquad (2)$$

$$\nabla\times E=-\frac{\partial B}{\partial t}. \qquad (3)$$

In accordance with this, there are two types of electromagnetic induction -

The first type is the case (3), when in the conductor emf appears due to a change in the magnetic flux, - *electromagnetic induction, caused by a change in the magnetic flux*;

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

The third type of electromagnetic induction arising in the unipolar Faraday generator is also known - *unipolar electromagnetic induction*. In this generator, the motor rotates a permanent magnet, and an emf is generated at the radius of the magnet, which is determined by the formula

$$e=\omega BL^2/2, \qquad (4)$$

where

B is induction of a permanent magnet,

L is the length of the radius of the magnet,

ω is angular velocity of rotation.

This formula was obtained by different methods: in [22] using the theory of relativity and in [26] on the basis of the law of conservation of momentum.

It is widely known that the current is induced in a conductor located in the flow of energy of an electromagnetic wave. We call *electromagnetic induction caused by the flow of electromagnetic energy* the fourth type of electromagnetic induction. Emf this induction is equal to the density of the forces acting on the charges and arising with the advent of an electromagnetic energy flux. Above these forces are defined by (2.9, 2.10). Therefore, the fourth emf induction equals

$$\varepsilon_4 = \frac{\partial}{\partial t}\left(\frac{S\varepsilon\mu}{c^2}\right) + \frac{S\sqrt{\varepsilon\mu}}{c} \tag{5}$$

or with a constant flow

$$\varepsilon_4 = \frac{S\sqrt{\varepsilon\mu}}{c} \tag{6}$$

Consequently, the electromagnetic flux allows the charges (charge current) to overcome the resistance to movement and does work (which is partially converted into heat). This force acts on all charges (electrons) in the wire, directed in the direction of the current (ie, it does not act on the wire as a whole). Thus, the flow creates an emf that “drives the current”.

On the other hand, in Chapter 5 shows that the electromagnetic energy density is a function of the current density J and the magnetic intensities H, which is expressed by the formula of the form - see (5.3.3):

$$S = \rho J H, \tag{7}$$

where ρ is the electrical resistance. Thus, each element of the wire with a current radiates a stream of electromagnetic energy. This flow penetrates the next element of the wire and creates in this element a force acting on the charges, i.e. determined above emf fourth electromagnetic induction. This force creates current. In this way,

> the current in the next element arises as a result of the flow of electromagnetic energy created by the current of the previous element.

Note that the energy flow created by some current element can NOT affect this current element, just like the charge field cannot affect this charge.

Such a view agrees well with the well-known fact that there is a leader in lightning moving at a speed of several hundred kilometers per second - see chapter 10, section 7.

A known experiment that can serve as experimental evidence for the existence of this induction [17].

Chapter 16. Electromagnetic Keeper of Energy and Information

Contents

1. Introduction

A well-known experiment demonstrates the preservation of the integrity of a certain structure in the absence of visible binding forces. Such an experiment was first described in 1842 but still has not found a scientific explanation. However, an interest in the problem continues unabated, which is reflected in Internet publications. Based on the solution of Maxwell's equations, this article shows that the experiment is explained by the conservation of electromagnetic energy inside the structure and the appearance of a keeping electromagnetic wave.

Based on this solution, it is shown that the design can be made not only on the basis of ferromagnetics (known fact) but also in the form of a capacitor, and the keepers themselves can have various forms. Understanding of the "principle of action" of the keeper, the existence of both magnetic and electrical keepers, the diversity of its forms can be the basis of various technical inventions [160].

Further it is shown that such designs can save not only energy but also information. This fact provides a basis for explaining such phenomena as the mirages of the past (battles with the sounds of battle). These phenomena are astounding and await their rigorous scientific explanation.

Observations show that mirages do not change their position on Earth. The stability of the position of the keeper is of particular interest.

The article shows that the stability of the position of a mirage can be explained by the fact that there is a standing electromagnetic wave, a pulsating flow of electromagnetic energy and a pulsating electromagnetic mass in the mirage zone. The center of mass does not change position, which ensures a stable position of the guardian on the ground. Thus, mirages can be viewed as experimental evidence of the existence of an electromagnetic mass. The very fact of such evidence can be a stimulus for the development of new technical devices using electromagnetic mass.

2. The description of the existing experiments

The following experiment is described in Internet [38, 133] and shown in figure 1. Take two bars of soft magnetic iron with a notch in the center of the bar along the entire length of the bar. These bars are folded so as to form a common channel. A wire is inserted into this channel, and a current pulse is passed through it. After this, the bars are held together by some kind of force. The force disappears when the wire passes a current pulse equal to the previous one in magnitude and duration but in opposite direction. A prerequisite for the occurrence of the effect is accurate processing of adjacent surfaces, preventing the appearance of an air gap between them.

Khmelnik [39] has already addressed this problem. Here it is described a more rigorous justification of this phenomenon. Now an interest in this problem has returned, thanks to the experiments carried out by Beletsky [133] shown in figure 2. However, this topic is not discussed in the scientific literature (and therefore this article has few references to published works). But in fact, this topic has a long history: in the book by [134] (1842) a similar design was considered. Figure 3 [134] shows a detachable electromagnet. The loads are suspended to it after switching on the electrical current. However, after turning off the electrical current, the electromagnet does not disintegrate.

Fig. 1.

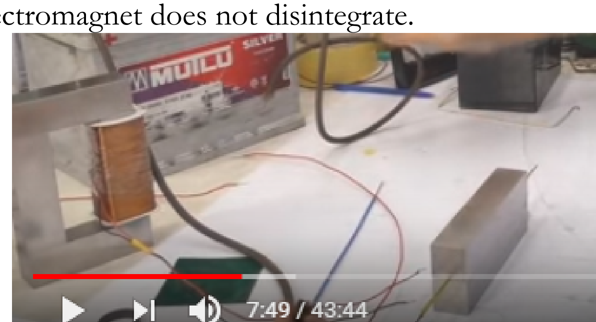

Fig. 2.

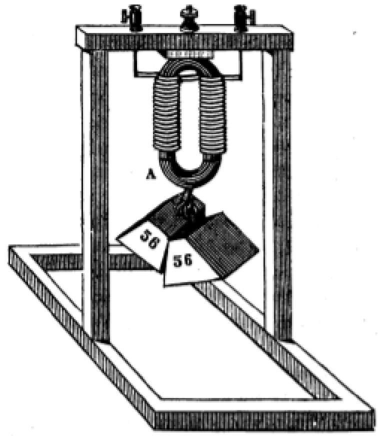

Fig. 3.

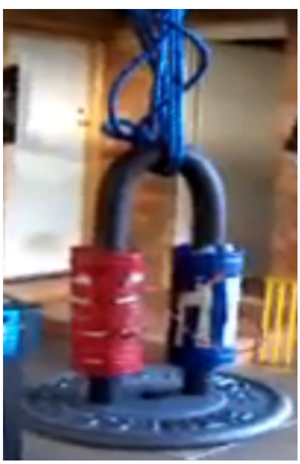

Fig. 4.

Fig. 5.

The effect cannot be explained by diffusion because the bars in figures 1 and 2 are applied to each other without pressure and "stick out" when the reverse impulse is turned on. Also, the effect cannot be explained by magnetic attraction because the material of the bars is magnetically soft and does not preserve magnetization.

There are other experiments that demonstrate the same effect. Figure 4 shows an electromagnet that retains the force of attraction after the current is turned off. It is assumed that Ed Leedskalnin used such electromagnets during the construction of the famous Coral Castle that is shown in figure 5 [38].

In all these structures, at the time of current shutdown, electromagnetic energy has some significance. This energy can be dissipated by radiation and heat loss. However, if these factors are not significant (at least in the initial period) the electromagnetic energy must be conserved. Next, we consider the conditions, under which the electromagnetic energy is stored for an arbitrarily long time, and the corresponding construction can be considered as an electromagnetic energy keeper.

3. Mathematical model

Consider a cube consisting of a soft magnetic material with a certain absolute magnetic permeability μ and absolute dielectric constant ε. Let an electromagnetic wave with energy arise as a result of some impact in a cube. Let an electromagnetic wave with energy W_o arise as a result of some impact in a cube. There are no heat losses in the cube, and the radiation of the cube (including thermal ones) is negligible. After some time, the wave parameters μ, ε, W_o will take stationary values determined by the size of the cube. These parameters are the electric field strength and the magnetic field intensity as functions of the Cartesian coordinates (x, y, z) and time (t), i.e. $E(x,y,z,t)$ and $H(x,y,z,t)$, respectively. Naturally, they satisfy the following set of the Maxwell homogenious equations:

$$\begin{cases} \frac{\partial H_z}{\partial y} - \frac{\partial H_y}{\partial z} - \varepsilon\frac{\partial E_x}{\partial t} = 0 \\ \frac{\partial H_x}{\partial z} - \frac{\partial H_z}{\partial x} - \varepsilon\frac{\partial E_y}{\partial t} = 0 \\ \frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y} - \varepsilon\frac{\partial E_z}{\partial t} = 0 \\ \frac{\partial E_z}{\partial y} - \frac{\partial E_y}{\partial z} + \mu\frac{\partial H_x}{\partial t} = 0 \\ \frac{\partial E_x}{\partial z} - \frac{\partial E_z}{\partial x} + \mu\frac{\partial H_y}{\partial t} = 0 \\ \frac{\partial E_y}{\partial x} - \frac{\partial E_x}{\partial y} + \mu\frac{\partial H_z}{\partial t} = 0 \\ \frac{\partial E_x}{\partial x} + \frac{\partial E_y}{\partial y} + \frac{\partial E_z}{\partial z} = 0 \\ \frac{\partial H_x}{\partial x} + \frac{\partial H_y}{\partial y} + \frac{\partial H_z}{\partial z} = 0 \end{cases} \tag{1}$$

where there are the partial first derivatives of components (E_x, E_y, E_z) and (H_x, H_y, H_z) with respect to time t and the real space components (x, y, z), respectively.

Consider the following functions proposed in [45]:

$$E_x(x,y,z,t) = e_x\cos(\alpha x)\sin(\beta y)\sin(\gamma z)\sin(\omega t) \tag{2}$$

$$E_y(x,y,z,t) = e_y\sin(\alpha x)\cos(\beta y)\sin(\gamma z)\sin(\omega t) \tag{3}$$

$$E_z(x,y,z,t) = e_z\sin(\alpha x)\sin(\beta y)\cos(\gamma z)\sin(\omega t) \tag{4}$$

$$H_x(x,y,z,t) = h_x \sin(\alpha x)\cos(\beta y)\cos(\gamma z)\cos(\omega t) \tag{5}$$
$$H_y(x,y,z,t) = h_y \cos(\alpha x)\sin(\beta y)\cos(\gamma z)\cos(\omega t) \tag{6}$$
$$H_z(x,y,z,t) = h_z \cos(\alpha x)\cos(\beta y)\sin(\gamma z)\cos(\omega t) \tag{7}$$

where

$e_x, e_y, e_z, h_x, h_y, h_z$ are the constant amplitudes of functions,

$\alpha, \beta, \lambda, \omega$ are the constants.

Differentiating equations from (2) to (7) and substituting the obtained result in equations' set (1), and after reducing by common factors, one can obtain the following form:

$$\begin{cases} h_z\beta - h_y\gamma + e_x\varepsilon\omega = 0 \\ h_x\gamma - h_z\alpha + e_y\varepsilon\omega = 0 \\ h_y\alpha - h_x\beta + e_z\varepsilon\omega = 0 \\ e_z\beta - e_y\gamma - h_x\mu\omega = 0 \\ e_x\gamma - e_z\alpha - h_y\mu\omega = 0 \\ e_y\alpha - e_x\beta - h_z\mu\omega = 0 \\ e_x\alpha + e_y\beta + e_z\gamma = 0 \\ h_x\alpha + h_y\beta + h_z\gamma = 0 \end{cases} \tag{8}$$

The considered system is symmetric and therefore, it is possible to apply the following equalities:

$$\alpha = \beta = \lambda \tag{9}$$

Then equations' set (8) takes the following form:

$$\begin{cases} h_z - h_y + \dfrac{e_x\varepsilon\omega}{\alpha} = 0 \\ h_x - h_z + \dfrac{e_y\varepsilon\omega}{\alpha} = 0 \\ h_y - h_x + \dfrac{e_z\varepsilon\omega}{\alpha} = 0 \\ e_z - e_y - \dfrac{h_x\mu\omega}{\alpha} = 0 \\ e_x - e_z - \dfrac{h_y\mu\omega}{\alpha} = 0 \\ e_y - e_x - \dfrac{h_z\mu\omega}{\alpha} = 0 \\ e_x + e_y + e_z = 0 \\ h_x + h_y + h_z = 0 \end{cases} \tag{10}$$

The seventh and eighth equations in equations' set (10) are satisfied only if $\omega > 0$, see in Appendix 1. In addition, the seventh and eighth equations in set (10) follow directly from the previous equations in the set. Indeed, adding the fourth and fifth to the sixth, we obtain the eighth, and adding the first and second equations to the third, we obtain the seventh. The first six equations in set (10) with six unknowns are independent and the amplitudes of functions $(e_x, e_y, e_z, h_x, h_y, h_z)$ can be found from them.

It is possible to obtain a solution for the set of the first six equations in (10) with the following condition:

$$h_z = 0 \tag{11}$$

Then this set of six homogenious equations will have the following form:

$$\left\{\begin{array}{c} \frac{e_x \varepsilon\omega}{\alpha} - h_y = 0 \\ \frac{e_y \varepsilon\omega}{\alpha} + h_x = 0 \\ \frac{e_z \varepsilon\omega}{\alpha} - h_x + h_y = 0 \\ -e_y + e_z - \frac{h_x \mu\omega}{\alpha} = 0 \\ e_x - e_z - \frac{h_y \mu\omega}{\alpha} = 0 \\ -e_x + e_y = 0 \end{array}\right. \tag{12}$$

The solution of equations' set (12) is:

$$h_y = -h_x \tag{13}$$

$$e_x = -\frac{h_x \alpha}{\varepsilon\omega} \tag{14}$$

$$e_y = e_x \tag{15}$$

$$e_z = -2e_x \tag{16}$$

It is possible to write intensities (2) in the following form:

$$E_x(x,y,z,t) = e_x \sin(\omega t) E_x^T(x,y,z) \tag{17}$$

where the trigonometric function $E_x^T(x,y,z)$ is

$$E_x^T(x,y,z) = \cos(\alpha x)\sin(\beta y)\sin(\gamma z) \tag{18}$$

Similarly, we can rewrite the functions from (3) to (7), taking into account formulas (11), (13) to (16)

$$E_y(x,y,z,t) = e_x \sin(\omega t) E_y^T(x,y,z) \tag{19}$$

$$E_z(x,y,z,t) = -2e_x \sin(\omega t) E_z^T(x,y,z) \tag{20}$$

$$H_x(x,y,z,t) = -\frac{\varepsilon\omega}{\alpha} e_x \cos(\omega t) H_x^T(x,y,z) \tag{21}$$

$$H_y(x,y,z,t) = \frac{\varepsilon\omega}{\alpha} e_x \cos(\omega t) H_y^T(x,y,z) \tag{22}$$

$$H_z(x,y,z,t) = 0 \tag{23}$$

Let us now find the square of the module of total intensities. They read as follows:

$$E^2 = \left(E_x^2 + E_y^2 + E_z^2\right) = 6e_x^2 \sin^2(\omega t) E_T^2(x,y,z) \tag{24}$$

$$H^2 = \left(H_x^2 + H_y^2\right) = 2\left(\frac{\varepsilon\omega}{\alpha}\right)^2 e_x^2 \cos^2(\omega t) H_T^2(x,y,z) \tag{25}$$

where

$$E_T^2(x,y,z) = \left(E_x^T(x,y,z)\right)^2 + \left(E_y^T(x,y,z)\right)^2 + \left(E_z^T(x,y,z)\right)^2 \tag{26}$$

$$H_T^2(x,y,z) = \left(H_x^T(x,y,z)\right)^2 + \left(H_y^T(x,y,z)\right)^2 \tag{27}$$

Consider now the following relationship

$$q = \frac{E_T^2(x,y,z)}{H_T^2(x,y,z)} \tag{28}$$

It can be shown that under condition (9) the ratio does not depend on the size of the cube and the value of *a*. This means that the amplitudes of the total strengths are referred to as

$$\frac{E^2}{H^2} = \frac{6e_x^2 q}{2\left(\frac{\varepsilon\omega}{\alpha}\right)^2} \tag{29}$$

or

$$\frac{|E|}{|H|} = \frac{\sqrt{6q}}{\frac{\varepsilon\omega}{\alpha}\sqrt{2}} = \frac{\alpha\sqrt{3q}}{\varepsilon\omega} \tag{30}$$

or

$$|H| = \frac{\varepsilon\omega}{\alpha\sqrt{3q}}|E| \tag{31}$$

For a cube, one has to use the following value:

$$q = 3 \tag{32}$$

As a result, one can obtain the following equality:

$$|H| = \frac{\varepsilon\omega}{3\alpha}|E| \tag{33}$$

4. Energy

Energy density is equal to

$$W = \varepsilon E^2 + \mu H^2 \tag{34}$$

or, taking into account the previous formulas, one can get

$$W = 6\varepsilon e_x^2 \sin^2(\omega t) E_T^2(x,y,z) + 2\mu\left(\frac{\varepsilon\omega}{\alpha}\right)^2 e_x^2 cos^2(\omega t) H_T^2(x,y,z) \tag{35}$$

Given (28), we write

$$W = E_T^2(x,y,z) e_x^2\left(6\varepsilon \cdot \sin^2(\omega t) + \frac{2\mu}{q}\left(\frac{\varepsilon\omega}{\alpha}\right)^2 cos^2(\omega t)\right) \tag{36}$$

If the frequency satisfies the condition

$$6\varepsilon = \frac{2\mu}{q}\left(\frac{\varepsilon\omega}{\alpha}\right)^2 \tag{37}$$

or, subject to (29), the condition

$$\omega = \frac{3\alpha}{\sqrt{\mu\varepsilon}} \tag{38}$$

then the reader can get

$$W = 6\varepsilon E_T^2(x,y,z)e_x^2\left(\sin^2(\omega t) + cos^2(\omega t)\right) \tag{39}$$

or

$$W = 6\varepsilon E_T^2(x,y,z)e_x^2 \tag{40}$$

Therefore, if the frequency satisfies condition (32), then the energy of the electromagnetic wave does not depend on time. The total energy in the cube volume is as follows:

$$\bar{\bar{W}} = \iiint_{x,y,z} W dxdydz = 6\varepsilon e_x^2 \iiint_{x,y,z} E_T^2(x,y,z)dxdydz \tag{41}$$

So, there is such a frequency of an electromagnetic wave, in which the energy of an electromagnetic wave in construction is kept constant.

With (33) and (38), it follows that in this case there is the following:

$$|H| = \frac{\varepsilon}{3\alpha}\frac{3\alpha}{\sqrt{\mu\varepsilon}}|E| = |E|\sqrt{\frac{\varepsilon}{\mu}} \tag{42}$$

With (18) and (23), it follows that

$$E = |E|\sin(\omega t) \tag{43}$$

$$H = |H|\cos(\omega t) \tag{44}$$

This means that under these conditions there is a standing electromagnetic wave in the cube. The standing wave does not radiate through the cube edges.

5. The other forms of the keeper

A keeper in the form of a cube under the condition (9) was considered above. For the existence of another form of a keeper, it is sufficient to make sure that for this form the value of relationship (28) does not depend on the body size and the value of *a*. The author has checked the fulfillment of this condition for a cylinder with a height equal to the diameter and for a sphere. The value of $q = 3$ was used for the cylinder, sphere, and cube. For bodies with a central point of symmetry (parallelepiped, cylinder of arbitrary height, cylinder with an elliptical base, ellipsoid) this condition is also satisfied. However, $q \neq 3$ for them.

6. The capacitor keeper

From the foregoing, it follows that the values of the parameters ε and μ do not affect the mere existence of the phenomenon under consideration. Therefore, there may exist a capacitor keeper in addition to the magnetic keeper. This can actualy exist.

The experiment is known, which is (in our opinion) the indisputable proof that the energy of a capacitor is stored in a dielectric [122]. For experiments, the installation was made of two capacitors, between which the dielectric moves. As a result, in one capacitor the dielectric is charged with energy from a high-voltage source, and from the other capacitor this energy is extracted. The capacitor discharges through the discharger. The author of the experiment explains this phenomenon by charge transfer in a dielectric. This is not surprising: the question of where the charge is stored is still being debated. Similar, but much less spectacular experiments, have so far been explained by the fact that a film of moisture retains charge on the surface of the dielectric after the removal of the metal plate [123]. However, the following issues are not considered: how this film manages to arise and how water manages to charge. Thus, electromagnetic energy, which is stored in a charged capacitor as a stationary stream of electromagnetic energy, when removing the plates, is converted into standing wave energy (see Chapter 7).

Let the capacitor dielectric consist of two loose parts. We charge it and remove the charged plates. Both parts of the dielectric will be held by some force. The author did not perform such an experiment that can be performed in the future.

7. About preserving force

The density of electromagnetic energy is equal, as is known, to the internal pressure in the body where this energy is located. The pressure force is directed towards the inside of the body (also, for instance, as in a charged capacitor). When a body is stretched, its energy increases, since its volume increases at a constant energy density. Therefore, to stretch the body you need to do the work. The tensile force is equal to the force of the internal pressure in the direction of the force. This means that the "destroyer" needs to overcome such a force. This is what is demonstrated in these experiments.

8. The vacuum keeper

We emphasize once again that the value of the parameters ε and μ does not affect the mere existence of the phenomenon under consideration. Therefore, in addition to the magnetic and capacitor keeper, there may be a vacuum keeper.

Concerning the vacuum keeper, it is difficult to imagine the keeper in a clearly limited volume, for instance, in the form of a vacuum cube with clear walls. The vacuum keeper may be, for example, in a volume that gradually decreases with distance from the center. Such a volume can be represented in the form of a rather flat ellipsoid. Another variant of the vacuum volume can be described by the following formula:

$$z = 2N - \frac{4}{N}\left(\left(x - \frac{N}{2}\right)^2 - \left(y - \frac{N}{2}\right)^2\right) \tag{45}$$

where N is a constant, $N = 200$ in figure 6. It is interesting to note that in this case $q = 3$.

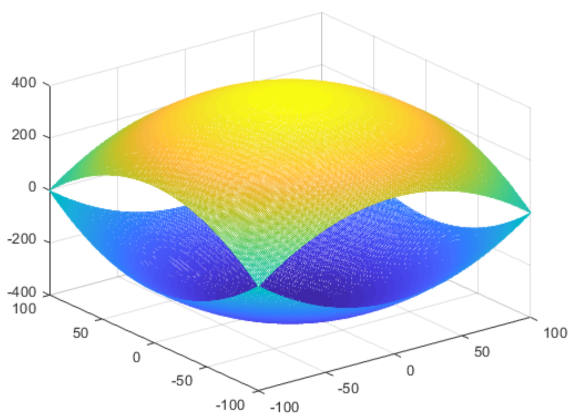

Fig. 6.

The electromagnetic wave in the vacuum energy saver can be modulated. In this case, this energy keeper becomes the information keeper. When such a keeper is destroyed, electromagnetic energy is emitted in the form of a modulated wave.

There have been cases of radio programs of the 1930s (songs, speech), mirages of the past (battles with the sounds of battle). These phenomena are striking and inexplicable [136]. It is important to note that they are tightly linked to the terrain. For example, in [137] we read: *"Every year, only in the Sahara, there are 160,000 all kinds of mirages. Moreover, the emerging paintings are immediately applied to Bedouin cards ... This is a necessary measure, as there have been cases when whole caravans died because of mirages."*

Considering the previous conclusions, these phenomena can be explained by the fact that the modulated electromagnetic wave is memorized in a certain amount. This volume can be destroyed and then this wave is emitted from it in the form of radio transmission or in the form of video transmission. It is possible that this volume may be partially destroyed and then such transfers will be repeated. It is also possible that this volume can expand with increasing energy (due to incoming energy from the outside) without changing the frequency of the wave. Then the recoverable information keeper is formed.

In this case, a question arises, to which my attention drew: how is the keeper volume held in place? If the keeper is implemented in an air dielectric, then the keeper should be moved by air flows. If it is realized in the vacuum volume, then the Earth must leave this volume in its motion.

The answer appears to be as follows. As mentioned, the electromagnetic energy W is stored in the custodian's volume and there is a standing electromagnetic wave. Consequently, in this volume the flow of electromagnetic energy S pulses. Together with this flow there is an momentum p electromagnetic wave and an mass m of electromagnetic wave. These values are related to each other and with the speed c of propagation of electromagnetic energy [13]:

$$S = Wc \tag{46}$$

$$p = \frac{W}{c} \tag{47}$$

$$m = \frac{p}{c} \tag{48}$$

Therefore,

$$m = \frac{W^3}{S^2} \tag{49}$$

This electromagnetic mass pulsates along with the flow of electromagnetic energy. However, the center of mass does not change position. Consequently, the volume of the custodian can be considered as the volume of the pulsating mass with a constant center of gravity. This mass is held in place by gravity and does not interact with the material mass, i.e. cannot be shifted by air flow. This ensures a stable position of the keeper on the ground.

Another question arises, to which my attention also drew: why are there no mirages of events that took place on Earth hundreds or thousands of years ago? The answer, apparently, is that the keeper is partially destroyed by the radiation of electric energy in the form of a modulated wave, and the recovery of energy may be incomplete. These factors limit the life of the custodian.

9. Conclusion

It follows from the written above that an electromagnetic wave can exist in a cube such that the cube faces do not radiate and there are no heat losses: there are no electric currents even in an iron cube. Under these conditions, an electromagnetic wave can exist for an arbitrarily long time. This cube saves

• magnitude of electromagnetic energy,
• structural integrity.

Such a keeper may have a different, noncubic form and is made of various materials. It can be implemented as a body or as a certain amount of a vacuum.

Together with energy the keeper can store information.

The keeper can have not only man-made but also natural origin. A vivid example is the keepers of information about events on Earth, manifesting themselves as mirages of past battles. Such guardians prove, moreover, the existence of an mass of electromagnetic wave.

Appendix 1

Let use $\omega = 0$ in (9). Then from (9) we get the following equalities:

$$e_z\beta - e_y\gamma = 0 \tag{A1}$$

$$e_x\gamma - e_z\alpha = 0 \tag{A2}$$

$$e_y\alpha - e_x\beta = 0 \tag{A3}$$

$$e_x\alpha + e_y\beta + e_z\gamma = 0 \tag{A4}$$

From (A4) we find:

$$e_y = e_x\frac{\beta}{\alpha} \tag{A5}$$

From (A2) we find:

$$e_z = e_x\frac{\gamma}{\alpha} \tag{A6}$$

From (A1, A5, A6) we find:

$$e_x\frac{\gamma}{\alpha}\beta - e_x\frac{\beta}{\alpha}\gamma \equiv 0 \tag{A7}$$

From (A4, A5, A6) we find:

$$e_x\alpha + e_x\frac{\beta}{\alpha}\beta + e_x\frac{\gamma}{\alpha}\gamma = 0 \tag{A8}$$

or

$$\alpha^2 + \beta^2 + \gamma^2 = 0 \tag{A9}$$

This means that $\alpha = \beta = \gamma = 0$, i.e. the electromagnetic field at $\omega = 0$ is absent.

Chapter 17. The Reversibility of Unipolar Induction

Содержание

1. Introduction

The reversible law of unipolar induction is stated below. It is shown that this law of unipolar induction can justify the magneto-hydrodynamic dynamo effect and the existence of the magnetic field of astronomical objects. Next, we consider convection magnetic currents that can exist without the existence of magnetic charges (magnetic monopoles). Relevant experiments are indicated.

2. Justification of the reversibility of the law of unipolar induction

Eichenwald in [86] considers a rotating charged disk, exciting a magnetic field. Eichenwald calls these rotating charges a convection current. His experiment suggests that ordinary electric current, convection current, a rotating electric field, and a rotating charged disk equally excite a magnetic field.

A rotating charged disk is a source of a rotating electric field. Thus, from the Eichenwald experiment, it follows that a rotating electric field excites a magnetic field.

The law of Faraday unipolar induction is widely known:

$$E = V \times B \tag{1}$$

or

$$E = V \times \mu H \tag{2}$$

On this basis, it can be assumed that there is a **reversible law of unipolar induction**:

$$H = V \times \varepsilon E \tag{3}$$

It is easy to make sure that formula (3) satisfies the requirements of the dimension of its variables.

Consider the case when the vector products (2, 3) can be replaced by a simple product, and the magnitudes of the strengths included in formulas (2, 3) coincide. Then we get:

$$E = V_2 \mu H \tag{4}$$

$$H = V_3 \varepsilon E \tag{5}$$

Multiplying (4, 5), we find:

$$V_2 V_3 = \frac{1}{\mu\varepsilon} = c^2 \tag{6}$$

Relation (4) is observed in known experiments at technically feasible speeds and tensions. At the same magnitude of the speed

$$V_3 = \frac{c^2}{V_2} \tag{7}$$

should reach fantastic values. However, for large electric strengths E and speeds V_3, the appearance of magnetic intensity H should be observed.

The magnetohydrodynamic dynamo is known - the effect of self-generation of a magnetic field in a certain motion of a conducting fluid [145]. This effect explains the formation and existence of the magnetic field of astronomical objects - galaxies, stars, planets [146]. In these phenomena, there is high-speed movement of electric charges in a liquid or plasma, which is equivalent to large electric intensities E and velocities V_3. Consequently, the reversible law of unipolar induction can serve as a justification for all these phenomena.

3. Magnetic currents

It was stated above that the magnetic field is created by the convection electric current of electric charges. In this case, equation (2) can be considered as the equation of magnetic intensity depending on the electric current of electric charges.

By analogy, it can be argued that the electric field is created by the convective magnetic current of magnetic charges. In this case, equation (1) can be considered as an equation of electrical intensity depending on the magnetic current of magnetic charges.

The idea of the existence of magnetic charges is not new. It is known that Heaviside was the first to introduce magnetic charges and magnetic currents into Maxwell's electrodynamics [140]. Note also that in the mathematical sense, the pole of a long magnet can be identified with a magnetic charge [141].

The creation of an electric field by the convection current of magnetic charges was observed in Searl's experiments. In [142] it is described as a generator, "... accelerating more and more, began to emit a pink glow around him." A similar effect is described in the forum [143]. It describes the disk of Azanov with many magnets attached to the circumference of the disk (for details, see answer 37). The author in the video (see answer 17) indicates that when his disk is rotated at a speed of 7000 rpm, a halo is formed. Indeed, in both cases, the rotation of the magnets is naturally identified with the convection current of the magnetic charges, and the resulting pink glow or halo is explained by the appearance of an electric field in accordance with (1).

Thus, the movement of magnets, the poles of which are oriented equally relative to the line of motion, can be considered as a magnetic current. This magnetic current creates an electric field. This does not mean that magnetic charges exist as a physical object but allows one to compactly describe the motion of a set of magnets.

4. Rotating fields

An electrically charged disc creates a symmetrical electric field. Eichenwald's experience shows that a rotating symmetric electric field creates a magnetic field. In connection with this, Bogach in [139] says that *"with a high probability we can expect the existence of the opposite effect: with the rotation of even a symmetric magnetic field, an electric field should arise. And this possibility should be experimentally verified. Many published experimental works have been devoted to the search for the mentioned electric field ... However, it was not possible to measure the electric field in any of them, which can be explained, as will be seen from the following, with erroneous ideas about the properties of the field under study"*.

The above experiments demonstrate the opposite effect, which says Bogach: a rotating magnetic field creates an electric field.

Bogach connects the question of the existence of this phenomenon with the question of the existence of a **static** electromagnetic field. In previous chapters, it is shown that a static electromagnetic field follows directly from Maxwell's equations. For example, there is a **static** electromagnetic field in a DC wire and in a charged capacitor.

5. Equations of unipolar induction in the system of Maxwell equations

Consider the table 1.

Table 1

		a	b
1	Current density	$j = DV$	$m = BV$
2	Maxwell's equations	$rotH = j$	$rotE = m$
3	Unipolar Induction Equations	$H = V \times D$	$E = V \times B$

Consider the case when the electric charge is located at the end of an electret moving at a speed V. In this case, the density of the electric convection current is described by formula (1a) since the electric induction at the end of the electret is equal to the density of the electric charge. Equation (2a), obtained above as (2.3), determines the magnetic intensity created by this convection current in the vicinity of the electret end. Equation (3a) determines the magnetic intensity created by this convection current directly at the end of the electret. Note that equation (2a) does not allow finding the intensity at the end. This also follows from the fact that the Bio-Savart-Laplace equation, equivalent to equation (2a), also does not allow to determine the intensity at the end, because in this case, the division by zero appears in the Bio-Savart-Laplace equation.

We now consider the case when the end of a permanent magnet with magnetic induction B moves at a speed V. The magnetic induction at the end of the magnet is equal to the density of the magnetic charge. Therefore, the movement of the end face of the magnet is equivalent to a magnetic current with a density (1b). Equation (2b) determines the electrical intensity generated by this convection current in the vicinity of the end of the permanent magnet. Equation (3b) determines the magnetic intensity created by this convection current directly at the end of the permanent magnet. Here it can also be noted that equation (2b) does not allow finding the tension at the end.

From this, it follows that equations (3) should be included in the system of Maxwell equations.

Chapter 18. The Forces of Lorentz, Ampere, and Khmelnik

Contents

1. Introduction

It is known that Ampere force contradicts the Third Newton Law, but it does not contradict the more general Law of Momentum Conservation, as the electromagnetic field has a momentum. It is important to note that a static electromagnetic field can also have a momentum and therefore the Ampere force does not contradict law of conservation of momentum, also in the case when it occurs in conjunction with a permanent magnetic field. From this it follows that the Ampere force must be balanced by the flow of electromagnetic field momentum. However, as far as the author knows, a quantitative comparison of the Ampere force with the flow of electromagnetic field momentum does not exist. Therefore this comparison will be discussed below – see also [25]. Here we shall also define some parameters, and taking them into account we shall show that the Lorentz force and Ampere force can be regarded as corollaries of the existence of electromagnetic field momentum and the law of momentum conservation.

2. The Field's Configuration

For an electromagnetic field let us denote:

W - the energy density (scalar), kg·m^{-1}·s^{-2},

S - the energy flow density (vector), kg·s^{-3},

p - the momentum density (scalar), kg·m^{-2}·s^{-1},

f - the electromagnetic field momentum density (vector), kg·m^{-1}·s^{-2},

V - the electromagnetic field volume (scalar), m^3.

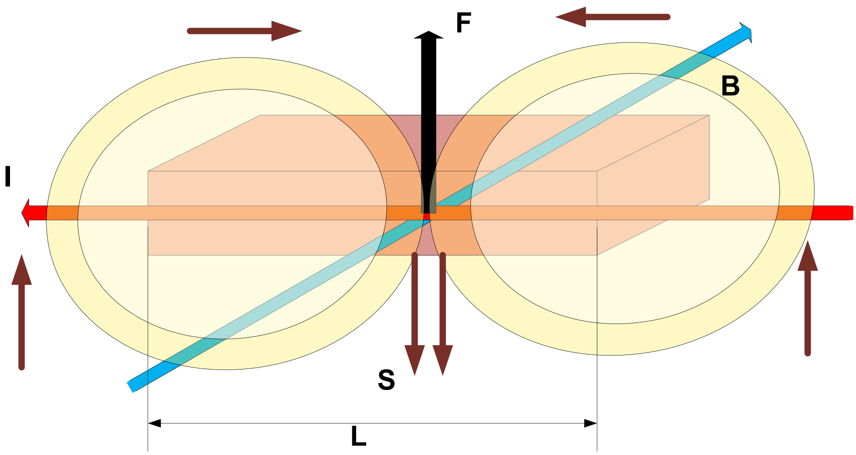

Fig. 1.

Fig. 1a clearly shows several lines of current, induction and flow. The"forest" of brown lines of the flow begins at the intersection points of the lines of current and the lines of induction, as shown by circles. The flow lines penetrate the body, pass out of the body and are closed as shown by horizontal arrows. On Fig. 1 these closing lines are shown by circles.

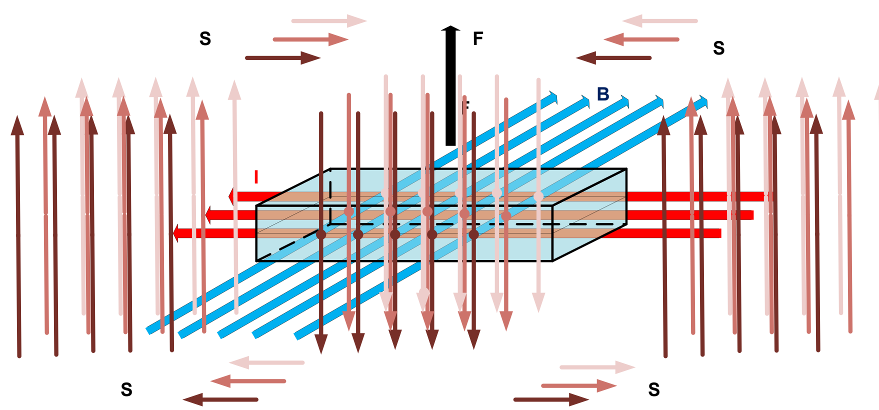

Fig. 1a.

It is known [1, 2], that

$$|f| = W \,. \tag{1}$$

$$S = W \cdot c \,, \tag{2}$$

$$p = W/c\,,\ p = S/c^2\,, \tag{3}$$

$$f = p \cdot c\,,\ f = S/c\,. \tag{4}$$

The integral of the density by volume will be denoted as

$$A_V = \int_V A \cdot dV\,. \tag{4a}$$

The energy flow S_V may exist also in a static electromagnetic field [13]. Therefore the momentum flow f_V exists also in a static electromagnetic field created by direct current and permanent magnetic field.

The law of momentum conservation for a device interacting with electromagnetic field can be written in a following form [13]:

$$-\frac{\partial}{\partial t}(J) = \frac{\partial}{\partial t}(pV) + fb\,, \tag{5}$$

where

J is mechanical momentum of the device,

V is volume device; the volume in which the electromagnetic field momentum interacts with the device, i.e. with charges and currents in this volume,

b is the cross-sectional area of the body along which the flow of energy and momentum propagates.

Equation (5) means that the total flux of momentum in the entire volume of the field is zero.

It is known that the force acting on the device is

$$F = -\frac{\partial}{\partial t}(J). \tag{6}$$

Consequently,

$$F = \frac{\partial}{\partial t}(pV) + fb\,, \tag{7}$$

Combining (7) and (3, 4), we get:

$$F = \frac{\partial}{\partial t}\left(\frac{SV}{c^2}\right) + \frac{Sb}{c}\,, \tag{8}$$

Thus, if the device is in the flow of electromagnetic energy S_V, <u>then it is influenced by a force (8), depending only on the flow of electromagnetic energy</u> S_V. This force exists also for a permanent flow S_V, and then

$$F = \frac{Sb}{c}\,, \tag{9}$$

In this case, if the flow of electromagnetic energy electromagnetic energy flux is distributed in the material with relative permittivity ε and permeability μ, then in the formulas (8, 9) the light speed c in vacuum should be replaced by the light speed in material

$$c_s = \frac{c}{\sqrt{\varepsilon\mu}} \tag{10}$$

Let us consider the case (shown on the fig. 1), when vector of permittivity E and permeability H are perpendicular. Then

$$S = EH \tag{11}$$

Let also the field in the device is uniform and is concentrated in the volume V. Then from (8, 10, 11) we get

$$F = \frac{\partial}{\partial t}\left(\frac{EHV\varepsilon\mu}{c^2}\right) + \frac{EHb\sqrt{\varepsilon\mu}}{c}, \tag{12}$$

If, besides that, the field is permanent, then

$$F = \frac{EHb\sqrt{\varepsilon\mu}}{c}, \tag{13}$$

or

$$F = \frac{Sb\sqrt{\varepsilon\mu}}{c}. \tag{13a}$$

3. The Lorentz Force

Let us consider the magnetic Lorentz force, acting on a body with charge q, moving with speed v perpendicularly to the vector of magnetic inductivity B:

$$F_L = qvB. \tag{14}$$

We shall neglect the intrinsic magnetic induction field of a moving charge (compared with the induction of an external magnetic field) and its own momentum moving charge. Then we have to accept that the force (14) is caused by the flow momentum of electromagnetic field that penetrates the body of the charge. Thus from (13, 14), we obtain:

$$qvB = \frac{EHb\sqrt{\varepsilon\mu}}{c}, \tag{16}$$

or, for $B = \mu_o \mu H$,

$$qvc = \frac{Eb\sqrt{\varepsilon/\mu}}{\mu_o}, \tag{17}$$

Consequently, inside the body there should be electric field intensity directed along the velocity, and equal to

$$E = \frac{qvc\mu_o}{b\sqrt{\varepsilon/\mu}}. \tag{18}$$

Let us note that

$$c\mu_o = \sqrt{\frac{\mu_o}{\varepsilon_o}} \approx 377 \tag{19}$$

From (18, 19) we find:

$$E = \frac{qvc\mu_o}{b}\sqrt{\frac{\varepsilon}{\mu}} \approx 377\frac{qv}{b}\sqrt{\frac{\varepsilon}{\mu}}. \tag{20}$$

Consequently, **inside** a charged body, moving in a magnetic field and being under the influence of Lorentz force, there exists an intensity of electric field proportional to the movement speed.

> **The example with an Electron**
> It has a charge $q_o = 1.6 \cdot 10^{-19}$, classical radius $r_o = 2.8 \cdot 10^{-15}$, square of the central section of electron $b_o = \pi r_o^2 = 25 \cdot 10^{-30}$. Also $E_o\sqrt{\varepsilon/\mu} = 25 \cdot 10^{21} v$. One may also say that on the diameter of the electron along the speed direction, there exists a potentials difference – a voltage $U_o = 2E_o r_o = 5 \cdot 10^{22} v\sqrt{\frac{\mu}{\varepsilon}}$. Considering the arguments of Feynman [13] on the internal forces of the electron, restraining the electron charges on the surface of the sphere, we can see that this voltage is the force which "pulls" lagging charges to their place on the sphere when they move under the action of the Lorentz force

Thus, the Lorentz force can be considered as a consequence of the existence of a pulse of an electromagnetic field and the law of conservation of momentum. But at the same time, it is necessary to assume that **inside the moving** charged body there is an electric field of the form (20) proportional to the speed of movement.

So, a charged body moving at a certain speed in a magnetic field turns out to be in an electromagnetic field with

- the flow of electromagnetic energy,
- electromagnetic pulse and
- momentum flux of the electromagnetic field.

It follows from the law of conservation of momentum that the time derivative of the mechanical impulse of this body (i.e. the force acting on the body) depends on

1) the time derivative of the electromagnetic field momentum and
2) momentum flux of the electromagnetic field.

This power is the power of Lorentz.

4. The Ampere Force

Let us consider the Ampere force acting on a conductor with current I , moving with speed v perpendicularly to the vector of magnetic induction B :

$$F_A = IBL. \tag{21}$$

If this force is caused by the momentum flux of the electromagnetic field penetrating the conductor, then from (13, 21) we get:

$$IBL = \frac{EHb\sqrt{\varepsilon\mu}}{c} \tag{23}$$

or, for $B = \mu_o \mu H$,

$$IHL\mu_o\mu = \frac{EHb\sqrt{\varepsilon\mu}}{c} \tag{24}$$

Therefore, the intensity of electric field in this case will be

$$E = \frac{IL\mu_o c}{b\sqrt{\varepsilon/\mu}}. \tag{25}$$

Qualitatively, this force can be explained by the fact that free electrons lag behind the body and accumulate in the "tail" of an accelerating body — this phenomenon was considered by Feynman for an accelerating electron [13]. The electrical resistance of the material inhibits the uniform distribution of charges. It consumes extra energy. Consequently, the movement of a charged body at a constant speed occurs with the expenditure of energy for heat losses. This ensures the constancy of the energy of the electric field inside a charged body.

If the resistivity of the conductor is equal ρ and the current density is equal to j, then

$$j = I/b \tag{26}$$

and

$$E = j\rho \tag{27}$$

Then from (25-27) we get:

$$\rho = L\mu_o c\sqrt{\frac{\varepsilon}{\mu}} \tag{28}$$

or

$$c = \frac{\rho}{L\mu_o}\sqrt{\frac{\mu}{\varepsilon}}. \tag{29}$$

Consequently, the speed of propagation of electromagnetic energy in a wire under the action of the Ampere force is less than the speed of light and is determined by (29).

From the above, it follows that the Ampere force can be considered as a consequence of the existence of a flux of an electromagnetic field pulse and the law of conservation of momentum.

5. The Khmelnik Force

On the basis of formula (12), it can be argued that there is another force that for brevity we will call the Khmelnik force (if, of course, no one has yet considered this force) [18]. In particular, it can be the power of Lorentz or the power of Ampere. But in other cases, it is not equivalent to these forces. Chapter 13 examines the experiments of Tamm, Graham and Lahoz, Ivanov GP, which can be explained by the existence of this force. These experiments were performed in stationary fields, but with a variable intensity E. In [18], a mental experiment is considered that works in static fields according to formula (13). Consider it.

Let us consider fig. 1, that shows a body located inside the solenoid with **direct** current I. The body has covering electrodes under **direct** voltage U. In this case, the body creates electromagnetic stationary field with electric field intensity E and magnetic field intensity H. In the body appears a flow of electromagnetic energy with density (11), which is shown in the fig. 1 by circles. It can be presented in the form of two spheres united in a body and threading it in the vertical direction. This flow creates force (13) acting on the body.

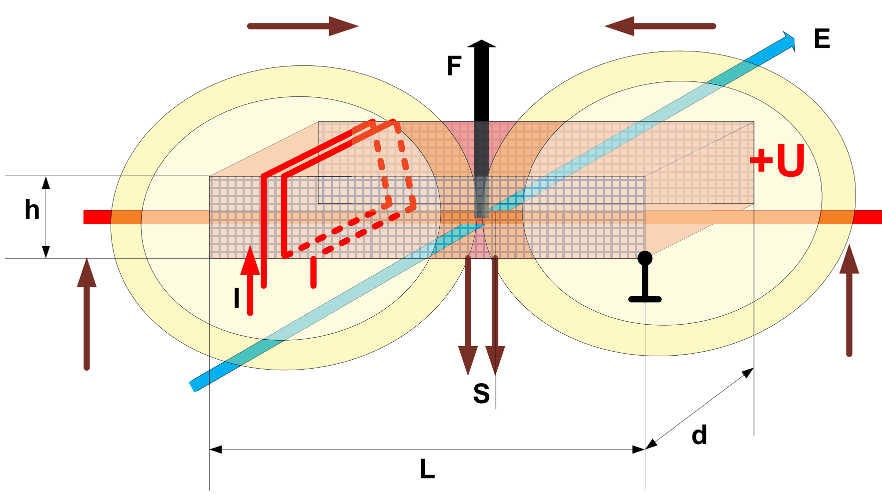

Рис. 1.

Let us consider in more detail the calculation of the force (13), using for this purpose the designations of body size, shown in fig. 1: L, d, h. Let the body be made of magnetodielectric with magnetic permeability $\mu = 400$, dielectric constant $\varepsilon = 10$, saturation induction $B = 0.5$. The magnetic intensity with maximum induction

$H = B/(\mu \cdot \mu_o) = 0.5/(400 \cdot 4\pi \cdot 10^{-7}) \approx 1000$. Let also $U = 30000,\ h = 0.2, d = 0.5$. Then $b = hd = 0.1, E = \frac{U}{d} = 15000$. Then by (13), we find:

$$F = \frac{EHb\sqrt{\varepsilon\mu}}{c} = 15000 \cdot 1000 \cdot 0.1 \cdot \frac{\sqrt{10 \cdot 400}}{c} \approx \frac{10^8}{c} \approx 0.3.$$

Thus, **we may expect that the device can be implemented**. The author suggests to experimenters to verify the generation of Khmelnik force and to supplement its name by their own names.

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