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The spiral structure of electromagnetic waves and of stationary electromagnetic fields

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I. 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. 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[1-4]. 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.

II. Characteristics of the new solution of Maxwell's equations

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.

For illustration in fig. 1 shows a helix of a given radius at which the intensities remains constant. In fig. 2 shows helix lines for different radius values. The straight lines show the geometric locations of the points with equal phase.In fig. 3 shows in Cartesian coordinates the electric E and magnetic intensities of the N wave.

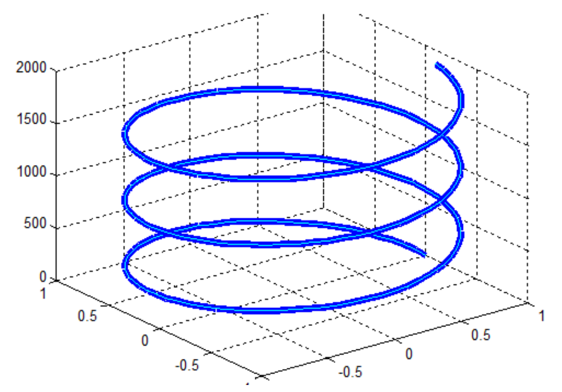

Fig. 1.

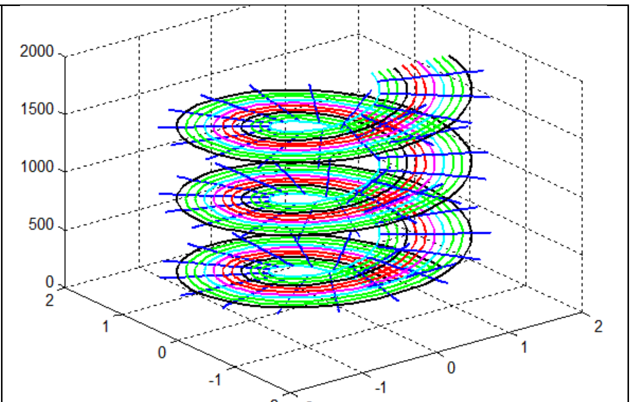

Fig. 2.

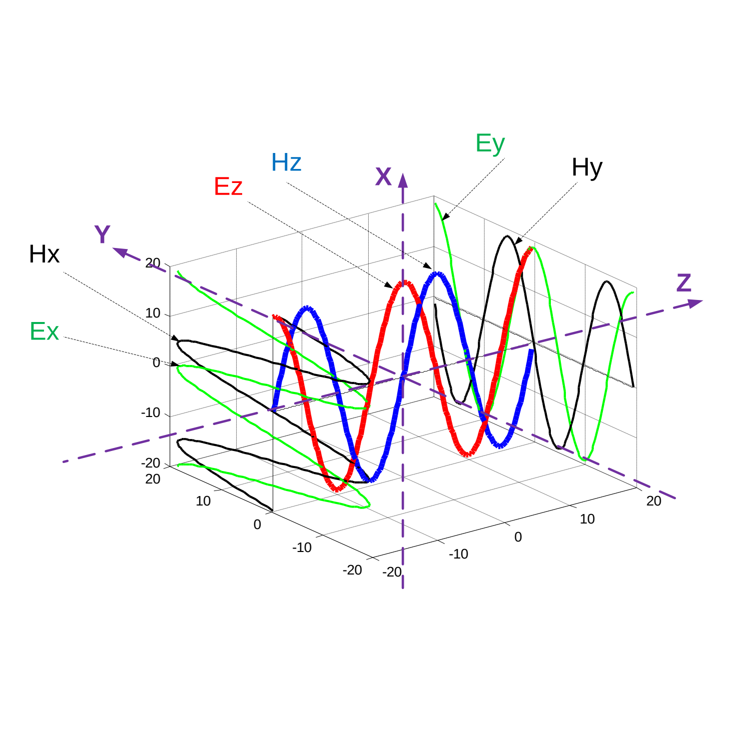

Fig. 3.

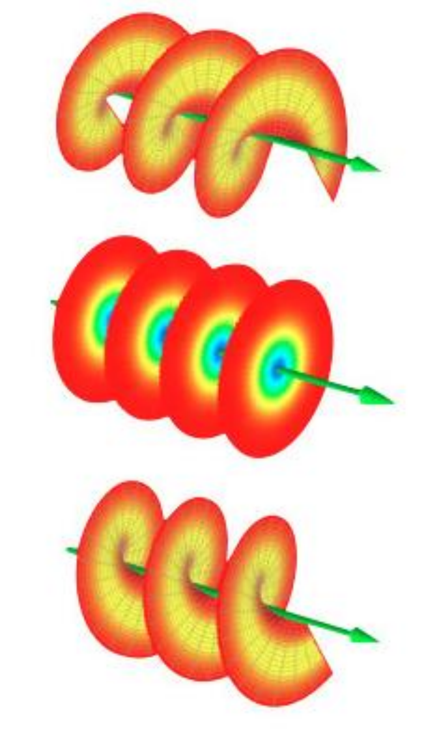

Fig. 4.

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.

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.

III. Example: cylindricalwaveinvacuum

Consider as an example the solution of the system of Maxwell equations for a cylindrical wave in the vacuum. Here the Maxwell equations in the GHS system are as follows:

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

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

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

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

where H, E is magnetic and electric intensity, respectively. In the system of cylindrical coordinates $r,\ \varphi,\ z$, these equations have the form:

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

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

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

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

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

$$\frac{1}{r}\cdot\frac{\partial H_z}{\partial \varphi}-\frac{\partial H_\varphi}{\partial z}=q\frac{dE_r}{dt}, \quad (6)$$

$$\frac{\partial H_r}{\partial z}-\frac{\partial H_z}{\partial r}=q\frac{dE_\varphi}{dt} \quad (7)$$

$$\frac{H_\varphi}{r}+\frac{\partial H_\varphi}{\partial r}-\frac{1}{r}\cdot\frac{\partial H_r}{\partial \varphi}=q\frac{dE_z}{dt}, \quad (8)$$

where

$E_r,\ E_\varphi,\ E_z$ iselectric intensity,

$H_r,\ H_\varphi,\ H_z$ ismagnetic intensity,

$$v=-\mu/c, \quad (9)$$

$$q=\varepsilon/c, \quad (10)$$

To shorten the record, we will further apply the following notation:

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

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

where $\alpha,\ \chi,\ \omega$ are some constants. We represent unknown functions in the following form:

$$H_r.=h_r(r)co, \quad (13)$$

$$H_\varphi.=h_\varphi(r)si, \quad (14)$$

$$H_z.=h_z(r)si, \quad (15)$$

$$E_r.=e_r(r)si, \quad (16)$$

$$E_\varphi.=e_\varphi(r)co, \quad (17)$$

$$E_z.=e_z(r)co, \quad (18)$$

where $h(r),\ e(r)$ are some functions of coordinate r.

By direct substitution, we can verify that functions (13-18) transform the system of equations (1-8) with four arguments $r,\ \varphi,\ z,\ t$ into a system of equations with one argument r and unknown functions $h(r),\ e(r)$. This system of equations has the following form:

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

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

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

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

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

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

$$-h_r(r)\chi-\dot{h}_z(r)+\frac{\varepsilon\omega}{c}e_\varphi(r)=0, \qquad (27)$$

$$\frac{h_\varphi(r)}{r}+\dot{h}_\varphi(r)+\frac{-h_r(r)}{r}\propto+\frac{\varepsilon\omega}{c}e_r(r)=0, \qquad (28)$$

Electromagnetic energy flux density - Poynting vector

$$S=\eta E\times H\,, \qquad (28a)$$

where

$$\eta=c/4\pi\,. \qquad (28в)$$

In cylindrical coordinates $r,\ \varphi,\ z$, the electromagnetic energy flux density has three components $S_r,\ S_\varphi,\ S_z$ directed along the radius, along the circumference, along the axis, respectively. They are determined by the formula

$$S=\begin{bmatrix}S_r\\S_\varphi\\S_z\end{bmatrix}=\eta\begin{bmatrix}E_\varphi H_z-E_zH_\varphi\\E_zH_r-E_rH_z\\E_rH_\varphi-E_\varphi H_r\end{bmatrix}. \qquad (29)$$

or, taking into account the previous formulas,

$$S_r=\eta\left(e_\varphi h_z-e_zh_\varphi\right)\mathrm{co}\cdot\mathrm{si} \qquad (30)$$

$$S_\varphi=\eta(e_zh_r\mathrm{co}^2-e_rh_z\mathrm{si}^2) \qquad (31)$$

$$S_z=\eta\left(e_rh_\varphi\mathrm{si}^2-e_\varphi h_r\mathrm{co}^2\right) \qquad (32)$$

Suppose that <u>these densities of energy flow to satisfy the energy conservation law, if</u>

$$h_r=ke_r, \qquad (33)$$

$$h_\varphi=-ke_\varphi. \qquad (34)$$

$$h_z=-ke_z. \qquad (35)$$

From (30, 34, 35) it follows that

$$S_r=\eta\left(-e_\varphi ke_z+ke_ze_\varphi\right)\mathrm{co}\cdot\mathrm{si}=0, \qquad (36)$$

i.e. no radial flow of energy.From (31, 33, 15) it follows that

$$S_\varphi=\eta(e_zke_r\mathrm{co}^2+ke_re_z\mathrm{si}^2)=\eta ke_re_z, \qquad (37)$$

i.e. the density of the energy flux along a circle at a given radius does not depend on time and other coordinates.From (32, 33, 34) it follows that

$$S_z=\eta ke_rh_\varphi(\mathrm{si}^2+\mathrm{co}^2)=\eta ke_rh_\varphi, \qquad (38)$$

i.e. vertical energy flux density at a given radius does not depend on time and other coordinates. <u>These statements were the goal of assumptions (12-14).</u>

Perform the change of variables according to (33-35) in equations (21-28) and rewrite them without changing the numbering:

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

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

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

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

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

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

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

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

It can be noted that equations (41) and (45) coincide and therefore equation (45) can be removed from the system of equations.

Further suppose that the longitudinal wave is absent, i.e. $\boldsymbol{E}_z = 0$. From here and from (18) it follows that $\boldsymbol{e_z} = \boldsymbol{0}$. Then the system of equations (41-44, 46-48) takes the form:

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

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

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

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

$$k e_\varphi \chi - \frac{\varepsilon\omega}{c} e_r = 0, \quad (46)$$

$$-k e_r \chi + \frac{\varepsilon\omega}{c} e_\varphi = 0, \quad (47)$$

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

In this system of equations, equations (44) and (48) coincide. Therefore, it is necessary to solve the system of 6 equations (41-44, 46, 47) with 5 unknowns $e_r, e_\varphi, k, \alpha, \chi$.

From (42, 46) we find

$$\frac{\mu\omega}{c} k = \frac{\varepsilon\omega}{ck} \quad (49)$$

or

$$k = \pm\sqrt{\frac{\varepsilon}{\mu}} \quad (50)$$

From (42, 50) we find

$$e_\varphi = \frac{\mu\omega}{c\chi} k e_r = \pm\frac{\omega\sqrt{\varepsilon\mu}}{c\chi} e_r. \quad (51)$$

From (43, 47) we also find (49, 50), and from (43, 50) we find

$$e_\varphi = \frac{\chi c}{k\mu\omega} e_r = \pm\frac{\chi c}{\omega\sqrt{\varepsilon\mu}} e_r. \quad (52)$$

From (51, 52) we find

$$\frac{\omega\sqrt{\varepsilon\mu}}{c\chi} = \frac{\chi c}{\omega\sqrt{\varepsilon\mu}}. \quad (53)$$

or

$$\frac{\omega\sqrt{\varepsilon\mu}}{c\chi} = \pm 1, \quad (54)$$

$$\chi = \mp\frac{\omega\sqrt{\varepsilon\mu}}{c}. \quad (55)$$

From (52, 55) we find

$$e_r = -e_\varphi, \quad (56)$$

When (56), equations (41) and (44) coincide and take the form:

$$\frac{e_\varphi}{r}(\alpha + 1) + \dot{e}_\varphi = 0. \quad (57)$$

The solution of equation (57) is

$$e_\varphi = A r^{(\alpha+1)}, \quad (58)$$

where A is some constant. Thus, for given $A,\ \alpha$ by (58, 56, 50.33, 34), it is possible to find the intensities $e_r, e_\varphi, h_r, h_\varphi$ as functions of $\boldsymbol{r}$.

Above it is shown that the radial energy flux is zero. When $e_z = 0$, it follows from (35, 37) that the flow of energy along a circle is also zero. From (35, 38, 56) we find the density of the longitudinal energy flow

$$S_z = \eta k e_r h_\varphi = -\eta k e_r k e_\varphi = \eta k^2 e_\varphi^2. \quad (59)$$

From (59, 58, 50) we find

$$S_z = \frac{\eta\varepsilon}{\mu} A^2 r^{2(\alpha+1)} \quad (60)$$

We now find the flow of energy in a cylindrical wave of radius R, which is equal to the power P carried by this wave:

$$\mathrm{P} = \int_0^{\mathrm{R}} \mathrm{S_z}\, 2\pi \mathrm{r dr} = \frac{2\pi\eta\varepsilon \mathrm{A}^2}{\mu}\int_0^{\mathrm{R}} \mathrm{r}^{(2\alpha+3)}\mathrm{dr}$$

or

$$P = -\frac{\eta\varepsilon A^2}{(2\alpha+4)\mu} R^{2\alpha+4}. \quad (61)$$

Thus, for given A, α, R by (61) it is possible to find the transmitted power P. On the other hand, for given P, R, and intensity $e_\varphi(R)$ from (61, 58) one can find A, α and then from (58, 56, 50.33, 34) find all the intensities $e_r, e_\varphi, h_r, h_\varphi$ as functions of r.

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