ROLE AND PLACE FOR THE KINETIC INDUCTANCE OF CHARGES IN CONTEMPORARY ELECTRODYNAMICS

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Abstract

The dielectric and magnetic constant of material media are the parameters, which are used during writing Maksvell equations. However, there is still one not less important material parameter, namely a kinetic inductance of charges, which has not less important role, than the parameters indicated. Unfortunately, importance and fundamentality of this parameter in the works on electrodynamics, until now, is not noted, and kinetic inductance is present in all equations of electrodynamics implicitly. This work is dedicated to the examination of the role of the kinetic inductance of charges in the electrodynamics of material media and to the restoration of its rights as the fundamental parameter, on the importance that not less meant than dielectric and magnetic constant.

1. Introduction

In the existing scientific literature occurs only the irregular references about the kinetic the inductance of charges [1-3]. However, recently appeared the works, which were directed toward the practical use of this phenomenon [4-5]. In connection with this that substantiated the posing of the question about place and role of kinetic inductance in the electrodynamics of material media appears.

The most in detail physical essence of this parameter and its place in the description of electrodynamic processes in the conductors is examined in work [4]. In this work is introduced the concept of the surface kinetic and field inductance of

$$L_K = \frac{1}{\omega |\vec{H}_T(0)|^2} \mathrm{Im} \int_0^\infty \vec{j}^* \vec{E} dz,$$

$$L_H = \frac{1}{|\vec{H}_T(0)|^2} \int_0^\infty |\vec{H}_T|^2 \, dz,$$

where L_K and L_H - surface kinetic and field inductance, $\vec{E}$ - the tension of electric field, $\vec{j}^*$ - the complexly conjugate value of current density, $\vec{H}_T$ - tension of magnetic field, $\vec{H}_T(0)$ - the value of the tension of magnetic field on the surface, ω - frequency of the applied field. These relationships are valid for the case of the arbitrary connection between the current and the field both in the normal metals and in the superconductors. They reveal the physical essence of surface kinetic and field inductance in this specific case. However, the role of this parameter in the electrodynamics of material media requires further refinements.

2. CONDUCTING MEDIA, IN WHICH BE ABSENT ACTIVE ARTERI

By plasma media we will understand such, in which the charges can move without the losses. To such media in the first approximation, can be related the superconductors, free electrons or ions in the vacuum (subsequently conductors). In the media indicated the equation of motion of electron takes the form:

$$m\frac{d\vec{v}}{dt} = e\vec{E} \text{ of },\qquad (1.2)$$

where m - mass, e - the electron charge, $\vec{E}$ - the tension of electric field, $\vec{v}$ - speed of the motion of charge. In the work [9] it is shown that this equation can be used also for describing the electron motion in the hot plasma. Therefore it can be disseminated also to this case.

Using an expression for the current density

$$\vec{j} = ne\vec{v},\qquad (2.2)$$

from (1/2) we obtain the current density of the conductivity

$$\vec{j}_L = \frac{ne^2}{m}\int \vec{E}\; dt.\qquad (2.3)$$

in relationships (2.2) and (2.3) the value n represents the specific density of charges. After introducing the designation

$$L_k = \frac{m}{ne^2}\qquad (2.4)$$

we find

$$\vec{j}_L = \frac{1}{L_k}\int \vec{E}\; dt.\qquad (2.5)$$

in this case the value L_k presents the specific kinetic inductance of charge carriers [2,10-13]. Its existence connected with the fact that charge, having a mass, possesses inertia properties.

Pour on relationship (2.5) it will be written down for the case of harmonics:

$$\vec{j}_L = -\frac{1}{\omega L_k} \vec{E}_0 \cos \omega t . \qquad (2.6)$$

For the mathematical description of electrodynamic processes the trigonometric functions will be here and throughout, instead of the complex quantities, used so that would be well visible the phase relationships between the vectors, which represent electric fields and current densities.

From relationship (2.5) and (2.6) is evident that $\vec{j}_L$ presents inductive current, since its phase is late with respect to the tension of electric field to the angle $\frac{\pi}{2}$.

If charges are located in the vacuum, then during the presence of summed current it is necessary to consider bias current

$$\vec{j}_\varepsilon = \varepsilon_0 \frac{\partial \vec{E}}{\partial t} = \varepsilon_0 \vec{E}_0 \cos \omega t .$$

Is evident that this current bears capacitive nature, since its phase anticipates the phase of the tension of electrical to the angle $\frac{\pi}{2}$. Thus, summary current density will compose [5-7]

$$\vec{j}_\Sigma = \varepsilon_0 \frac{\partial \vec{E}}{\partial t} + \frac{1}{L_k} \int \vec{E} \, dt ,$$

or

$$\vec{j}_\Sigma = \left(\omega \varepsilon_0 - \frac{1}{\omega L_k} \right) \vec{E}_0 \cos \omega t . \qquad (2.7)$$

If electrons are located in the material medium, then should be considered the presence of the positively charged ions. However, with the examination of the properties of such media in the rapidly changing fields, in connection with the fact that the mass of ions is considerably more than the mass of electrons, their presence usually is not considered. in relationship (6.7) the value, which stands in the brackets, presents summary susceptance of this medium and it consists it, in turn, of the the capacitive and by the inductive the conductivity

$$\sigma_{\Sigma} = \sigma_{C} + \sigma_{L} = \omega\varepsilon_0 - \frac{1}{\omega L_k}.$$

Relationship (2.9) can be rewritten, also, in other form

$$\vec{j}_{\Sigma} = \omega\varepsilon_0 \left(1 - \frac{\omega_0^2}{\omega^2}\right) \vec{E}_0 \cos\omega t,$$

where $\omega_0 = \sqrt{\frac{1}{L_k \varepsilon_0}}$ - plasma frequency.

And large temptation here appears to name the value

$$\varepsilon^*(\omega) = \varepsilon_0 \left(1 - \frac{\omega_0^2}{\omega^2}\right) = \varepsilon_0 - \frac{1}{\omega^2 L_k}.$$

by the depending on the frequency dielectric constant of dielectric. But this is incorrect, since this mathematical symbol is the composite parameter, into which simultaneously enters the dielectric constant of vacuum and the specific kinetic inductance of charges. is accurate another point of view. Relationship (2.7) can be rewritten and differently:

$$\vec{j}_{\Sigma} = -\frac{\left(\frac{\omega^2}{\omega_0^2} - 1\right)}{\omega L} \ \vec{E}_0 \cos \omega t \ ,$$

and to introduce another mathematical symbol

$$L*(\omega) = \frac{L_k}{\left(\frac{\omega^2}{\omega_0^2} - 1\right)} = \frac{L_k}{\omega^2 L_k \varepsilon_0 - 1} \ .$$

In this case also appears temptation to name this bending coefficient on the frequency kinetic inductance. But this value it is not possible to call inductance also, since this also the composite parameter, which includes those not depending on the frequency kinetic inductance and the dielectric constant of vacuum.

Thus

$$\vec{j}_{\Sigma} = \omega \varepsilon *(\omega) \ \vec{E}_0 \cos \omega t ,$$

or, something the very

$$\vec{j}_{\Sigma} = -\frac{1}{\omega L*(\omega)} \ \vec{E}_0 \cos \omega t \ .$$

But this altogether only the symbolic mathematical record of one and the same relationship (2.7). Both equations are completely equivalent, and separately mathematically completely is characterized the medium examined. But view neither $\varepsilon *(\omega)$ nor $L*(\omega)$ by dielectric constant or inductance are from a physical point. The physical sense of their names consists of the following:

$$\varepsilon *(\omega) = \frac{\sigma_X}{\omega} \ , \qquad (2.8)$$

i.e. $\varepsilon*(\omega)$ presents summary susceptance of medium, divided into the frequency, and

$$L_k*(\omega)=\frac{1}{\omega\sigma_X}\ ,$$

it represents the reciprocal value of the work of frequency and susceptance of medium.

As it is necessary to enter, if at our disposal are values $\varepsilon*(\omega)$ and $L*(\omega)$, and we should calculate total specific energy. Natural to substitute these values in the formulas, which determine energy of electrical pour on

$$W_E=\frac{1}{2}\varepsilon_0 E_0^2$$

and kinetic energy of charge carriers

$$W_j=\frac{1}{2}L_k j_0^2$$

is cannot simply because these parameters are neither dielectric constant nor inductance. It is not difficult to show that in this case the total specific energy can be obtained from the relationship

$$W_\Sigma=\frac{1}{2}\cdot\frac{d\left(\omega\varepsilon*(\omega)\right)}{d\omega}E_0^2 \tag{2.9}$$

from where we obtain

$$W_\Sigma=\frac{1}{2}\varepsilon_0 E_0^2+\frac{1}{2}\ \frac{1}{\omega^2 L_k}\ E_0^2=\frac{1}{2}\varepsilon_0 E_0^2+\frac{1}{2}L_k j_0^2\ . \tag{2.10}$$

We will obtain the same result, after using the formula

$$W = \frac{1}{2} \frac{d\left[\dfrac{1}{\omega L_k *(\omega)}\right]}{d\omega} E_0^2. \qquad (2.11)$$

The given relationships show that the specific energy consists of potential energy of electrical pour on and to kinetic energy of charge carriers. However, looking at relationships (2.9) and (2.11), at first glance it can seem that energy is the function only of electrical pour on.

With the examination of any media by our final task appears the presence of wave equation. In this case this problem is already practically solved. Maxwell equations for this case take the form:

$$\begin{aligned} rot\ \vec{E} &= -\mu_0 \frac{\partial\ \vec{H}}{\partial\ t}, \\ rot\ \vec{H} &= \varepsilon_0 \frac{\partial\ \vec{E}}{\partial\ t} + \frac{1}{L_k}\int \vec{E}\ dt, \end{aligned} \qquad (2.12)$$

where ε_0 and μ_0 - dielectric and magnetic constant of vacuum. System of equations (2.10) completely describes all properties of the conductors, in which be absent the ohmic losses. From it we obtain

$$rot\ rot\ \vec{H} + \mu_0\varepsilon_0 \frac{\partial^2 \vec{H}}{\partial\ t^2} + \frac{\mu_0}{L_k}\vec{H} = 0. \qquad (2.13)$$

For the case pour on, time-independent, equation (2.11) passes into London equation

$$rot\ rot\ \vec{H} + \frac{\mu_0}{L_k}\vec{H} = 0\ ,$$

where $\lambda_L{}^2 = \frac{L_k}{\mu_0}$- London depth of penetration.

Thus, it is possible to conclude that the equations of London being a special case of equation (2.11), and do not consider bias currents on Wednesday.

Pour on wave equation in this case it appears as follows for the electrical:

$$rot\ rot\ \vec{E} + \mu_0 \varepsilon_0 \frac{\partial^2 \vec{E}}{\partial t^2} + \frac{\mu_0}{L_k} \vec{E} = 0.$$

For constant electrical pour on it is possible to write down

$$rot\ rot\ \vec{E} + \frac{\mu_0}{L_k} \vec{E} = 0.$$

consequently, DC fields penetrate the superconductor in the same manner as for magnetic, diminishing exponentially. However, the density of current at each point of superconductor in this case grows according to the linear law

$$\vec{j}_C = \frac{1}{L_k} \int \vec{E}\ dt.$$

The carried out examination showed that the dielectric constant of this medium was equal to the dielectric constant of vacuum and this permeability on frequency does not depend. The accumulation of potential energy is obliged to this parameter. Furthermore, this medium is characterized still and the kinetic inductance of charge carriers and this parameter determines the kinetic energy, accumulated on Wednesday.

Thus, are obtained all necessary given, which characterize the process of the propagation of electromagnetic waves in conducting media examined. However, in contrast to the conventional procedure [5-7] with this examination nowhere was introduced polarization vector, but as the basis of examination assumed equation of motion and in this case in the second Maxwell equation are extracted all components of current densities explicitly. In this case in the second Maxwell equation are extracted all components of current densities explicitly.

Based on the example of work [5] let us examine a question about how similar problems, when the concept of polarization vector is introduced are solved for their solution. Paragraph 59 of this work, where this question is examined, it begins with the words: “We pass now to the study of the most important question about the rapidly changing electric fields, whose frequencies are unconfined by the condition of smallness in comparison with the frequencies, characteristic for establishing the electrical and magnetic polarization of substance” (end of the quotation). These words mean that that region of the frequencies, where, in connection with the presence of the inertia properties of charge carriers, the polarization of substance will not reach its static values, is examined. With the further consideration of a question is done the conclusion that “in any variable field, including with the presence of dispersion, the polarization vector $\vec{P}=\vec{D}-\varepsilon_0\vec{E}$ (here and throughout all formulas cited they are written in the system OF SI) preserves its physical sense of the electric moment of the unit volume of substance” (end of the quotation). Let us give the still one quotation: “It proves to be possible to establish (unimportantly - metals or dielectrics) maximum form of the function $\varepsilon(\omega)$ with the high frequencies valid for any bodies. Specifically, the field frequency must be great in comparison with “the frequencies” of the motion of all (or, at least, majority) electrons in the atoms of this substance. With the observance of this condition it is possible with the calculation of the polarization of substance to consider electrons as free, disregarding their interaction with each other and with the atomic nuclei” (end of the quotation).

Further, as this is done and in this work, is written the equation of motion of free electron in the ac field

$$m\frac{d\vec{v}}{dt}=e\vec{E},$$

from where its displacement is located

$$\vec{r}=-\frac{e\vec{E}}{m\omega^2}$$

then is indicated that the polarization of $\vec{P}$ is a dipole moment of unit volume and the obtained displacement is put into the polarization

$$\vec{P}=ne\vec{r}=-\frac{ne^2\vec{E}}{m\omega^2}.$$

In this case point charge is examined, and this operation indicates the introduction of electrical dipole moment for two point charges with the opposite signs, located at a distance $\vec{r}$

$$\vec{p}_e=-e\vec{r},$$

where the vector $\vec{r}$ is directed from the negative charge toward the positive charge. This step causes bewilderment, since the point electron is examined, and in order to speak about the electrical dipole moment, it is necessary to have in this medium for each electron another charge of opposite sign, referred from it to the distance $\vec{r}$. In this case is examined the gas of free electrons, in which there are no charges of opposite signs. Further follows the standard procedure, when introduced thus illegal polarization vector is introduced into the dielectric constant

$$\vec{D}=\varepsilon_0\vec{E}+\vec{P}=\varepsilon_0\vec{E}-\frac{ne^2\vec{E}}{m\omega^2}=\varepsilon_0\left(1-\frac{1}{\varepsilon_0 L_k\omega^2}\right)\vec{E} \ ,$$

and since plasma frequency is determined by the relationship

$$\omega_p{}^2=\frac{1}{\varepsilon_0 L_k},$$

the vector of the induction immediately is written

$$\vec{D}=\varepsilon_0\left(1-\frac{\omega_p{}^2}{\omega^2}\right)\vec{E} \ .$$

With this approach it turns out that constant of proportionality

$$\varepsilon(\omega)=\varepsilon_0\left(1-\frac{\omega_p{}^2}{\omega^2}\right),$$

between the electric field and the electrical induction, illegally named dielectric constant, depends on frequency.

Precisely this approach led to the fact that all began to consider that the value, which stands in this relationship before the vector of electric field, is the dielectric constant depending on the frequency, and electrical induction also depends on frequency. And this it is discussed in all, without the exception, fundamental works on the electrodynamics of material media [5-9].

But, as it was shown above this parameter it is not dielectric constant, but presents summary susceptance of medium, divided into the frequency. Thus, traditional approach to the solution of this problem from a physical point of view is erroneous, although formally this approach is completely legal from a mathematical point of view. So in the electrodynamics the concept of the dielectric constant of conductors depending on the frequency was illegally inculcated, and was born the point of view about the fact that the dielectric constant of plasma depends on frequency. The dielectric constant of vacuum in fact is the dielectric constant of plasma. And with this parameter connected pour on accumulation in the plasma of potential energy of electrical. Furthermore, plasma characterizes this physical parameter as the specific kinetic inductance of electrons, with which is connected the accumulation of kinetic inductance in this medium.

Further into §61 of work [5] is examined a question about the energy of electrical and magnetic field in the media, which possess by the so-called dispersion. In this case is done the conclusion that relationship for the energy of such pour on

$$W = \frac{1}{2}\left(\varepsilon E_0{}^2 + \mu H_0{}^2\right) \qquad (2.14)$$

that making precise thermodynamic sense in the usual media, with the presence of dispersion this interpretation is already impossible. These words mean that the knowledge of real electrical and magnetic pour on Wednesday with the dispersion insufficiently for determining the difference in the internal energy per unit of volume of substance in the presence pour on in their absence. After such statements is given the formula, which gives correct result for enumerating the specific energy of electrical and magnetic pour on when the dispersion ofis present,

$$W = \frac{1}{2}\frac{d\left(\omega\varepsilon(\omega)\right)}{d\omega}E_0^2 + \frac{1}{2}\frac{d\left(\omega\mu(\omega)\right)}{d\omega}H_0^2 , \qquad (2.15)$$

but if we compare the first part of the expression in the right side of relationship (2.15) with relationship (2.9), then it is evident that they coincide. This means that in relationship (2.15) this term presents the total energy, which includes not only potential energy of electrical pour on, but also kinetic energy of the moving charges.

Therefore conclusion about the impossibility of the interpretation of formula (2.14), as the internal energy of electrical and magnetic pour on in the media with the dispersion it is correct. However, this circumstance consists not in the fact that this interpretation in such media is generally impossible. It consists in the fact that for the definition of the value of specific energy as the thermodynamic parameter in this case is necessary to correctly calculate this energy, taking into account not only electric field, which accumulates potential energy, but also current of the conduction electrons, which accumulate the kinetic energy of charges (6.8). The conclusion, which now can be made, consists in the fact that, introducing into the custom some mathematical symbols, without understanding of their true physical sense, and, all the more, the awarding to these symbols of physical designations unusual to them, it is possible in the final analysis to lead to the significant errors, that also occurred in the work [5].

In radio engineering exists the simple method of the idea of radio-technical elements with the aid of the equivalent diagrams. This method is very visual and gives the possibility to present in the form such diagrams elements both with that concentrated and with the distributed parameters. The use of this method will allow us still better to understand, and in connection with this why were committed such significant physical errors during the introduction of this concept as the depending on the frequency dielectric constant of plasma.

In order to show that the single volume of conductor or plasma according to its electrodynamic characteristics is equivalent to parallel resonant circuit with the lumped parameters, let us examine parallel resonant circuit. For this let us examine the parallel resonant circuit, which consists of the capacity C and inductance L. The connection between the voltage U, applied to the outline, and the summed current I_{Σ}, which flows through this chain, takes the form

$$I_{\Sigma} = I_C + I_L = C\frac{dU}{dt} + \frac{1}{L}\int U\ dt \quad ,$$

where $I_C = C\frac{dU}{dt}$ - current, which flows through the capacity, and $I_L = \frac{1}{L}\int U\ dt$ - current, which flows through the inductance. for the case of the harmonic stress of we obtain

$$I_{\Sigma} = \left(\omega C - \frac{1}{\omega L}\right) U_0 \cos\omega t . \qquad (2.16)$$

in relationship (2.7) the value, which stands in the brackets, presents summary susceptance of this medium and it consists it, in turn, of the capacitive and by the inductive the conductivity

$$\sigma_{\Sigma} = \sigma_C + \sigma_L = \omega C - \frac{1}{\omega L} .$$

In this case relationship (2.5) can be rewritten as follows:

$$I_{\Sigma} = \omega C\left(1 - \frac{\omega_0^2}{\omega^2}\right) U_0 \cos \omega t\,,$$

where $\omega_0{}^2 = \dfrac{1}{LC}$ - the resonance frequency of parallel circuit.

And large temptation here appears to name the value

$$C^*(\omega) = C\left(1 - \frac{\omega_0^2}{\omega^2}\right) = C - \frac{1}{\omega^2 L}\,, \tag{2.17}$$

which is the composite parameter, the capacity depending on the frequency. Conducting this symbol it is permissible from a mathematical point of view. However, inadmissible is awarding to it the proposed name, since this parameter of no relation to the true capacity has and includes in itself simultaneously and capacity and the inductance of outline, which do not depend on frequency.

Is accurate another point of view. Relationship (2.7) can be rewritten and differently:

$$I_{\Sigma} = -\frac{\left(\frac{\omega^2}{\omega_0^2} - 1\right)}{\omega L} U_0 \cos \omega t\,,$$

and to consider that the chain in question not at all has capacities, and consists only of the inductance depending on the frequency

$$L^*(\omega) = \frac{L}{\left(\frac{\omega^2}{\omega_0^2} - 1\right)} = \frac{L}{\omega^2 LC - 1}\,. \tag{2.18}$$

But just as $C^*(\omega)$, the value $L^*(\omega)$ cannot be called inductance, since this is the also composite parameter, which includes simultaneously capacity and inductance, which do not depend on frequency.

Using expressions (2.17) and (2.18), let us write down:

$$I_\Sigma = \omega C^*(\omega)\ U_0 \cos \omega t \tag{2.19}$$

or

$$I_\Sigma = -\frac{1}{\omega L^*(\omega)}\ U_0 \cos \omega t\,. \tag{2.20}$$

Relationship (6.15) and (6.16) are equivalent, and separately mathematically completely is characterized the chain examined. But view neither $C^*(\omega)$nor $L^*(\omega)$ by capacity and inductance are from a physical point, although they have the same dimensionality. The physical sense of their names consists of the following:

$$C^*(\omega) = \frac{\sigma_X}{\omega}\ ,$$

i.e. $C^*(\omega)$ presents summary susceptance of medium, divided into the frequency, and

$$L^*(\omega) = \frac{1}{\omega \sigma_X}\ ,$$

it is the reciprocal value of the work of summary susceptance and frequency.

Accumulated in the capacity and the inductance energy, is determined from the relationships

$$W_C = \frac{1}{2} C U_0{}^2, \tag{2.21}$$

$$W_L = \frac{1}{2} L I_0^{\ 2}. \quad (2.22)$$

but how one should enter, if at our disposal are $C^*(\omega)$ and $L^*(\omega)$? Certainly, to put these relationships in formulas (2.17) and (2.18) cannot for that reason, that these values can be both the positive and negative, and the energy, accumulated in the capacity and the inductance, is always positive. But if we for these purposes use ourselves the parameters indicated, then it is not difficult to show that the summary energy, accumulated in the outline, is determined by the expressions:

$$W_\Sigma = \frac{1}{2} \frac{d\sigma_X}{d\omega} U_0^{\ 2}, \quad (2.23)$$

or

$$W_\Sigma = \frac{1}{2} \frac{d\left[\omega C^*(\omega)\right]}{d\omega} U_0^{\ 2}, \quad (2.24)$$

or

$$W_\Sigma = \frac{1}{2} \frac{d\left(\frac{1}{\omega L^*(\omega)}\right)}{d\omega} U_0^{\ 2}. \quad (2.25)$$

If we paint equations (2.19) or (2.20) and (2.21), then we will obtain identical result, namely:

$$W_\Sigma = \frac{1}{2} C U_0^{\ 2} + \frac{1}{2} L I_0^{\ 2},$$

where U_0 - amplitude of stress on the capacity, and I_0- amplitude of the current, which flows through the inductance.

If we compare the relationships, obtained for the parallel resonant circuit and for the conductors, then it is possible to see that they are identical, if we make $E_0 \to U_0$, $j_0 \to I_0$, $\varepsilon_0 \to C$ and $L_k \to L$. Thus, the single volume of conductor, with the uniform distribution of electrical pour on and current densities in it is equivalent to parallel resonant circuit with the lumped parameters indicated.

3. Transverse plasma resonance

Now let us show how the poor understanding of physics of processes in conducting media it led to the fact that proved to be unnoticed the interesting physical phenomenon transverse plasma resonance in the nonmagnetized plasma, which can have important technical appendices [5, 7, 12].

Is known that the plasma resonance is longitudinal. But longitudinal resonance cannot emit transverse electromagnetic waves. However, with the explosions of nuclear charges, as a result of which is formed very hot plasma, occurs electromagnetic radiation in the very wide frequency band, up to the long-wave radio-frequency band. Today are not known those of the physical mechanisms, which could explain the appearance of this emission. There were no other resonances of any kind, except plasma, earlier known on existence in the nonmagnetic plasma. But it occurs that in the confined plasma the transverse resonance can exist, and the frequency of this resonance coincides with the frequency of plasma resonance, i.e. these resonance are degenerate. Specifically, this resonance can be the reason for the emission of electromagnetic waves with the explosions of nuclear charges.

For explaining the conditions for the excitation of this resonance let us examine the long line, which consists of two ideally conducting planes, as shown in Fig. 1.

Linear (falling per unit of length) capacity and inductance of this line without taking into account edge effects they are determined by the relationships [10,11]: Therefore with an increase in the length of line its total capacitance of and summary inductance of increase proportional to its length.

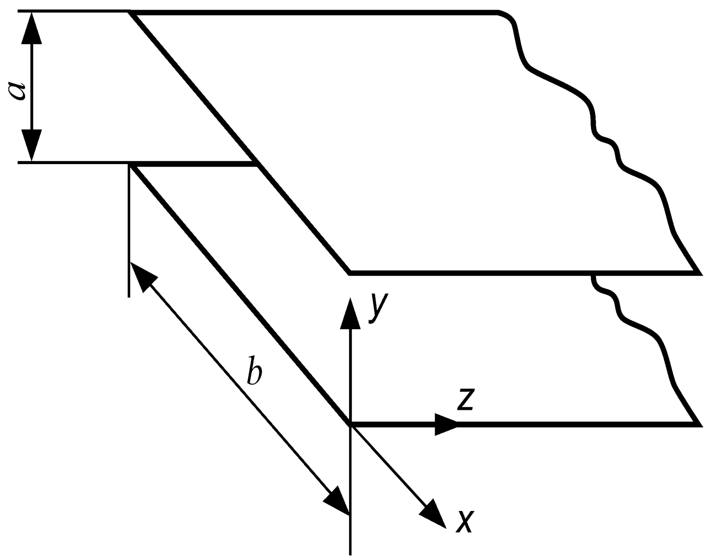


Fig. 1. The two-wire circuit, which consists of two ideally conducting planes.

If we into the extended line place the plasma, charge carriers in which can move without the losses, and in the transverse direction pass through the plasma the current I, then charges, moving with the definite speed, will accumulate kinetic energy. Let us note that here are not examined technical questions, as and it is possible confined plasma between the planes of line how. This there can be, for example, magnetic traps or directed flows of plasma. Can be considered the case of other media of such type as semiconductors. In this case only fundamental questions, which are concerned transverse plasma resonance in the nonmagnetic plasma, are examined.

Since the transverse current density in this line is determined by the relationship

$$j = \frac{I}{bz} = nev,$$

that summary kinetic energy of all moving charges will be written down

$$W_{k\Sigma} = \frac{1}{2}\ \frac{m}{ne^2}\ abzj^2 = \frac{1}{2}\ \frac{m}{ne^2}\ \frac{a}{bz} I^2. \tag{1.3}$$

Relationship (1.3) connects the kinetic energy, accumulated in the line, with the square of current therefore the coefficient, which stands in the right side of this relationship before the square of current, is the summary kinetic inductance of line.

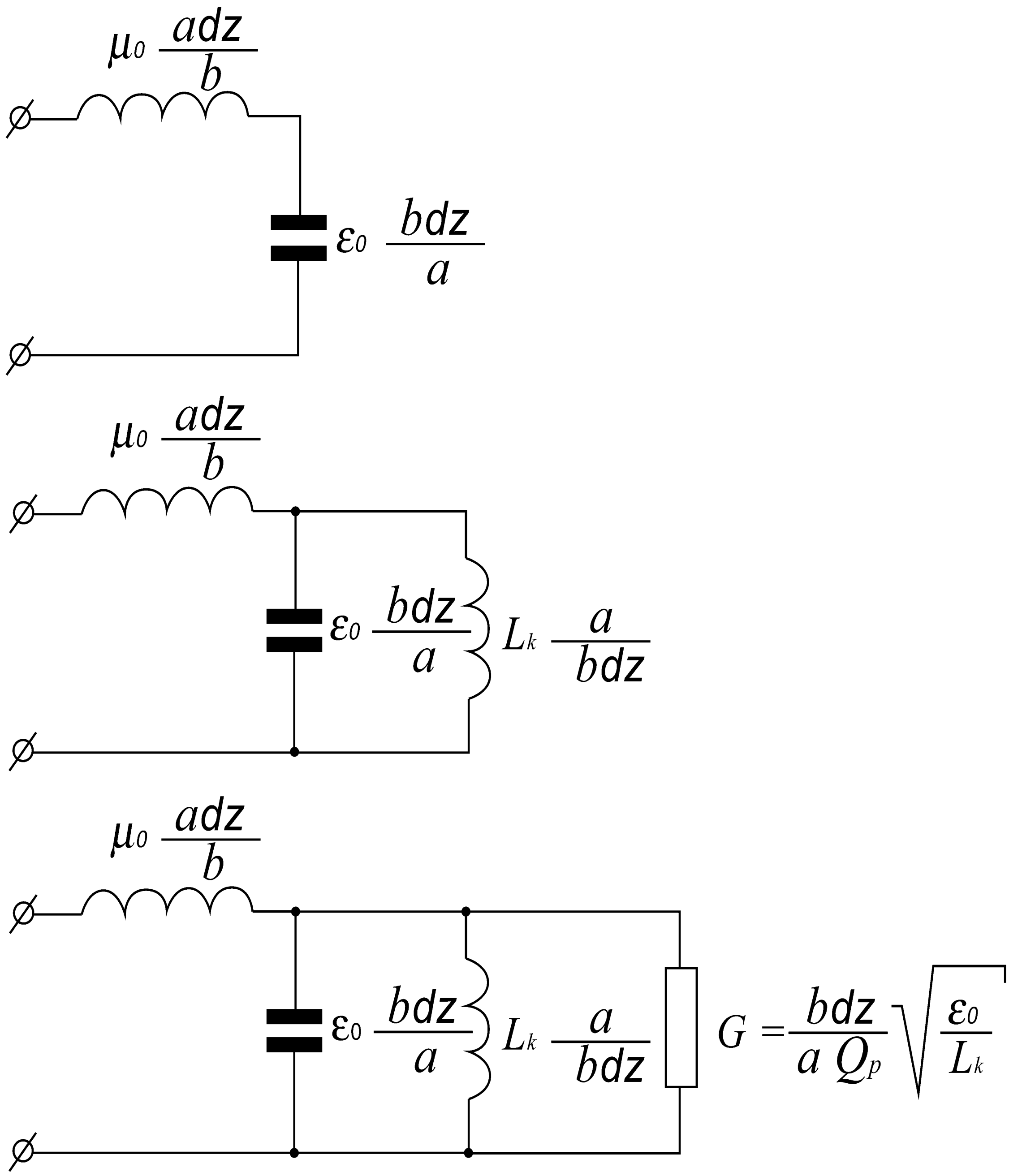
$$L_{k\Sigma} = \frac{m}{ne^2} \cdot \frac{a}{bz}. \tag{2.3}$$

Thus, the value

$$L_k = \frac{m}{ne^2} \tag{3.3}$$

presents the specific kinetic inductance of charges. We already previously introduced this value in another manner (see relationship (2.4)). Relationship (3.3) is obtained for the case of the direct current, when current distribution is uniform.

Subsequently for the larger clarity of the obtained results, together with their mathematical idea, we will use the method of equivalent diagrams. The section, the lines examined, long of dz can be represented in the form the equivalent diagram, shown in Fig. 2 (a).



а

б

в

Fig. 2. a - the equivalent the schematic of the section of two-wire circuit; b - the equivalent the schematic of the section of the two-wire circuit, filled with plasma without the losses; в - the equivalent the schematic of the section of the two-wire circuit, filled with the plasma, in which there are ohmic losses.

From the relationship (3.2) is evident that in contrast to C_Σ and L_Σ the value $L_{k\Sigma}$ with an increase in z does not increase, but it decreases. This is understandable from a physical point of view, connected this with the fact that with an increase in z a quantity of parallel-connected inductive elements grows. Line itself in this case will be equivalent to parallel circuit with the lumped parameters: $C = \frac{\varepsilon_0 bz}{a}$ and $L = \frac{L_k a}{bz}$, in series with which is connected the inductance $\mu_0 \frac{adz}{b}$.

But if we calculate the resonance frequency of this outline, then it will seem that this frequency generally not on what sizes depends, actually:

$$\omega_\rho^2 = \frac{1}{CL} = \frac{1}{\varepsilon_0 L_k} = \frac{ne^2}{\varepsilon_0 m} \quad .$$

Is obtained the very interesting result, which speaks, that the resonance frequency macroscopic of the resonator examined does not depend on its sizes. Impression can be created, that this is plasma resonance, since the obtained value of resonance frequency exactly corresponds to the value of this resonance. But it is known that the plasma resonance characterizes longitudinal waves in the long line they, while occur transverse waves. In the case examined the value of the phase speed in the direction of

z is equal to infinity and the wave vector $\vec{k} = 0$. this result corresponds to the solution of system of equations (2.12) for the line with the assigned configuration. Wave number in this case is determined by the relationship

$$k_z^2 = \frac{\omega^2}{c^2}\left(1 - \frac{\omega_\rho^2}{\omega^2}\right), \tag{3.4}$$

and the group and phase speeds

$$v_g^2 = c^2\left(1 - \frac{\omega_\rho^2}{\omega^2}\right), \tag{3.5}$$

$$v_F^2 = \frac{c^2}{\left(1 - \frac{\omega_\rho^2}{\omega^2}\right)}, \tag{3.6}$$

where $c = \left(\frac{1}{\mu_0 \varepsilon_0}\right)^{1/2}$ - speed of light in the vacuum.

For the present instance the phase speed of electromagnetic wave is equal to infinity, which corresponds to transverse resonance at the plasma frequency. Consequently, at each moment of time pour on distribution and currents in this line uniform and it does not depend on the coordinate, but current in the planes of line in the direction of is absent. This, from one side, it means that the inductance L_Σ will not have effects on electrodynamic processes in this line, but instead of the conducting planes can be used any planes or devices, which limit plasma on top and from below. Let us note that only fundamental side of a question is discussed based on this example, since, for example, gas-discharge plasma to limit for the data of purposes by planes is impossible, since. the charges will settle on these planes. Possibly, this must be plasma in the solid, or gas-discharge plasma in the magnetic trap or the plasma of nuclear explosion.

From the relationships (3.4 -3.6) it is not difficult to see that at the point of $\omega = \omega_p$ we deal concerning the transverse resonance with the infinite quality. The fact that in contrast to the plasma, this resonance is transverse, will be one can see well for the case, when the quality of this resonance does not be equal to infinity. In this case $k_z \neq 0$, and in the line will be extended the transverse wave, the direction of propagation of which will be perpendicular to the direction of the motion of charges. The examination of this task was begun from the examination of the plasma, limited from two sides by the planes of long line. But in the process of this examination it is possible to draw the conclusion that the frequency of this resonance generally on the dimensions of line does not depend. It should be noted that the fact of existence of this resonance previously was not realized and in the literature it was not described.

Let us pause at the energy processes, which occur in the line in the case of the absence of losses examined. Pour on the characteristic impedance of plasma, which gives the relation of the transverse components of electrical and magnetic, let us determine from the relationship

$$Z = \frac{E_y}{H_x} = \frac{\mu_0 \omega}{k_z} = Z_0 \left(1 - \frac{\omega_\rho^2}{\omega^2} \right)^{-1/2},$$

where $Z_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}}$ - characteristic resistance of vacuum. The obtained value of is characteristic for the transverse electrical waves in the waveguides. It is evident that when $\omega \rightarrow \omega_p$, then $Z \rightarrow \infty$, and $H_x \rightarrow 0$. When $\omega > \omega_p$ in the plasma there is electrical and magnetic component of field. The specific energy of these pour on it will be written down:

$$W_{E,H} = \frac{1}{2}\varepsilon_0 E_{0y}^2 + \frac{1}{2}\mu_0 H_{0x}^2.$$

Thus, the energy, concluded in the magnetic field, in $\left(1 - \frac{\omega_\rho^2}{\omega^2}\right)$ of times is less than the energy, concluded in the electric field. Let us note that this examination, which is traditional in the electrodynamics, is not complete, since. in this case is not taken into account one additional form of energy, namely kinetic energy of charge carriers. Occurs that pour on besides the waves of electrical and magnetic, that carry electrical and magnetic energy, in the plasma there exists even and the third - kinetic wave, which carries kinetic energy of current carriers. The specific energy of this wave is written:

$$W_k = \frac{1}{2} L_k j_0^2 = \frac{1}{2} \cdot \frac{1}{\omega^2 L_k} E_0^2 = \frac{1}{2}\varepsilon_0 \frac{\omega_\rho^2}{\omega^2} E_0^2 .$$

Consequently, the total specific energy of wave is written as

$$W_{E,H,j} = \frac{1}{2}\varepsilon_0 E_{0y}^2 + \frac{1}{2}\mu_0 H_{0x}^2 + \frac{1}{2} L_k j_0^2 .$$

Thus, for finding the total energy, by the prisoner per unit of volume of plasma, calculation only pour on E and H it is insufficient.

At the point $\omega = \omega_p$ is carried out the relationship

$$W_H = 0$$
$$W_E = W_k ,$$

i.e. magnetic field in the plasma is absent, and plasma presents macroscopic electromechanical resonator with the infinite quality, ω_p resounding at the frequency.

Since with the frequencies $\omega > \omega_p$ the wave, which is extended in the plasma, it bears on itself three forms of the energy: electrical, magnetic and kinetic, then this wave can be named electromagnetokinetich wave. Kinetic wave represents the wave of the current density $\vec{j} = \frac{1}{L_k}\int \vec{E}\, dt$. This wave is moved with respect to the electrical wave the angle $\frac{\pi}{2}$.

If losses are located, moreover completely it does not have value, by what physical processes such losses are caused, then the quality of plasma resonator will be finite quantity. For this case Maxwell equation they will take the form:

$$rot\ \vec{E} = -\mu_0 \frac{\partial \vec{H}}{\partial t},$$

$$rot\ \vec{H} = \sigma_{ef}\, \vec{E} + \varepsilon_0 \frac{\partial \vec{E}}{\partial t} + \frac{1}{L_k}\int \vec{E}\, dt.$$

The presence of losses is considered by the term $\sigma_{ef}\vec{E}$, and, using near the conductivity of the index ef, it is thus emphasized that us does not interest very mechanism of losses, but only very fact of their existence interests. The value σ_{ef} determines the quality of plasma resonator. For measuring σ_{ef} should be selected the section of line by the length z_0, whose value is considerably lower than the wavelength in the plasma. This section will be equivalent to outline with the lumped parameters:

$$C = \varepsilon_0 \frac{bz_0}{a}, \tag{8.3}$$

$$L = L_k \frac{a}{bz_0}, \tag{9.3}$$

$$G = \sigma_{\rho.ef} \frac{bz_0}{a}, \tag{10.3}$$

where G - conductivity, connected in parallel C and L.

Conductivity and quality in this outline enter into the relationship:

$G = \frac{1}{Q_\rho}\sqrt{\frac{C}{L}}$, from where, taking into account (3.8 - 3.10), we obtain

$$\sigma_{ef} = \frac{1}{Q_\rho}\sqrt{\frac{\varepsilon_0}{L_k}}. \tag{11.3}$$

Thus, measuring its own quality plasma of the resonator examined, it is possible to determine σ_{ef}. Using (3.11) and (3.7) we will obtain

$$rot\ \vec{E} = -\mu_0 \frac{\partial\, \vec{H}}{\partial\, t},$$
$$rot\ \vec{H} = \frac{1}{Q_\rho}\sqrt{\frac{\varepsilon_0}{L_k}}\ \vec{E} + \varepsilon_0 \frac{\partial\, \vec{E}}{\partial\, t} + \frac{1}{L_k}\int \vec{E}\ dt. \qquad (3.12)$$

The equivalent schematic of this line, filled with dissipative plasma, is represented in Fig. 2 в.

Let us examine the solution of system of equations (3.12) at the point $\omega = \omega_p$, in this case, since

$$\varepsilon_0 \frac{\partial\, \vec{E}}{\partial\, t} + \frac{1}{L_k}\int \vec{E}\ dt = 0,$$

we obtain

$$rot\ \vec{E} = -\mu_0 \frac{\partial\, \vec{H}}{\partial\, t},$$
$$rot\ \vec{H} = \frac{1}{Q_P}\sqrt{\frac{\varepsilon_0}{L_k}}\ \vec{E}.$$

These relationships determine wave processes at the point of resonance.

4. Dielectrics

In the existing literature there are no indications that the kinetic inductance of charge carriers plays some role in the electrodynamic processes in the dielectrics. However, this not thus. This parameter in the electrodynamics of dielectrics plays not less important role, than in the electrodynamics of conductors.

Let us examine the simplest case, when oscillating processes in atoms or molecules of dielectric obey the law of mechanical oscillator [10].

$$\left(\frac{\beta}{m}-\omega^2\right)\vec{r}_m=\frac{e}{m}\vec{E}, \tag{4.1}$$

where $\vec{r}_m$ - deviation of charges from the position of equilibrium, β - coefficient of elasticity, which characterizes the elastic electrical binding forces of charges in the atoms and the molecules. Introducing the resonance frequency of the bound charges

$$\omega_0=\frac{\beta}{m},$$

we obtain from (4.1)

$$\vec{r}_m=-\frac{e\ \vec{E}}{m(\omega^2-\omega_o^2)}. \tag{4.2}$$

Is evident that in relationship (4.2) as the parameter is present the natural vibration frequency, into which enters the mass of charge. This speaks, that the inertia properties of the being varied charges will influence oscillating processes in the atoms and the molecules.

Since the general current density on Wednesday consists of the bias current and conduction current

$$rot\vec{H}=\vec{j}_\Sigma=\varepsilon_0\frac{\partial\vec{E}}{\partial t}+ne\vec{v},$$

finding the speed of charge carriers in the dielectric as the derivative of their displacement through the coordinate

$$\vec{v} = \frac{\partial r_m}{\partial t} = -\frac{e}{m(\omega^2 - \omega_o^2)} \frac{\partial \vec{E}}{\partial t},$$

from relationship (4.2) we find

$$rot\vec{H} = \vec{j}_\Sigma = \varepsilon_0 \frac{\partial \vec{E}}{\partial t} - \frac{1}{L_{kd}(\omega^2 - \omega_0{}^2)} \frac{\partial \vec{E}}{\partial t}. \quad (4.3)$$

But the value

$$L_{kd} = \frac{m}{ne^2}$$

presents the kinetic inductance of the charges, entering the constitution of atom or molecules of dielectrics, when to consider charges free. Therefore relationship (4.3) it is possible to rewrite

$$rot\vec{H} = \vec{j}_\Sigma = \varepsilon_0 \left(1 - \frac{1}{\varepsilon_0 L_{kd}(\omega^2 - \omega_0{}^2)} \right) \frac{\partial \vec{E}}{\partial t}. \quad (4.4)$$

But, since the value

$$\frac{1}{\varepsilon_0 L_{kd}} = \omega_{pd}{}^2$$

it represents the plasma frequency of charges in atoms and molecules of dielectric, if we consider these charges free, then relationship (4.4) takes the form:

$$rot\vec{H} = \vec{j}_\Sigma = \varepsilon_0 \left(1 - \frac{\omega^2{}_{pd}}{(\omega^2 - \omega_0{}^2)} \right) \frac{\partial \vec{E}}{\partial t} \quad (4.5)$$

To appears temptation to name the value

$$\varepsilon^*(\omega)=\varepsilon_0\left(1-\frac{\omega^2{}_{pd}}{(\omega^2-\omega_0{}^2)}\right) \tag{4.6}$$

by the depending on the frequency dielectric constant of dielectric. But this, as in the case conductors, cannot be made, since this is the composite parameter, which includes now those not already three depending on the frequency of the parameter: the dielectric constant of vacuum, the natural frequency of atoms or molecules and plasma frequency for the charge carriers, entering their composition.

Let us examine two limiting cases:

If $\omega \ll \omega_0$, then from (4.5) we obtain

$$rot\vec{H}=\vec{j}_\Sigma=\varepsilon_0\left(1+\frac{\omega_{pd}{}^2}{\omega_0{}^2}\right)\frac{\partial\vec{E}}{\partial t}. \tag{4.7}$$

In this case the coefficient, confronting the derivative, does not depend on frequency, and it presents the static dielectric constant of dielectric. As we see, it depends on the natural frequency of oscillation of atoms or molecules and on plasma frequency. This result is intelligible. Frequency in this case proves to be such small that the inertia properties of charges it is possible not to consider, and bracketed expression in the right side of relationship (4.7) presents the static dielectric constant of dielectric. Hence immediately we have a prescription for creating the dielectrics with the high dielectric constant. In order to reach this, should be in the assigned volume of space packed a maximum quantity of molecules with maximally soft connections between the charges inside molecule itself.

The case, when $\omega \gg \omega_0$, is exponential. then

$$rot\vec{H} = \vec{j}_{\Sigma} = \varepsilon_0 \left(1 - \frac{{\omega_{pd}}^2}{\omega^2}\right)\frac{\partial \vec{E}}{\partial t},$$

and dielectric is converted in conductor (plasma) since. The obtained relationship coincides with the case of plasma.

One cannot fail to note the circumstance that in this case again nowhere was used this concept as polarization vector, but examination is carried out by the way of finding the real currents in the dielectrics on the basis of the equation of motion of charges in these media. In this case as the parameters are used the electrical characteristics of the media, which do not depend on frequency.

From relationship (4.5) is evident that in the case of fulfilling the equality of $\omega = \omega_0$, the amplitude of fluctuations is equal to infinity. This indicates the presence of resonance at this point. The infinite amplitude of fluctuations occurs because of the fact that they were not considered losses in the resonance system, in this case its quality was equal to infinity. In a certain approximation it is possible to consider that lower than the point indicated we deal concerning the dielectric, whose dielectric constant is equal to its static value. Higher than this point we deal already actually concerning the metal, whose density of current carriers is equal to the density of atoms or molecules in the dielectric.

Now it is possible to examine the question of why dielectric prism decomposes polychromatic light into monochromatic components or why rainbow is formed. So that this phenomenon would occur, it is necessary to have the frequency dispersion of the phase speed of electromagnetic waves in the medium in question. If we to relationship (4.5) add the first Maxwell equation, then we will obtain:

$$rot\vec{E} = -\mu_0 \frac{\partial \vec{H}}{\partial t}$$
$$rot\vec{H} = \varepsilon_0 \left(1 - \frac{\omega^2{}_{pd}}{(\omega^2 - \omega_0{}^2)} \right) \frac{\partial \vec{E}}{\partial t} \quad . \tag{4.7}$$

That we will obtain the wave equation

$$\nabla^2 \vec{E} = \mu_0 \varepsilon_0 \left(1 - \frac{\omega_{pd}{}^2}{\omega^2 - \omega_0{}^2} \right) \frac{\partial^2 \vec{E}}{\partial t^2} .$$

If one considers that

$$\mu_0 \varepsilon_0 = \frac{1}{c^2}$$

where c - speed of light, then no longer will remain doubts about the fact that with the propagation of electromagnetic waves in the dielectrics the frequency dispersion of phase speed will be observed. But this dispersion will be connected not with the fact that this material parameter as dielectric constant, it depends on frequency. In the formation of this dispersion it will participate immediately three, which do not depend on the frequency, physical quantities: the self-resonant frequency of atoms themselves or molecules, the plasma frequency of charges, if we consider it their free, and the dielectric constant of vacuum.

Now let us show, where it is possible to be mistaken, if with the solution of the examined problem of using a concept of polarization vector. Let us introduce polarization vector in the dielectric similarly, as this was done for the conductors, after taking the mixing of bound charge from relationship (4.2)

$$\vec{P} = -\frac{ne^2}{m}\cdot\frac{1}{(\omega^2-\omega_0^2)}\vec{E}.$$

The dependence of polarization vector on the frequency, is connected with the presence of mass in charges and their inertness does not make possible for this vector accurately to follow the electric field, reaching that value, which it has in the permanent fields. Since the electrical induction is determined by the relationship:

$$\vec{D}=\varepsilon_0\vec{E}-\frac{ne^2}{m}\cdot\frac{1}{(\omega^2-\omega_0^2)}\vec{E}. \qquad (4.8)$$

That introduced thus electrical induction depends on frequency. But the real significance of this parameter earlier is already examined.

If introduced thus electrical induction was introduced into the second equation of Maxwell, then it signs the form:

$$rot\vec{H} = j_\Sigma = \varepsilon_0\frac{\partial\vec{E}}{\partial t}+\frac{\partial\vec{P}}{\partial t}$$

or

$$rot\vec{H} = j_\Sigma = \varepsilon_0\frac{\partial\vec{E}}{\partial t}-\frac{ne^2}{m}\frac{1}{(\omega^2-\omega_0^2)}\frac{\partial\vec{E}}{\partial t} \qquad (4.9)$$

where j_Σ - the summed current, which flows through the model. In expression (4.9) the first member of right side presents bias current in the vacuum, and the second - current, connected with the presence of bound charges in atoms or molecules of dielectric. In this expression again appeared the specific kinetic inductance of the charges, which participate in the oscillating process

$$L_{kd} = \frac{m}{ne^2} .$$

this kinetic inductance determines the inductance of bound charges. Taking into account this relationship (4.9) it is possible to rewrite

$$rot\vec{H} = j_{\Sigma} = \varepsilon_0 \frac{\partial \vec{E}}{\partial t} - \frac{1}{L_{kd}} \frac{1}{(\omega^2 - \omega_0{}^2)} \frac{\partial \vec{E}}{\partial t} .$$

Thus, is obtained relationship coinciding with relationship (4.3). Consequently, the eventual result of examination by both methods coincides, and from a mathematical point of view of any claims to the method, with which the polarization vector is introduced, no. But from a physical point of view, and especially in the part of the awarding to the parameter, introduced in accordance with relationship (4.8) of the designation of electrical induction, are large claims, which we discussed. Is certain, this not electrical induction, but the certain composite parameter. But, without having been dismantled at the essence of a question, all, until now, consider that the dielectric constant of dielectrics depends on frequency. And about this written in all literary sources, beginning from the Great Soviet Encyclopedia and concluding by any electrotechnical reference book. In the essence, physically substantiated is the introduction to electrical induction in the dielectrics only in the static electric fields.

for the purpose of the decrease of the size of the article we will not here carry out computations for establishing the equivalent electrical schematic of dielectric. These questions are examined in works [5-7]. let us show that the equivalent the schematic of dielectric presents the sequential resonant circuit, whose inductance is the kinetic inductance of , and capacity is equal to the static dielectric constant of dielectric minus the capacity of the equal dielectric constant of vacuum. In this case outline itself proves to be that shunted by the capacity, equal to the specific dielectric constant of vacuum.

5. Conclusion

This examination showed that this parameter as the kinetic inductance of charges characterizes any electromagnetic processes in the material media, be it conductors or dielectrics. It has the same fundamental value as the dielectric and magnetic constant of medium. Why this parameter has not yet been allotted its proper place? This is due to the fact that physics is often used to thinking mainly mathematical concepts, not much delving into the essence of the physical processes themselves. However very creator Maksvell equations considered that these parameters on frequency do not depend, but they are fundamental constants. As the idea of the dispersion of dielectric and magnetic constant was born, and what way it was past, sufficiently colorfully characterizes quotation from the monograph of well well-known specialists in the field of physics plasma [4]: “J. itself. Maxwell with the formulation of the equations of the electrodynamics of material media considered that the dielectric and magnetic constants are the constants (for this reason they long time they were considered as the constants). It is considerably later, already at the beginning of this century with the explanation of the optical dispersion phenomena (in particular the phenomenon of rainbow) J. Heaviside and R.Vul showed that the dielectric and magnetic constants are the functions of frequency. But very recently, in the middle of the 50's, physics they came to the conclusion that these values depend not only on frequency, but also on the wave vector. On the essence, this was the radical breaking of the existing ideas. It was how a serious, is characterized the case, which occurred at the seminar L. D. Landau into 1954. During the report A. I. Akhiezer on this theme of Landau suddenly exclaimed, after smashing the speaker: ” This is delirium, since the refractive index cannot be the function of refractive index”. Note that this said L. D. Landau - one of the outstanding physicists of our time” (end of the quotation).

Is now clear that rights Maksvell, and, as it was shown above, the dielectric constant of material media on frequency does not depend. However, in a number of fundamental works on electrodynamics [5-9] are committed conceptual, systematic and physical errors, as a result of which in physics they penetrated and solidly in it were fastened such metaphysical concepts as the frequency dispersion of the dielectric constant of material media and, in particular, plasma. The propagation of this concept to the dielectrics led to the fact that all began to consider that also the dielectric constant of dielectrics also depends on frequency. These physical errors penetrated in all spheres of physics and technology.

The same concept, as kinetic inductance, until now, is located in the shadow and thus far there is no understanding the fact that this parameter in the electrodynamics of material media not is less important than dielectric and magnetic constant, and without it is impossible competent, physically substantiated, the description of material media.

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