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Physical and Effective Electrodynamic Parameters of the Material Media

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Physical and Effective Electrodynamic Parameters of the Material Media

F. F. Mende [α] & A. S. Dubrovin [σ]

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I. Introduction

The classical electrodynamics of material media is one of the most important branches of physics not only on its theoretical, but also, in not smaller measure, to practical significance. Nevertheless, the traditional study even of this basic for it problem, as the frequency dispersion of electromagnetic waves [1-5], it does not manage without essential omissions and weak places.It is widely-known that physics is the quantitative science, based on the physical experiment, which is rested on the measurements, i.e., the comparison of the characteristics of the phenomena with the specific standards being investigated. For this in physics are introduced physical quantities, physical units of their measurement and meters. The experimentally obtained quantitative dependences make it possible to use mathematical methods for their working and to build the theoretical, i.e., mathematical models of the studied phenomena. Fundamental component of mathematical model are the functional dependences, which mutually connect different variables of the model accepted.

Such variables can be not only the physical quantities, but also the parameters of the mathematical model (briefly – the mathematical parameters), which play in the model auxiliary role. Mathematical models allow, among entire other, to quantitatively formulate (i.e., to formulate in the language of mathematics) physical laws, but in this case it is important that during the writing of physical law it is possible to use only physical quantities as the variab. This makes it possible to examine the physical sense of laws, since the mathematical parameters, in contrast to the physical quantities, are not allotted by physical sense. In particular, the mathematical parameter can be expressed by the complex number (for example, the complex dielectric constant, utilized in the method of complex amplitudes), while physical quantity cannot be complex-valued (for example, the relative dielectric constant of medium). The given examples are trivial, but in cases when the sequential analysis of the physical sense of dependences is difficult, confusion in the differentiation of the physical quantities and mathematical parameters can app ear.

By all is well known this phenomenon as rainbow. To any specialist in the electrodynamics it is clear that the appearance of rainbow is connected with the dependence on the frequency of the phase speed of the electromagnetic waves, passing through the drops of rain. Since water is dielectric, with the explanation of this phenomenon Heaviside and Vul assumed that this dispersion was connected with the frequency dispersion (dependence on the frequency) of the dielectric constant of water. Since then this point of view is ruling [1-6].

Let us recall that the relative dielectric constant of medium – this is the physical quantity, which characterizes the dielectric properties of medium and which shows, by how many times the force of interaction of two electric charges in this medium is less than in the vacuum. However, frequency characterizes separate monochromatic component of electromagnetic wave and straight relation to the electric field a charge it does not have. Consequently, speaking about the frequency dispersion of dielectric constant, Heaviside and Vul had in the form a dependence on the frequency not of the physical quantity of the relative dielectric constant of medium, but some new mathematical parameter.

Certainly, to avoid confusion, better there would be this dielectric constant to name other (for example, by effective dielectric constant), similarly, as complex dielectric constant is not called relative dielectric constant. But for some reason these famous scientists of this did not make, apparently, simply hoping for the fact that misunderstandings it will not be. Especially

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because already Maxwell noted [7], that relative dielectric constant it is constant.

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 of plasma [1]: “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) Heaviside and 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 I. D. Landau into 1954 during the report of 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 I. D. Landau - one of the outstanding physicists of our time” (end of the quotation). It is incomprehensible from the given quotation, that precisely had in the form Landau. However, its subsequent publications speak, that it accepted this concept [2]. And again for some reason, following Heaviside and Vul, Landau did not introduce new name for the new mathematical parameter. Hardly this outstanding physicist XX of century could not understand this obvious thing, that the discussion deals precisely with the new mathematical parameter. It is faster, so it considered that misunderstandings it will not be.

However, a similar examination occurred in a number of fundamental works on electrodynamics [2-6], as a result what in physics solidly it was fastened this concept 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 ideas about the fact that their dielectric constant also depends on frequency. There is the publications of such well-known scholars as the Drudes, Heaviside, Landau, Ginsburg, Akhiezer, Tamm [2-6], where it is indicated that the dielectric constant of plasma and dielectrics depends on frequency.

Unfortunately, this caused many misunderstandings. Thus, many specialists cannot believe in the fact that the physical quantity of the relative dielectric constant of plasma is equal to the relative dielectric constant of vacuum, but the dispersion of the physical quantity of the dielectric constant of dielectrics is absent. However, main negative moment here lies in the fact that is not accentuated the attention of researchers in the urgency of the improvement of the mathematical models of the dispersion of electromagnetic waves in the direction of passage from the examination of the mathematical parameter by the name of dielectric constant to the examination of the physical quantity of relative dielectric constant.

The construction of such models of dispersion is possible only on the basis of a fundamental understanding of the physical sense of the proceeding processes. But precisely such models can describe those aspects of the phenomena, which previously proved to be inaccessible for the theoretical studies. Further we will show how the proper determination of the role and position for the kinetic inductance of charges in the electrodynamics it allows with the examination of the phenomenon of the dispersion of electromagnetic waves to limit to the use only of physical quantity of the relative dielectric constant of medium without the attraction of the corresponding mathematical parameters.

Contemporary electrodynamics in general form uses the conventional concept of the tensor of complex dielectric constant (tensor of magnetic permeability for the anisotropic media, including of those limited, it is ambiguously determined and it is not necessary), which considers frequency (temporary) and spatial dispersion. In the electrically isotropic media the tensor degenerates into scalar. If the dimensions of electrodynamic system are much greater the dimensions of the heterogeneity of field (wavelength of emission), then it is possible to disregard the effects of spatial dispersion and to examine only temporary dispersion. Let us further limit to the examination of precisely this special case.

II. Plasmo-Like and Conducting Media

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 absence magnetic field in the media indicated equation of motion for the electrons takes the form:

$$m\frac{d\mathbf{v}}{dt}=e\mathbf{E}\,, \tag{2.1}$$

Where m - mass electron, e - electron charge, $\mathbf{E}$ - tension of electric field, $\mathbf{v}$ - speed of the motion of charge.

`In this equation is considered that the electron charge is negative. In [15] it is shown that this equation can be disseminated to the case of electron motion in the hot plasma.

Using an interrelation of the current densities and electrons

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

from (2.1) we obtain the current density of the conductivity

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

After introducing the accordingly [8-12] specific kinetic inductance of charge carriers, whose existence is connected with the inertia properties of massive charge carriers,

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

let us write down equality (2.3) in the form

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

The relationship (2.5) it will be written down for the case of harmonicsfields $\mathbf{E}=\mathbf{E}_0\sin\omega t$:

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

Here and throughout, as a rule, is used not the complex, but actual form of the record of electrodynamic formulas because of its clarity for the reflection of the phase relationships between the vectors, which represent electric fields and current densities.

From relationship (6.5) and (6.6) is evident that $\mathbf{j}_L$ presents inductive current, since. its phase is late with respect to the tension of electric field to the angle $\pi/2$.

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

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

Is evident that this current bears capacitive nature, since. its phase anticipates the phase of the tension of electrical to the angle $\pi/2$. Thus, summary current density will compose [10-15]:

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

or pour on for the case of harmonics

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

If electrons are located in the material medium, then in the general case should be still considered the presence of the positively charged ions, but rapidly changing in the particular case pour on their presence it is possible not to consider in connection with the significant exceeding of the mass of the ions above the mass of electrons.

In (2.7) value in the brackets is summary susceptance of medium σ_Σ, that folding from the capacitive σ_C and σ_L inductive susceptance

$$\sigma_\Sigma=\sigma_C+\sigma_L=\omega\varepsilon_0-\frac{1}{\omega L_k}.$$

Relationship (2.7) can be rewritten and differently:

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

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

The scalar quantity thus came out

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

which in the scientific literature, in particular, in the works on physics of plasma [1-6], is named the dielectric constant of plasma. If we treat this value, as the absolute dielectric constant of plasma in the sense that its relation to the electrical constant gives the physical quantity of the relative dielectric constant of plasma, then it will come out that the physical quantity of relative dielectric of the permeability of plasma depends on frequency. In the previous paragraph it was noted, that this is erroneous, and the obtained value is the certain mathematical parameter, which must be distinguished from the absolute and relative dielectric constant. In contrast to the absolute dielectric constant, which is conveniently called also in the more expanded version of designation physical absolute dielectric constant, the introduced value let us name effective absolute dielectric constant. It is analogous, in contrast to the relative dielectric constant, which is conveniently called also in the more expanded version of designation physical relative dielectric constant, let us name the ratio of the introduced value to the electrical constant effective relative dielectric constant. If the physical absolute and relative dielectric constants of medium do not depend on frequency, then the effective absolute and relative dielectric constants of medium on frequency depend.

It is important to note that the effective absolute dielectric constant of plasma proved to be the composite mathematical parameter, into which simultaneously enters electrical constant and specific kinetic inductance of the charges [16-18].

For further concrete definition of the examination of the dispersion of electromagnetic waves let us determine the concepts of the physical dielectric constants of medium (absolute and relative) for the case of variables pour on. Entering the Maxwell second equation summary current density (subsequently for the brevity we will use word "current" instead of "current density") in any medium is added only from following three components, which depend on the electric field:

1) The current of resistance losses there will be in-phase to electric field.
2) Hhepermittance current, called bias current (is determined by first-order derivative of electric field by the time and anticipates the tension of electric field on the phase on $\pi/2$);
3) The conduction current, determined by integral of the electric field from the time, will lag behind the electric field on the phase on $\pi/2$.

All these components must be present in any nonmagnetic regions with the heat losses. Therefore it is completely natural, the dielectric constant of any medium to define as the coefficient, confronting that term, which is determined by the derivative of electric field by the time in the second equation of Maxwell. In this case one should consider that this dielectric constant cannot be negative in connection with the fact that through it it is determined energy of electrical pour on, but energy is always non-negative. Accordingly, physical relative dielectric constant is equal to the ratio of physical absolute dielectric constant to the electrical constant. Let us generally note that both for the effective and for the physical dielectric constant acts the trivial general rule – the relative permeability is always equal to the ratio of absolute permeability to the electrical constant, so that word "absolute" or "relative" we will for the brevity as far as possible omit.

The proposed mathematical model of the dispersion of electromagnetic waves in the plasma is differed from the previously known the fact that not the effective, but physical dielectric constant of plasma is used. This becomes possible due to the calculation of the kinetic inductance of charges on the basis of the deep understanding of the physical sense of dispersion. As a result, the proposed model makes it possible to consider initial conditions during the solution of integrodifferential equation for the current by means of the introduction to the appropriate integration constant.

However, the physical dielectric constant of plasma in the ac fields is not determined with the traditional examination and even current is not spread to the bias current and the conduction current, one of which is determined electrical constant and derivative of electric field, but another is determined by specific kinetic inductance and integral of the electric field. To a certain degree this "dumping of currents into the total heap" is justified, since derivative and integral of the function of harmonic oscillation are distinguished only by sign. Let us emphasize that from a mathematical point of view to reach in the manner that it entered to Landau, it is possible, but in this case is lost the integration constant, which is necessary to account for initial conditions during the solution of the equation, which determines current density in the material medium.

The separation of currents in the proposed model makes it possible to better understand physics of phenomenon. One of these two antiphase competing currents depends on frequency linearly, another – it is inversely proportional to frequency. The conduction current predominates with the low frequencies, the bias current, on the contrary, predominates with the high. At the plasma current frequency are equal and enter into the resonance with each other.

Analogous with introduction to effective dielectric constant it is possible to introduce the effective (different from the physical) kinetic inductance depending on the frequency

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

after writing down relationship (2.7) in the form:

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

The parameters $\varepsilon^*(\omega)$, $L^*(\omega)$ make it possible to write down (2.7) in two equivalent forms:

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

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

The first of these parameters is equal to the ratio of summary susceptance of medium to the frequency, and the second is equal to the reciprocal value of the work of frequency and of susceptance of the medium:

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

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

$$W_j = \frac{1}{2} L_k j_0^2 , \qquad (2.8)$$

it is simple because in these formulas not the effective, but corresponding physical quantities figure. It is not difficult to show that in this case the total specific energy can be obtained from the relationship of

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

from which we obtain

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

We will obtain the same result, after using the formula

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

The given relationships show that the specific energy consists of potential energy of electrical pour on and to kinetic energy of charge carriers.

Wave equation follows from the appropriate system of Maxwell equations, which completely describes the electrodynamics of the non dissipative conductors:

$$\operatorname{rot} \mathbf{E} = -\mu_0 \frac{\partial \mathbf{H}}{\partial t}, \qquad \operatorname{rot} \mathbf{H} = \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t} + \frac{1}{L_k}\int \mathbf{E}dt , \qquad (2.10)$$

where ε_0 and μ_0 – electrical and magnetic constants. We obtain from (2.10):

$$\operatorname{rot}\ \operatorname{rot} \mathbf{H} + \mu_0\varepsilon_0 \frac{\partial^2 \mathbf{H}}{\partial t^2} + \frac{\mu_0}{L_k}\mathbf{H} = 0 \qquad (2.11)$$

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

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

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

Thus, it is possible to conclude that the equations of London being a special case of equation (6.11), and do not consider bias currents on medium. Therefore they do not give the possibility to obtain the wave equations, which describe the processes of the propagation of electromagnetic waves in the superconductors.

For the electrical pour on the wave equation of signs the form:

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

For the variable electrical pour on we have:

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

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

$$\mathbf{j}_L = \frac{1}{L_k}\int \mathbf{E}dt .$$

It is evident from the developed mathematical model of dispersion that the physical absolute dielectric constant of this medium is connected with the accumulation of potential energy, it does not depend on frequency and it is equal to the physical absolute dielectric constant of vacuum, i.e., by electrical constant. Furthermore, this medium is characterized still and the kinetic inductance of charge carriers and this parameter determines the kinetic energy, accumulated on medium.

Thus, in contrast to the conventional procedure [2-4] of the examination of the process of the propagation of electromagnetic waves in non dissipative conducting media, the proposed procedure does not require the introduction of polarization vector, but equation of motion is assumed as the basis of examination in it, and in this case in the Maxwell second equation are extracted all components of current densities explicitly.

For further understanding of physical nature of the phenomenon of dispersion we will use the simple radio-technical method of equivalent diagrams, which makes it possible to clearly present in the form such diagrams not only radio-technical elements with the concentrated and distributed parameters, but also material media. As it will be shown below, according to this method, 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 with the parallel connection of 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

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

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Where $I_C = C\frac{dU}{dt}$, $I_L = \frac{1}{L}\int U dt$ – the currents, which flow through the capacity and the inductance respectively.

We obtain for the alternating voltage according to the harmonic $U = U_0 \sin \omega t$ law

$$I_\Sigma = \left(\omega C - \frac{1}{\omega L}\right) U_0 \cos \omega t \,. \qquad (2.12)$$

In (2.12) value in the brackets there is summary susceptance σ_Σ of chain, which consists of the capacitive σ_C and σ_L inductive susceptance

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

In this case relationship (2.12) can be rewritten as follows:

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

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

As in the case conductors, it is possible to introduce the new mathematical parameter of the effective capacity

$$C^*(\omega) = C\left(1 - \frac{\omega_0^2}{\omega^2}\right) = C - \frac{1}{\omega^2 L} \qquad (2.13)$$

depending on the frequency, capacity and even inductance and susceptance of chain to the frequency equal to relation. And it is again necessary this mathematical parameter to distinguish from the physical capacity, which is conventionally designated as simply the capacity, and which is not the mathematical parameter, but physical quantity.

Relationship (2.12) can be rewritten and differently:

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

after introducing the new mathematical parameter of the effective inductance

$$L^*(\omega) = \frac{L}{\left(\frac{\omega^2}{\omega_0^2} - 1\right)} = \frac{L}{\omega^2 LC - 1} \,. \qquad (2.14)$$

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

Using expressions (2.13, 2.14), let us write down:

$$I_\Sigma = \omega C^*(\omega)\; U_0 \cos \omega t \,, \qquad (2.15)$$

$$I_\Sigma = -\frac{1}{\omega L^*(\omega)}\; U_0 \cos \omega t \,. \qquad (2.16)$$

Relationships (2.15) and (2.16), using the different parameters $C^*(\omega)$ and $L^*(\omega)$, they are equivalent, and each of them completely characterizes chain.

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

$$W_C = \frac{1}{2} C U_0{}^2 \,, \qquad (2.17)$$

$$W_L = \frac{1}{2} L I_0{}^2 \,. \qquad (2.18)$$

It is interesting that if we into the formulas (2.17, 2.18) instead of the physical of capacity and inductance substitute the appropriate effective values (2.13, 2.14), that it will come out that energy can be negative. The so-called problem of negative energy, which is inherent in a whole series of the mathematical models of frequency dispersion, including to Klein-Gordon equations for the scalar massive particles and Dirac for the fermions in quantum physics, appears. However, in the case of parallel resonant circuit it is obvious that the problem indicated is obliged to its appearance to the incorrect replacement of physical quantities to the appropriate effective mathematical parameters. This gives the specific orientators for the more in-depth research of the problem of negative energy in the different models of the frequency dispersion, including of quantum, but these questions already they exceed the scope of the thematics of this monograph.

It is easy to see that the summary energy, accumulated in the outline, can be expressed by the mutually equivalent equalities:

$$W_\Sigma = \frac{1}{2}\frac{d\sigma_X}{d\omega} U_0{}^2 \,, \qquad (2.19)$$

$$W_\Sigma = \frac{1}{2}\frac{d\left[\omega C^*(\omega)\right]}{d\omega} U_0{}^2 \,, \qquad (2.20)$$

$$W_\Sigma = \frac{1}{2}\frac{d\left(\frac{1}{\omega L^*(\omega)}\right)}{d\omega} U_0{}^2 \,. \qquad (2.21)$$

Any of the equalities (2.19 - 2.21) gives the identical result:

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

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

Thus, parallel resonant circuit can be mathematically simulated from three mutually equivalent points of view:

1) physical capacity and physical inductance form
2) outline; outline is described by the frequency-dependent effective capacity;
3) outline is described by the frequency-dependent effective inductance.

In the quasi-static regime electrodynamic processes in the conductors are similar to processes in the parallel resonant circuit with the lumped parameters. Relationships for the parallel resonant circuit are identical to relationships for the conductors during the replacement: $E_0 \to U_0$, $j_0 \to I_0$, $\varepsilon_0 \to C$, $L_k \to L$. Thus, the single volume of conductor, with the uniform distribution of electrical pour on and current densities in it, it is equivalent to parallel resonant circuit with the lumped parameters indicated. In this case the capacity of this outline is numerically equal to the dielectric constant of vacuum, and inductance is equal to the specific kinetic inductance of charges.

This approach does not require introduction into the examination of polarization vector in the conductors in contrast to the conventional procedure [2-5]. In particular, the paragraph 59 of work [2] 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 $\mathbf{P} = \mathbf{D} - \varepsilon_0 \mathbf{E}$ (here and throughout all formulas cited they are written in the system 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 of $\varepsilon(\omega)$ 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

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

from where its displacement is located

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

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

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

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 $\mathbf{r}$

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

where the vector $\mathbf{r}$ 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 $\mathbf{r}$. 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

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

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

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

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, named dielectric constant, depends on frequency, and following it and electrical induction was declared depending on the frequency
[2-6]. But, as it was shown above, this mathematical parameter is not physical absolute dielectric constant, but ratio of summary susceptance of medium to the frequency.

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

$$W=\frac{1}{2}\left(\varepsilon E_0{}^2+\mu H_0{}^2\right), \qquad (2.22)$$

that making precise thermodynamic sense in the usual media, with the presence of dispersion so interpreted be cannot. These words mean that the knowledge of real electrical and magnetic pour onmedium 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 this assertion is given the formula, which gives the same result for enumerating the specific energy of electrical and magnetic pour on with the presence of dispersion, that also the proposed in this monograph approach:

$$W=\frac{1}{2}\frac{d\left(\omega\varepsilon(\omega)\right)}{d\omega}E_0^2+\frac{1}{2}\frac{d\left(\omega\mu(\omega)\right)}{d\omega}H_0^2. \qquad (2.23)$$

First term in the right side (2.23) corresponds (2.9), and it means it is the total energy, which includes not only potential energy of electrical pour on, but also kinetic energy of the moving charges. This confirms conclusion about the impossibility of the interpretation precisely of formula (2.22), as the internal energy of electrical and magnetic pour on in the dispersive media, although this interpretation in the media in principle examined is possible. 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 kinetic energy of charges (6.8).

III. Transverse Plasma Resonance

The development of the mathematical model of the dispersion of electromagnetic waves in conducting media, the using a physical dielectric constant plasma, make it possible to advance the theoretically substantiated hypothesis about existence of new physical phenomenon. It can be named transverse plasma resonance in the nonmagnetized plasma. This phenomenon not only is of great theoretical interest, but also can have the important technical applications [20, 21].

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. On existence in the nonmagnetized plasma of any other resonances, except Langmuir, earlier known it was not, but it occurs that in the confined plasma the transverse resonance can exist, and the frequency of this resonance coincides with the frequency of Langmuir resonance, i.e., these razonansy 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.

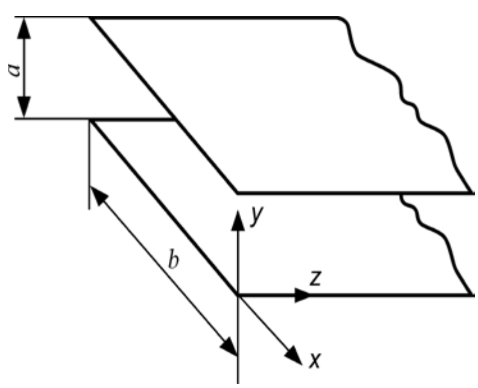

Fig. 2 : The two-wire circuit, which consists of two ideally conducting planes.

Linear (falling per unit of length) capacity and inductance of this line without taking into account edge effects they are determined by the relationships:

$$C_0=\varepsilon_0\frac{b}{a} \text{ and } L_0=\mu_0\frac{a}{b}.$$

Therefore with an increase in the length of line its total capacitance $C_\Sigma=\varepsilon_0\frac{b}{a}z$ and summary inductance $L_\Sigma=\mu_0\frac{a}{b}z$ increase proportional to its length.

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. 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 the moving charges can be written down

$$W_{k\Sigma} = \frac{1}{2}\frac{m}{ne^2}abzj^2 = \frac{1}{2}\frac{m}{ne^2}\frac{a}{bz}I^2. \qquad (3.1)$$

Relationship (3.1) 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.

$$L_{k\Sigma} = \frac{m}{ne^2}\cdot\frac{a}{bz}. \qquad (3.2)$$

Thus, the value

$$L_k = \frac{m}{ne^2} \qquad (3.3)$$

presents the specific kinetic inductance of charges. Relationship (7.3) 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 dz can be represented in the form the equivalent diagram, shown in Fig. 2 (a).

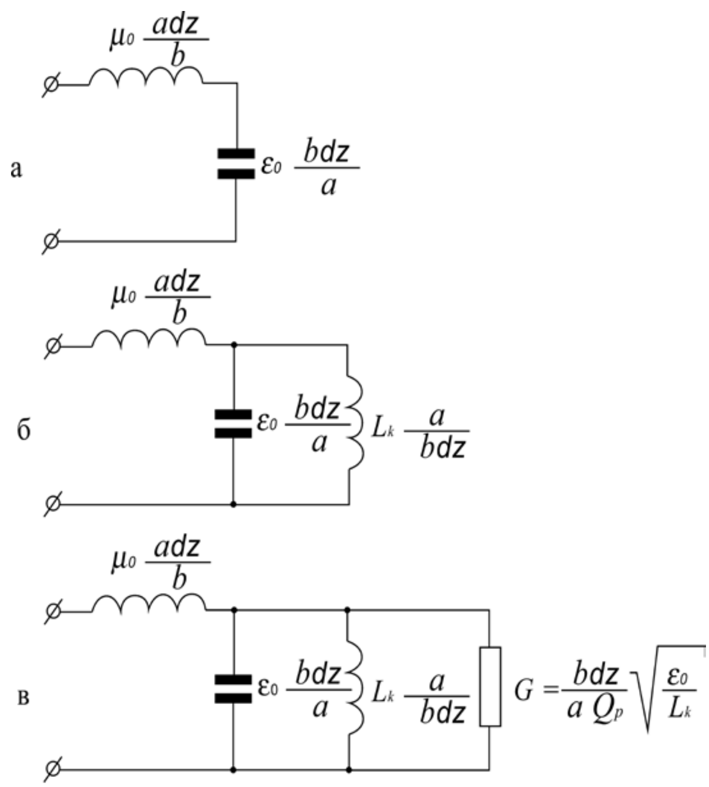

Fig. 3 : a - and the equivalent the schematic of the section of the two-wire circuit:

б - the equivalent the schematic of the section of the two-wire circuit, filled with nondissipative plasma;
в - the equivalent the schematic of the section of the two-wire circuit, filled with dissipative plasma.

From relationship (3.2) is evident that in contrast to C_Σ, L_Σ the value $L_{k\Sigma}$ with an increase in Z does not increase, but it decreases. Is connected this with the fact that with the increase Z a quantity of parallel-connected inductive elements grows.

The equivalent the schematic of the section of the line, filled with nondissipative plasma, it is shown in Fig. 3 б. The Line itself in this case will be equivalent to parallel circuit with the lumped parameters:

$$C = \frac{\varepsilon_0 bz}{a},$$

$$L = \frac{L_k a}{bz}$$

in series with which is connected the inductance

$$\mu_0 \frac{adz}{b}.$$

The resonance frequency of this outline takes the form:

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

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 z is equal to infinity and the wave vector $\vec{k} = 0$.

This result corresponds to the solution of system of equations (2.10) for the line with the assigned configuration. In this case the squares of wave number, group and phase speed are determined by the relationships:

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

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

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

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 of , 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.

From relationships (3.4 - 3.6) is evident that at the point $\omega = \omega_p$ occurs the transverse resonance with the infinite quality. With the presence of losses in the resonator will occur the damping, and in the long line in this case $k_z \neq 0$, and in the line will be extended the damped transverse wave, the direction of propagation of which will be normal to the direction of the motion of charges. It should be noted that the fact of existence of this resonance is not described by other authors.

Before to pass to the more detailed study of this problem, 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 of $Z_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}}$ - characteristic (wave) resistance of vacuum.

The obtained value Z is characteristic for the transverse electrical waves in the waveguides. With $\omega \to \omega_p$ we have: $Z \to \infty$, $H_x \to 0$. When $\omega > \omega_p$ in the plasma there is electrical and magnetic component of field. The specific energy of these pour on it takes the form:

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

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. This examination is traditional in the electrodynamics, but is not considered 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 takes the form:

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

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 of are 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 electric magnetic kinetic wave. Kinetic wave is the wave of the current density $\mathbf{j} = \frac{1}{L_k}\int \mathbf{E} dt$. This wave is moved with respect to the electrical wave the angle $\pi / 2$.

Until now considered physically unrealizable case where there are no losses in the plasma, which corresponds to an infinite quality factor plasma resonator. 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 of Maxwell's equation they will take the form:

$$\text{rot}\,\mathbf{E} = -\mu_0 \frac{\partial \mathbf{H}}{\partial t},. \qquad (3.7)$$
$$\text{rot}\,\vec{H} = \sigma_{p.ef}\,\mathbf{E} + \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t} + \frac{1}{L_k}\int \mathbf{E}dt.$$

The presence of losses is considered by the term $\sigma_{p.ef}\mathbf{E}$. In this case designation ef emphasizes the importance of the very fact of existence of losses, but not their concrete mechanism. The value σ_{ef} determines the quality of plasma resonator. For measuring σ_{ef} should be selected the section of line by the length of z_0, whose value is considerably lower than the wavelength in the plasma. This section will be equivalent to outline with the lumped parameters:

$$C = \varepsilon_0 \frac{bz_0}{a}, \qquad (3.8)$$

$$L = L_k \frac{a}{bz_0}, \qquad (3.9)$$

$$G = \sigma_{\rho.ef} \frac{bz_0}{a}, \qquad (3.10)$$

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

$$\sigma_{\rho.ef} = \frac{1}{Q_\rho}\sqrt{\frac{\varepsilon_0}{L_k}}. \qquad (3.11)$$

Thus, measuring its own quality plasma of the resonator examined, it is possible to determine $\sigma_{p.ef}$. Using (3.2) and (3.11) we will obtain

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

The equivalent the 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 in this case

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

we obtain

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

These relationships determine wave processes at the point of resonance.

If losses in the plasma, which fills line are small, and strange current source is connected to the line, then it is possible to assume:

$$\text{rot}\,\mathbf{E} \cong 0, \qquad (3.13)$$
$$\frac{1}{Q_p}\sqrt{\frac{\varepsilon_0}{L_k}}\mathbf{E} + \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t} + \frac{1}{L_k}\int \mathbf{E}dt = \mathbf{j}_{CT},$$

where $\mathbf{j}_{CT}$ - density of strange currents.

After integrating (7.13) with respect to the time and after dividing both parts to ε_0, we will obtain

$$\omega_p^2\,\mathbf{E} + \frac{\omega_p}{Q_p}\cdot\frac{\partial \mathbf{E}}{\partial t} + \frac{\partial^2 \mathbf{E}}{\partial t^2} = \frac{1}{\varepsilon_0}\cdot\frac{\partial \mathbf{j}_{CT}}{\partial t}. \qquad (3.14)$$

If we relationship (3.14) integrate over the surface of normal to the vector $\mathbf{E}$ and to introduce the electric flux $\Phi_E = \int \mathbf{E}d\mathbf{s}$ we will obtain:

$$\omega_p^2 \Phi_E + \frac{\omega_p}{Q_p}\cdot\frac{\partial \Phi_E}{\partial t} + \frac{\partial^2 \Phi_E}{\partial t^2} = \frac{1}{\varepsilon_0}\cdot\frac{\partial I_{CT}}{\partial t}, \qquad (3.15)$$

where I_{CT} - strange current.

The equation (3.15) is the equation of harmonic oscillator with the right side, characteristic for the two-level laser [15]. If the source of excitation was opened, then relationship (3.14) presents “cold” laser resonator, in which the fluctuations will attenuate exponentially

$$\Phi_E(t) = \Phi_E(0)\; e^{i\omega_P t}\cdot e^{-\frac{\omega_P}{2Q_P}t},$$

i.e. it will oscillate macroscopic $\Phi_E(t)$ electric flux with the frequency ω_p. Relaxation time in this case is determined by the relationship:

$$\tau = \frac{2Q_P}{\omega_P} .$$

The problem of developing of laser consists to now only in the skill excite this resonator.

If resonator is excited by strange currents, then this resonator presents band-pass filter with the resonance frequency to equal plasma frequency and the passband $\Delta\omega = \frac{\omega_p}{2Q_p}$.

Another important practical application of transverse plasma resonance is possibility its use for warming-up and diagnostics of plasma. If the quality of plasma resonator is great, then can be obtained the high levels of electrical pour on, and it means high energies of charge carriers.

IV. Magnetic Materials

If we consider all components of current density in the conductor, then the Maxwell second equation can be written down:

$$\mathrm{rot}\,\mathbf{H} = \sigma_E \mathbf{E} + \varepsilon \frac{\partial \mathbf{E}}{\partial t} + \frac{1}{L_k}\int \mathbf{E}dt , \qquad (4.1)$$

where σ_E - conductivity of metal.

At the same time, the Maxwell first equation can be written down as follows:

$$\mathrm{rot}\,\mathbf{E} = -\mu \frac{\partial \mathbf{H}}{\partial t} \qquad (4.2)$$

where μ - magnetic permeability of medium. It is evident that equations (4.1) and (4.2) are asymmetrical.

To somewhat improve the symmetry of these equations are possible, introducing into equation (4.2) term linear for the magnetic field, that considers heat losses in the magnetic materials in the variable fields:

$$\mathrm{rot}\,\mathbf{E} = -\sigma_H \mathbf{H} - \mu \frac{\partial \mathbf{H}}{\partial t} , \qquad (4.3)$$

where σ_H - conductivity of magnetic currents. But here there is no integral of such type, which is located in the right side of equation (4.1), in this equation. At the same time to us it is known that the atom, which possesses the magnetic moment $\mathbf{m}$, placed into the magnetic field, and which accomplishes in it precessional motion, has potential energy $U_m = -\mu\mathbf{mH}$. Therefore potential energy can be accumulated not only in the electric fields, but also in the precessional motion of magnetic moments, which does not possess inertia. Similar case is located also in the mechanics, when the gyroscope, which precesses in the field of external gravitational forces, accumulates potential energy. Regarding mechanical precessional motion is also noninertial and immediately ceases after the removal of external forces. For example, if we from under the precessing gyroscope, which revolves in the field of the earth's gravity, rapidly remove support, thus it will begin to fall, preserving in the space the direction of its axis, which was at the moment, when support was removed. The same situation occurs also for the case of the precessing magnetic moment. Its precession is noninertial and ceases at the moment of removing the magnetic field.

Therefore it is possible to expect that with the description of the precessional motion of magnetic moment in the external magnetic field in the right side of relationship (4.3) can appear a term of the same type as in relationship (4.1). It will only stand L_k, i.e., instead C_k the kinetic capacity[23,24], which characterizes that potential energy, which has the precessing magnetic moment in the magnetic field:

$$\mathrm{rot}\,\mathbf{E} = -\sigma_H \mathbf{H} - \mu \frac{\partial \mathbf{H}}{\partial t} - \frac{1}{C_k}\int \mathbf{H}dt . \qquad (4.4)$$

For the first time this idea of the first equation of Maxwell taking into account kinetic capacity was given in the work [25].

Let us explain, can realize this case in practice, and that such in this case kinetic capacity. Resonance processes in the plasma and the dielectrics are characterized by the fact that in the process of fluctuations occurs the alternating conversion of electrostatic energy into the kinetic kinetic energy of charges and vice versa. This process can be named electric kinetic and all devices: lasers, masers, filters, etc, which use this process, can be named electric kinetic. At the same time there is another type of resonance - magnetic. If we use ourselves the existing ideas about the dependence of magnetic permeability on the frequency, then it is not difficult to show that this dependence is connected with the presence of magnetic resonance. In order to show this, let us examine the concrete example of ferromagnetic resonance. If we magnetize ferrite, after applying the stationary field H_0 in parallel to the axis z, the like to relation to the external variable field medium will come out as anisotropic magnetic material with the complex permeability in the form of tensor [26]

$$\mu = \begin{pmatrix} \mu_T *(\omega) & -i\,\alpha & 0 \\ i\,\alpha & \mu_T *(\omega) & 0 \\ 0 & 0 & \mu_L \end{pmatrix} ,$$

where

$$\mu_T*(\omega)=1-\frac{\Omega\ |\gamma|\ M_0}{\mu_0(\omega^2-\Omega^2)},\qquad \alpha=\frac{\omega\ |\gamma|\ M_0}{\mu_0(\omega^2-\Omega^2)},\qquad \mu_L=1$$

moreover

$$\Omega=|\gamma|\,H_0 \tag{4.4}$$

is natural frequency of precession, and

$$M_0=\mu_0(\mu-1)H_0 \tag{4.5}$$

is a magnetization of medium. Taking into account (4.4) and (4.5) for $\mu_T*(\omega)$, it is possible to write down

$$\mu_T*(\omega)=1-\frac{\Omega^2(\mu-1)}{\omega^2-\Omega^2}. \tag{4.6}$$

It came out that magnetic permeability of magnetic material depends on frequency, and appears the assumption that this case must be examined analogously with the case with the plasma.

If we consider that the electromagnetic wave is propagated along the axis x and there are components pour on H_y of and H_z, then in this case the Maxwell first equation will be written down:

$$rot\mathbf{E}=\frac{\partial \mathbf{E}_Z}{\partial x}=\mu_0\mu_T\frac{\partial \mathbf{H}_y}{\partial t}.$$

Taking into account (4.6), we will obtain

$$\mathrm{rot}\,\mathbf{E}=\mu_0\left[1-\frac{\Omega^2(\mu-1)}{\omega^2-\Omega^2}\right]\frac{\partial \mathbf{H}_y}{\partial t}.$$

for the case of $\omega>>\Omega$ we have

$$\mathrm{rot}\,\mathbf{E}=\mu_0\left[1-\frac{\Omega^2(\mu-1)}{\omega^2}\right]\frac{\partial \mathbf{H}_y}{\partial t}. \tag{4.7}$$

assuming $H_y=H_{y0}\sin\omega t$ and taking into account that in this case

$$\frac{\partial \mathbf{H}_y}{\partial t}=-\omega^2\int \mathbf{H}_y\,dt,$$

we obtain from (4.7)

$$\mathrm{rot}\,\mathbf{E}=\mu_0\frac{\partial \mathbf{H}_y}{\partial t}+\mu_0\,\Omega^2(\mu-1)\int \mathbf{H}_y\,dt,$$

or

$$\mathrm{rot}\,\mathbf{E}=\mu_0\frac{\partial \mathbf{H}_y}{\partial t}+\frac{1}{C_k}\int \mathbf{H}_y\,dt. \tag{4.8}$$

for the case $\omega<<\Omega$ we find

$$\mathrm{rot}\,\mathbf{E}=\mu_0\mu\frac{\partial \mathbf{H}_y}{\partial t}.$$

Value

$$C_k=\frac{1}{\mu_0\,\Omega^2(\mu-1)},$$

which is introduced in relationship (4.8), let us name kinetic capacity.

With which is connected existence of this parameter, and its what physical sense? If the direction of magnetic moment does not coincide with the direction of external magnetic field, then the vector of this moment begins to precess around the vector of magnetic field with the frequencyΩ. The magnetic moment of $\mathbf{m}$ possesses in this case potential energy $U_m=-\mathbf{m}\cdot\mathbf{B}$. This energy similar to energy of the charged capacitor is potential, because precessional motion, although is mechanical, however, it not inertia and instantly it does cease during the removal of magnetic field. However, with the presence of magnetic field precessional motion continues until the accumulated potential energy is spent, and the vector of magnetic moment will not become parallel to the vector of magnetic field.

The equivalent diagram of the case examined is given in Fig. (3) At the point $\omega=\Omega$ occurs magnetic resonance, in this case $\mu_T*(\omega)\to-\infty$. The resonant frequency ofthe macroscopic magneticresonatoris easily seenfromthe equivalent circuitis also independent ofthe size oflines andequal to Ω..Thus, the parameter

$$\mu_H*(\omega)=\mu_0\left[1-\frac{\Omega^2(\mu-1)}{\omega^2-\Omega^2}\right]$$

is the frequency dependent magnetic permeability, but it is the combined parameter, including μ_0, μ и C_k, which are included on in accordance with the equivalent diagram, depicted in Fig. 4.

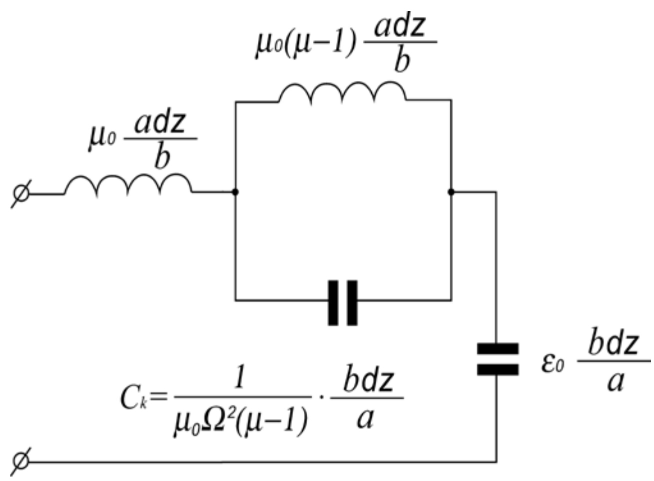

Fig. 3 : Equivalent the schematic of the two-wire circuit of that filled with magnetic material.

Is not difficult to show that in this case there are three waves: electrical, magnetic and the wave, which carries potential energy, which is connected with the precession of magnetic moments around the vector H_0. For this reason such waves can be named electric magnetic potentsial wave. Before the appearance of a work [25] in the electrodynamics this concept, as kinetic capacity it was not used, although this the real parameter has very intelligible physical interpretation.

V. 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. This not thus [27-28]. 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 [28]. Let us write down the equation of motion

$$\left(\frac{\beta}{m}-\omega^2\right)\mathbf{r}_m=\frac{e}{m}\mathbf{E}\,, \qquad (5.1)$$

where $\mathbf{r}_m$ - 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 (5.1):

$$\mathbf{r}_m=-\frac{e\,\mathbf{E}}{m(\omega^2-\omega_o^2)}\,. \qquad (5.2)$$

Is evident that in relationship (9.2) 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

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

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

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

from relationship (5.2) we find

$$\mathrm{rot}\,\mathbf{H}=\mathbf{j}_\Sigma=\varepsilon_0\frac{\partial\mathbf{E}}{\partial t}-\frac{1}{L_{kd}(\omega^2-\omega_0{}^2)}\frac{\partial\mathbf{E}}{\partial t}\,. \qquad (5.3)$$

Let us note that 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 (5.3) it is possible to rewrite

$$\mathrm{rot}\,\mathbf{H}=\mathbf{j}_\Sigma=\varepsilon_0\left(1-\frac{1}{\varepsilon_0L_{kd}(\omega^2-\omega_0{}^2)}\right)\frac{\partial\mathbf{E}}{\partial t}\,. \qquad (5.4)$$

Since the value

$$\frac{1}{\varepsilon_0L_{kd}}=\omega_{pd}{}^2$$

it represents the plasma frequency of charges in atoms and molecules of dielectric, if we consider these charges free, then relationship (5.4) takes the form:

$$\mathrm{rot}\,\mathbf{H} = \mathbf{j}_\Sigma = \varepsilon_0 \left(1 - \frac{\omega^2{}_{pd}}{(\omega^2 - \omega_0{}^2)} \right) \frac{\partial \mathbf{E}}{\partial t}. \qquad (5.5)$$

And again it is possible to name the value

$$\varepsilon^*(\omega) = \varepsilon_0 \left(1 - \frac{\omega^2{}_{pd}}{(\omega^2 - \omega_0{}^2)} \right) \qquad (5.6)$$

by the effective dielectric constant of dielectric. It furthermore depends on frequency. But this mathematical parameter is not the physical dielectric constant of dielectric, but has composite nature. It includes now those not already three depending on the frequency of the value: electrical constant, natural frequency of atoms or molecules and plasma frequency for the charge carriers, entering their composition, if we consider charges free.

Let us examine two limiting cases:

1. $\omega << \omega_0$,then from (5.5) we obtain

$$\mathrm{rot}\,\mathbf{H} = \mathbf{j}_\Sigma = \varepsilon_0 \left(1 + \frac{\omega_{pd}{}^2}{\omega_0{}^2} \right) \frac{\partial \mathbf{E}}{\partial t}. \qquad (5.7)$$

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 low that the charges manage to follow the field and their inertia properties do not influence electrodynamic processes. In this case the bracketed expression in the right side of relationship (5.7) 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. 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.

2. The case, when $\omega >> \omega_0$ is exponential. In this case

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

and dielectric became conductor (plasma) since. the obtained relationship exactly coincides with the equation, which describes 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 in this mathematical model as the initial electrical characteristics of medium are used the values, which do not depend on frequency.

From relationship (5.5) 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. For this the phase speed of electromagnetic waves in the medium in question must depend on frequency (frequency wave dispersion). If we to relationship (5.5) add the Maxwell first equation, then we will obtain:

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

$$\mathrm{rot}\,\mathbf{H} = \varepsilon_0 \left(1 - \frac{\omega^2{}_{pd}}{(\omega^2 - \omega_0{}^2)} \right) \frac{\partial \mathbf{E}}{\partial t},$$

from where we immediately find the wave equation:

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

If one considers that

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

where c - the speed of light, then is easy to see that in the dielectrics the frequency dispersion occurs. But this dependence of phase speed on the frequency is connected not with the dependence of physical dielectric constant on the 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 the weak places of the traditional approach, based on the use of a concept of polarization vector,

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

Its dependence on the frequency, is connected with the presence of mass in the charges, entering the constitution of atom and molecules of dielectrics. The inertness of charges is not allowed for this vector, following the electric field, to reach that value, which it would have in the permanent fields. Since the electrical induction is determined by the relationship:

$$\mathbf{D} = \varepsilon_0\mathbf{E} + \mathbf{PE} = \varepsilon_0\mathbf{E} - \frac{ne^2}{m}\cdot\frac{1}{(\omega^2-\omega_0^2)}\mathbf{E}, \qquad (5.8)$$

That, introduced thus, it depends on frequency.

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

$$\operatorname{rot}\mathbf{H} = \mathbf{j}_\Sigma = \varepsilon_0\frac{\partial\mathbf{E}}{\partial t} + \frac{\partial\mathbf{P}}{\partial t}$$

or

$$\operatorname{rot}\mathbf{H} = \mathbf{j}_\Sigma = \varepsilon_0\frac{\partial\mathbf{E}}{\partial t} - \frac{ne^2}{m}\frac{1}{(\omega^2-\omega_0^2)}\frac{\partial\mathbf{E}}{\partial t}, \qquad (5.9)$$

where $\mathbf{j}_\Sigma$ - the summed current, which flows through the model. In expression (5.9) 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 (5.9) it is possible to rewrite

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

Obtained expression exactly coincides with relationship (5.3). Consequently, the eventual result of examination by both methods coincides, and there are no claims to the method from a mathematical point of view. But from a physical point of view, and especially in the part of the awarding to the parameter, introduced in accordance with relationship (5.8) of the designation of electrical induction, are large claims, which we discussed. These are the physical quantity of electrical induction, but the certain composite mathematical parameter. In the essence, physically substantiated is the introduction to electrical induction in the dielectrics only in the static electric fields.

Let us show that the equivalent the schematic of dielectric presents the sequential resonant circuit, whose inductance is the kinetic inductance L_{kd}, 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. For the proof of this let us examine the sequential oscillatory circuit, when the inductance of L and the capacity of C are connected in series.

The connection between the current I_C, which flows through the capacity C, and the voltage U_C, applied to it, is determined by the relationships:

$$U_C = \frac{1}{C}\int I_C dt$$

and

$$I_C = C\frac{dU_C}{dt}. \qquad (5.10)$$

This connection will be written down for the inductance:

$$I_L = \frac{1}{L}\int U_L dt$$

and

$$U_L = L\frac{dI_L}{dt}.$$

If the current, which flows through the series circuit, changes according to the law $I = I_0 \sin\omega t$, then a voltage drop across inductance and capacity they are determined by the relationships

$$U_L = \omega L I_0 \cos\omega t$$

and

$$U_C = -\frac{1}{\omega C} I_0 \cos\omega t,$$

and total stress applied to the outline is equal

$$U_{\Sigma}=\left(\omega L-\frac{1}{\omega C}\right)I_0\cos\omega t .$$

In this relationship the value, which stands in the brackets, presents the reactance of sequential resonant circuit, which depends on frequency. The stresses, generated on the capacity and the inductance, are located in the reversed phase, and, depending on frequency, outline can have the inductive, the whether capacitive reactance. At the point of resonance the summary reactance of outline is equal to zero.

It is obvious that the connection between the total voltage applied to the outline and the current, which flows through the outline, will be determined by the relationship

$$I=-\frac{1}{\omega\left(\omega L-\frac{1}{\omega C}\right)}\frac{\partial U_{\Sigma}}{\partial t} . \qquad (5.11)$$

The resonance frequency of outline is determined by the relationship

$$\omega_0=\frac{1}{\sqrt{LC}} ,$$

therefore let us write down

$$I=\frac{C}{\left(1-\frac{\omega^2}{\omega_0{}^2}\right)}\frac{\partial U_{\Sigma}}{\partial t} . \qquad (5.12)$$

Comparing this expression with relationship (5.10) it is not difficult to see that the sequential resonant circuit, which consists of the inductance L and capacity C , it is possible to present to the capacity of in the form dependent on the frequency

$$C(\omega)=\frac{C}{\left(1-\frac{\omega^2}{\omega_0{}^2}\right)} . \qquad (5.13)$$

The inductance is not lost with this idea, since it enters into the resonance frequency of the outline ω_0 . Relationships (5.12) (5.11) are equivalent. Consequently, value $C(\omega)$ is not the physical capacitance value of outline, but is the certain composite mathematical parameter.

Relationship (5.11) can be rewritten and differently:

$$I=-\frac{1}{L\left(\omega^2-\omega_0{}^2\right)}\frac{\partial U_{\Sigma}}{\partial t}$$

and to consider that

$$C(\omega)=-\frac{1}{L\left(\omega^2-\omega_0{}^2\right)} . \qquad (5.14)$$

Is certain, the parameter $C(\omega)$, introduced in accordance with relationships (5.13) and (5.14) no to capacity refers.

Let us examine relationship (9.12) for two limiting cases:

1. When $\omega << \omega_0$, we have

$$I=C\frac{\partial U_{\Sigma}}{\partial t} .$$

This result is intelligible, since. at the low frequencies the reactance of the inductance, connected in series with the capacity, is considerably lower than the capacitive and it is possible not to consider it.

the equivalent the schematic of the dielectric, located between the planes of long line is shown in Fig. 4.

2. For the case, when $\omega >> \omega_0$, we have

$$I=-\frac{1}{\omega^2 L}\frac{\partial U_{\Sigma}}{\partial t} . \qquad (5.15)$$

Taking into account that for the harmonic signal

$$\frac{\partial U_{\Sigma}}{\partial t}=-\omega^2\int U_{\Sigma}dt ,$$

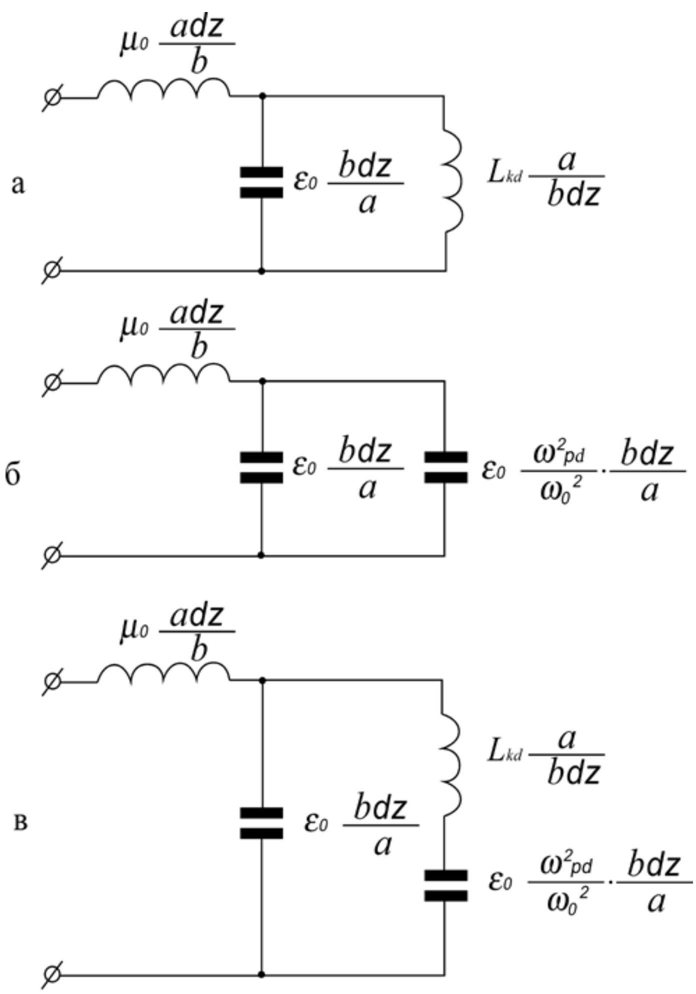

Fig. 8 : a- the equivalent the schematic of the section of the line, filled with dielectric, for the case $\omega >> \omega_0$;б - the equivalent the schematic of the section of line for the case $\omega << \omega_0$; в - the equivalent the schematic of the section of line for entire frequency band.

we obtain from (5.15):

$$I_L = \frac{1}{L} \int U_\Sigma dt .$$

In this case the reactance of capacity is considerably less than in inductance and chain has inductive reactance.

the carried out analysis speaks, that is in practice very difficult to distinguish the behavior of resonant circuits of the inductance or of the capacity. In order to understand the true composition of the chain being investigated it is necessary to remove the amplitude and phase response of this chain in the range of frequencies. In the case of resonant circuit this dependence will have the typical resonance nature, when on both sides resonance the nature of reactance is different. However, this does not mean that real circuit elements: capacity or inductance depend on frequency.

In Fig. 4 (a) and 4 (б) are shown two limiting cases. In the first case, when $\omega >> \omega_0$, dielectric according to its properties corresponds to conductor, in the second case, when $\omega << \omega_0$, it corresponds to the dielectric, which possesses the static dielectric constant of $\varepsilon = \varepsilon_0 \left(1 + \frac{\omega_{pd}^2}{\omega_0^2} \right)$

Thus, it is possible to draw the conclusion that the use of a term "dielectric constant of dielectrics" in the context of its dependence on the frequency is not completely correct. If the discussion deals with the dielectric constant of dielectrics, with which the accumulation of potential energy is connected, then correctly examine only static permeability, which is the constant, which does not depend on the frequency. Specifically, static permeability enters into all relationships, which characterize the electrodynamic characteristics of dielectrics.

the most interesting results of applying such new approaches occur precisely for the dielectrics. In this case each connected pair of charges presents the separate unitary unit with its individual characteristics and its participation in the processes of interaction with the electromagnetic field (if we do not consider the connection between the separate pairs) strictly individually. Certainly, in the dielectrics not all dipoles have different characteristics, but there are different groups with similar characteristics, and each group of bound charges with the identical characteristics will resound at its frequency. Moreover the intensity of absorption, and in the excited state and emission, at this frequency will depend on a relative quantity of pairs of this type. Therefore the partial coefficients, which consider their statistical weight in this process, can be introduced. Furthermore, these processes will influence the anisotropy of the dielectric properties of molecules themselves, which have the specific electrical orientation in crystal lattice. By these circumstances is determined the variety of resonances and their intensities, which is observed in the dielectric media. The lines of absorption or emission, when there is a electric coupling between the separate groups of emitters, acquire even more complex structure. In this case the lines can be converted into the strips. Such individual approach to each separate type of the connected pairs of charges could not be realized within the framework earlier than the existing approaches.

Should be still one important circumstance, which did not up to now obtain proper estimation. With the examination of processes in the material media, which they are both conductors and dielectrics in all relationships together with the dielectric and magnetic constant figures the kinetic inductance of charges [13]. This speaks, that the role of this parameter with the examination of processes in the material media has not less important role, than dielectric and magnetic constant. This is for the first time noted in a number the already mentioned sources, including in the recently published article [29].

VI. Conclusion

Work examines two concepts, which determine the dielectric constant of material media. Is most extended the concept of the tensor of complex dielectric constant, which depends on frequency. But this value is not the physical quantity, but the mathematical parameter, which can be with the specific assumptions determined through several not depending on the frequency physical quantities. This parameter is named effective dielectric constant. At the same time in the work is used the concept of physical dielectric constant, which does not depend on frequency. The same procedures are carried out with respect to magnetic permeability of magnetic materials. This approach removes those misunderstandings, which are connected with the insufficient understanding of the physical sense of the mathematical models of the temporary dispersion of electromagnetic waves in the isotropic media with the use of the frequency-dependent dielectric constant.

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