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PECULIARITIES OF THE MANIFESTATION AND INFLUENCE ON THE ELECTROMAGNETIC PROCESSES OF THE TRANSIENT SKIN EFFECT IN METAL CONDUCTORS WITH PULSED CURRENT

Purpose. ***Preparation of brief scientific review of basic results of the known theoretical researches of the electrophysics phenomenon of linear transient skin effect (TSE) in the non-magnetic homogeneous massive conductors of flat and cylindrical configurations on which in the discharge electric circuits of high-voltage electrophysical installations (EPHI) the pulsed currents $i_p(t)$ flow with given amplitude-temporal parameters (ATPs). Methodology. Theoretical bases of electrical engineering, bases of theoretical electrophysics, electrophysics bases of technique of high-voltage and high pulsed currents. Results. The brief scientific review of results of the known theoretical researches of the electrophysical phenomenon of linear TSE in non-magnetic homogeneous massive flat and cylindrical metal conductors with pulsed axial (azimuthal) current $i_p(t)$, formed in the discharge circuit of powerful high-voltage EPHI. In the generalized and systematized form the basic features of manifestation of linear TSE in the indicated conductors and influence of the considered skin effect on electromagnetic processes are presented at flow in conductors and discharge circuit of a high-voltage EPHI with the pulsed current $i_p(t)$ time-varying by law of attenuated sinewave. Influence of linear TSE is described in non-magnetic massive conductors during transient in a discharge circuit of EPHI with the pulsed current $i_p(t)$ of given ATP, depth of penetration of the electromagnetic field in materials of the indicated conductors, own integral electric parameters of the considered conductors and their good quality in the high-current discharge circuit of high-voltage EPHI. It is shown that at the analysis of electromagnetic transients in high-current discharge electric circuits of powerful high-voltage EPHI it is necessary to take into account flowing in materials of the examined massive conductors of such known electrophysical phenomenon as linear TSE. Originality. Generalization and systematization is first executed regarding domestic and foreign scientists-electrical engineers' results of theoretical researches for long-term period of the electrophysics phenomenon of linear TSE in the flat and cylindrical metallic conductors of different thickness with the pulsed current $i_p(t)$of given ATP. Practical value. The results presented in the generalized and systematized form will be useful for electrical engineers in deepening of understanding of basic features of manifestation in non-magnetic massive homogeneous conductors with the pulsed current $i_p(t)$ of given ATP of such widely widespread in area of high-voltage high-current pulsed technique electrophysics phenomenon as linear TSE and its influences on electromagnetic transients in similar metallic conductors and high-current discharge circuits of high-voltage EPHI.*** References 28, figures 2.

Key words: **metal conductors, pulsed current, linear transient skin effect, features of the manifestation of linear skin effect in conductors and its influence on electromagnetic processes.**

Приведений короткий огляд результатів відомих теоретичних досліджень електрофізичного явища лінійного нестаціонарного поверхневого ефекту (НПЕ) в немагнітних однорідних масивних плоских і циліндричних металевих провідниках з імпульсним аксіальним (азимутним) струмом, що формується в розрядному колі високовольтної електрофізичної установки (ЕФУ). У узагальненому і систематизованому вигляді представлені основні особливості прояву лінійного НПЕ у вказаних провідниках і впливу даного скін-ефекту на електромагнітні процеси, що протікають в провідниках і розрядному колі ЕФУ з імпульсним струмом, що змінюється в часі за законом затухаючої синусоїди. Описаний вплив лінійного НПЕ на тривалість перехідного процесу в розрядному колі ЕФУ, глибину проникнення електромагнітного поля в матеріал провідників, власні електричні параметри провідників і їх добротність в розрядному колі ЕФУ. Бібл. 28, рис. 2.

Ключові слова: **металеві провідники, імпульсний струм, лінійний нестаціонарний поверхневий ефект, особливості прояву лінійного скін-ефекту в провідниках і його впливу на електромагнітні процеси**.

Приведен краткий обзор результатов известных теоретических исследований электрофизического явления линейного нестационарного поверхностного эффекта (НПЭ) в немагнитных однородных массивных плоских и цилиндрических металлических проводниках с импульсным аксиальным (азимутальным) током, формируемым в разрядной цепи высоковольтной электрофизической установки (ЭФУ). В обобщенном и систематизированном виде представлены основные особенности проявления линейного НПЭ в указанных проводниках и влияния рассматриваемого скин-эффекта на электромагнитные процессы, протекающие в проводниках и разрядной цепи ЭФУ с импульсным током, изменяющимся во времени по закону затухающей синусоиды. Описано влияние линейного НПЭ на длительность переходного процесса в разрядной цепи ЭФУ, глубину проникновения электромагнитного поля в материал проводников, собственные электрические параметры проводников и их добротность в разрядной цепи ЭФУ. Библ. 28, рис. 2.

Ключевые слова: **металлические проводники, импульсный ток, линейный нестационарный поверхностный эффект, особенности проявления линейного скин-эффекта в проводниках и его влияния на электромагнитные процессы.**

Introduction. In high-voltage high-current pulse technology, electrophysical installations (EPHI) have been widely used, which are designed to achieve various scientific and electrotechnological goals in practice [1-6]. In this case, non-metallic and insulated conductors are commonly used in electric power circuits of such EPHI, the current-carrying parts of which contain non-magnetic conductors made of materials with high electrical conductance γ_C (for example, copper and aluminum) and through which pulsed currents $i_p(t)$ with different amplitude-temporal parameters (ATPs). The sources of generation in EPHI circuits of pulsed axial (longitudinal) and azimuthal (circular) currents $i_p(t)$, as a rule, are powerful capacitive (CES) or inductive (IES) energy storages [1-3]. Considering the physical nature of the formation and flow of a pulsed current $i_p(t)$ in conducting media, in these materials of conductors of discharge circuits of EPHI with CES (IES), transient skin effect (TSE) appears, the study of which was given quite a lot of attention [2, 7-19]. Nevertheless, today there are practically no publications in the scientific world devoted to the generalization and systematization of the results of theoretical studies of the phenomenon of TSE in metal conductors with a pulsed current $i_p(t)$ of various ATPs for many years obtained by domestic and foreign scientists in the area of electrical engineering. Therefore, the preparation at the first stage of even a brief overview of the main publications on TSE in conductors is of scientific and practical interest. We also indicate that the available foreign publications (for example, [20-22]) are mainly devoted to the study of the stationary skin effect in metallic conductors. In this regard, the preparation of a brief review of well-known works on the phenomenon of TSE in conductors of EPHI with a pulse current $i_p(t)$, containing the main results of its manifestation and influence on the electromagnetic processes occurring in them and in the discharge circuits of EPHI, is an important task.

The goal of the paper is performing a brief scientific review of the main results of the well-known theoretical studies of the electrophysical phenomenon of linear TSE in nonmagnetic homogeneous massive conductors of flat and cylindrical configurations, along which pulsed currents $i_p(t)$ with given ATPs flow in the discharge electric circuits of high-voltage high-current EPHIs.

1. Problem definition. Consider non- and insulated solid non-magnetic homogeneous conductors with flat (Fig. 1) or cylindrical configuration (Fig. 2) [2, 13] that are widely used in high-voltage EPHIs. We assume that for the considered conductors with thickness h or b (see Fig. 1, 2), inequalities of the form h/Δ_C>>1 and b/Δ_C>>1 are satisfied, where $\Delta_C=[2/(\omega_p\mu_0\gamma_C)]^{1/2}$ is the penetration depth in the stationary (steady-state) mode of the external electromagnetic field with the circular frequency ω_p in time t into the conductor material with electrical conductance γ_C, and $\mu_0=4\pi\cdot10^{-7}$ H/m is the magnetic constant [2]. In this regard, a sharp manifestation of the skin effect takes place in the indicated conductors of the discharge circuit of the EPHI, and the conductors can be considered massive [2, 9, 13]. The cases when $h/\Delta_C\leq1$ and $b/\Delta_C\leq1$ are atypical for conductors used in high-current discharge circuits of the EPHI, and therefore they are not of particular interest.

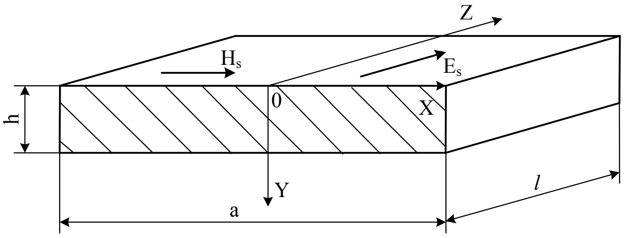

Fig. 1. Flat massive non-insulated metal conductor with pulsed axial electric conduction current $i_p(t)$ flowing along its longitudinal axis OZ (E_S, H_S are, respectively, the strength of the pulsed electric and magnetic fields on the outer flat surface of the conductor) [13]

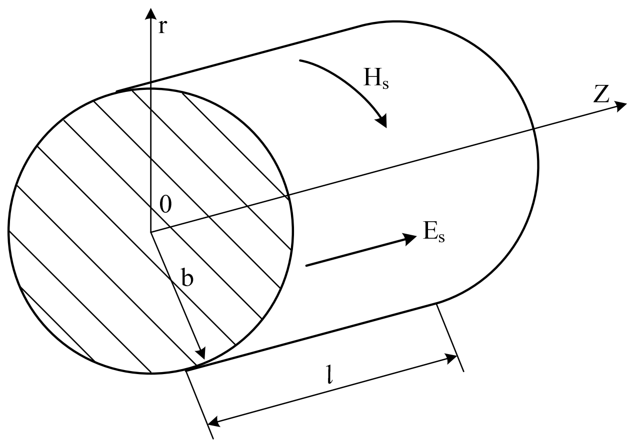

Fig. 2. Cylindrical massive non-insulated metal conductor with pulsed axial electric conduction current $i_p(t)$ flowing along its longitudinal axis OZ (E_S, H_S are, respectively, the strength of the pulsed electric and magnetic fields on the outer cylindrical surface of the conductor) [13]

We believe that the electrical conductance γ_C of the material of the conductors is almost the same in time t value, and the linear dimensions of the conductors (their length l and width a) significantly exceed their thickness h or radius b. The displacement currents in the Maxwell equations for the studied conductors are neglected [2, 12]. Let in considered conductors along their longitudinal axes OZ only pulsed conduction currents $i_p(t)$ with arbitrary ATPs flow. It is required, based on the published results of investigations of linear TSE in the considered non-magnetic homogeneous massive metal conductors of the discharge circuit of the EPHI with pulsed current $i_p(t)$ of specified ATPs, to formulate in generalized and systematic form the main features of the specified skin effect manifestation and its influence on the electromagnetic processes occurring in the material of conductors and discharge electric circuit of the EPHI.

2. The main features of the manifestation of linear TSE in massive conductors with pulsed current. We confine ourselves to the case typical for high-power high-voltage EPHI, when the pulsed current $i_p(t)$ in the studied conductors changes in time t according to the law of a damped sinusoid and is described by the well-known relation of the form [9, 13]:

$$i_p(t) = k_p I_{mp1} \exp(-\delta_p t)\sin(\omega_p t) \,, \qquad (1)$$

where I_{mp1}, δ_p, ω_p are, respectively, the first amplitude, attenuation coefficient and circular frequency of oscillations of the pulsed current in the discharge electric circuit of the EPHI; k_p=[exp($-\delta_p/\omega_p$·arcctgδ_p/ω_p)× ×sin(arcctgδ_p/ω_p)]$^{-1}$ is the normalization factor ($k_p \geq 1$).

The temporal dependence (1) for the current $i_p(t)$ makes it possible to establish the main and characteristic features of the space-temporal distributions of the strengths of the pulsed electromagnetic field in the materials of the studied massive conductors and their influence on the electrical parameters of the conductors, as well as on the behavior of transient electromagnetic processes in the discharge circuits of high-voltage EPHIs.

2.1. Features of the distribution of the strength of a pulsed electric field in the material of conductors. The data of analytical solutions of linear diffusion problems for penetration into a cylindrical tubular metal conductor, often used in the discharge circuit of EPHI with a pulse current $i_p(t)$ of a temporary form (1), the strengths of a pulsed axial E_Z and azimuthal E_θ electric fields given in [14, 15] makes it possible to formulate the following main features of the manifestation of linear TSE in the specified conductor:

- the first amplitude of the strength E_Z of the pulsed axial electric field in the outer layers of the massive conductor wall is significantly less than the corresponding strength characteristic of the steady-state (stationary) electromagnetic process in the conductor material. For the outer surface of a massive conductor, this discrepancy between the non- and stationary modes of penetration of this field is approximately 33 %;
- the amplitude of the first half-wave E_θ of the pulsed azimuthal electric field strength on the outer surface of the massive conductor wall is approximately 31 % less than in the stationary mode of penetration of a similar field into it;
- the strengths E_Z and E_θ of the pulsed electric field on the outer surface of the massive conductor wall are characterized by an increased slew rate on the frontal parts of their first half-waves, the duration of which turns out to be significantly less (from 30 to 35 %) to the duration of the next half-waves of this field change;
- the strengths E_Z and E_θ of the pulsed electric field faster become steady in the inner layers of the wall of a non-magnetic massive conductor with pulsed axial or azimuthal current;
- full attenuation in the material of the massive conductor of the indicated strengths E_Z and E_θ of the pulsed electric field occurs almost at the depth of its wall, approximately equal to 5Δ_C.

2.2. Features of the distribution of the strength of a pulsed magnetic field in the material of conductors. The results of a linear TSE study in the specified massive cylindrical conductor, presented in [14, 15], indicate that:

- the first amplitude of the strength H_θ of the pulsed azimuthal magnetic field across the entire wall thickness of the massive conductor in the transient penetration mode is much larger than in the stationary one. This discrepancy in the values of the strength H_θ for the inner layers of the wall of the conductor considered reaches up to 35 %;
- the first half-waves of the strengths H_θ и H_Z of the pulsed magnetic field as it penetrates into the inner layers of the wall of a non-magnetic massive conductor undergo a considerable attenuation in amplitude and change in shape. There is a smoothing of their frontal parts and a shift of their amplitude values towards longer times;
- the first amplitude of the strength H_Z of the pulsed axial field into the inner layers of the conductor wall is approximately 32 % higher than its corresponding values, determined from the condition of the steady-state (stationary) electromagnetic mode of its penetration into the conductor material;
- the strengths H_θ and H_Z of the pulsed magnetic field faster become steady in the outer layers of the wall of the massive conductor with pulsed current;
- full attenuation in the non-magnetic material of the massive conductor of the indicated strengths H_θ and H_Z of the pulsed magnetic field practically occurs at a depth of its wall equal to about 5Δ_C.

3. Main features of the influence of linear TSE in massive conductors with pulsed current on the electromagnetic processes in them and in the discharge electric circuit of the EPHI. Based on presented in [2, 8-10, 12-19] the results of studies of linear TSE in flat and cylindrical conductors with pulse current $i_p(t)$ varying in time t according to (1), it can be concluded that its (skin effect's) the main effects are as follows.

3.1. The effect on the duration of the transient in the discharge electric circuit of the EPHI. Analysis of the obtained data for linear TSE in massive conductors with pulsed axial (azimuthal) current $i_p(t)$ of the form (1) indicates that the transient process of becoming steady of the strengths of the pulsed electromagnetic field in their non-magnetic homogeneous (isotropic) material lasts almost one and a half period T_p (no more than $3\pi/\omega_p$) of changes of the external field generated by the considered discharge current of the EPHI near their outer surfaces. This circumstance is clearly indicated by the results of studies in [9, 16] of pulsed penetration of plane electromagnetic waves into a flat non-magnetic massive wall of a tubular conductor of unlimited radial dimensions, as well as by theoretical data from [14, 15] on the study of linear TSE in a non-conductive cylindrical tubular conductor with arbitrary wall thickness with pulsed axial or azimuthal current $i_p(t)$ of a temporary form (1). Therefore, the duration of the transient electromagnetic process in the discharge circuit of a high-voltage EPHI with massive metal conductors (tires), due to transient diffusion in their walls of the external pulsed electromagnetic field strengths with an oscillation period T_p, practically does not exceed the value $1,5 \cdot T_p = 3\pi/\omega_p$.

3.2. The effect on the depth of penetration of the electromagnetic field into the material of conductors. As is known, to calculate the depth of penetration Δ_N in the transient (unsteady) mode of the external pulsed electromagnetic field into the considered non-magnetic massive homogeneous conductors of the discharge circuit of the EPHI, the following analytical relation can be used [13, 23]:

$$\Delta_N = H_S / (\gamma_C E_S) , \quad (2)$$

where E_S, H_S are, respectively, the strengths of the pulsed electric and magnetic fields on the outer surface of a flat (cylindrical) conductor (see Fig. 1, 2), the non-ferromagnetic material of which has a constant electrical conductance γ_C.

Knowing in (2) the temporal dependencies of the surface strengths E_S and H_S of the pulsed electric and magnetic fields for the considered flat and cylindrical conductors included in the discharge circuit of EPHI with time-varying in t according to the law (1) the pulsed axial (azimuthal) current $i_p(t)$, it is relatively easy to determine the desired penetration depth Δ_N for transient process of diffusion of the external pulsed electromagnetic field into their walls and is compared with the known classical penetration depth Δ_C characteristic of the steady-state (stationary) field diffusion mode.

From the analysis of the results obtained in [13, 23], it follows that in the area of the first half-wave of a pulsed damped sinusoidal axial current $i_p(t)$ according to (1) (δ_p/ω_p=0,3; ω_p=666,58 kHz; T_p=9,42 μs) flowing through a round solid copper tire (b=2,5 mm; γ_C=5,81·10^7 S/m; Δ_C=0,202 mm; b/Δ_C=12,37) of the radio frequency cable brand PK 75-33-17 [24], the value of the depth of penetration Δ_N of the field into this core for the transient mode, compared with the value of the depth of penetration Δ_C into it of a similar field for the stationary mode, is approximately 37 % larger. For the area of the second half-wave of the pulsed electromagnetic field penetrating into a cylindrical tire, the value of Δ_N becomes 19 % less than the value of Δ_C characteristic of the stationary mode of penetration of the external electromagnetic field into the specified massive conductor. In the area of the third half-wave of the investigated type of electromagnetic field, the ratio Δ_N/Δ_C approaches almost 1. Therefore, for the analyzed case, the depth of penetration Δ_N of the pulsed electromagnetic field into the massive cylindrical conductor varies most noticeably in the interval of the first two half-waves of this field or the pulsed current $i_p(t)$ described by (1).

The above feature for the temporal distribution of Δ_N allows to explain from electrophysical positions the nature of the value of the intensity E_{ZS} of the pulsed axial electric field on the outer surface of the massive cylindrical conductor during a transient in the discharge circuit of the EPHI (see subsection 2.1). It is a mentioned increase in Δ_N (by about 37 %) in the first half-wave area of the penetrating pulsed electromagnetic field, in transient mode, by reducing the instantaneous value of active resistance R_N of the current skin layer in the massive cylindrical conductor, results in a corresponding decrease (approximately by 33 %) in the first half-wave amplitude of the surface strength E_{ZS} of the pulsed axial electric field (respectively, also the drop of the pulsed electric voltage on this conductor [25]) by comparing to its value in the steady state diffusion mode of similar alternating field into the consideration conductor. In the area of the second half-wave of the discharge current $i_p(t)$ of the form (1), the decrease in Δ_N (by about 19 %) results, due to an increase in the instantaneous value of the active resistance R_N of the current skin layer in the massive cylindrical conductor, in a corresponding increase in the transient penetration mode into it of the analyzed field of the specified amplitude of the strength E_{ZS} of the axial electric field on the outer surface of the conductor.

Therefore, it can be stated that the nature of the penetration mode (transient or steady state in the electrodynamic sense) into the indicated massive flat and cylindrical conductors of the discharge circuit of the EPHI of the external electromagnetic field significantly affects the calculation of its penetration depth into their non-magnetic materials.

3.3. Influence on the intrinsic electrical parameters of the conductors of the discharge circuit of the EPHI. The values of active resistances R_{Na} and internal inductances L_{Na} (external inductances determined by the geometry of the conductors and not dependent on the electrodynamic mode of current propagation in them, are not considered) for non- and massive flat and cylindrical conductors, averaged over an arbitrary time interval [t_s, t_e] used in the discharge circuits of high-voltage EPHIs with pulse current $i_p(t)$, can be represented in a generalized electrical engineering form [26, 27]:

$$R_{Na} = k_R R_0 ; \quad (3)$$

$$L_{Na} = k_L L_0 , \quad (4)$$

where R_{Na}, L_{Na} are, respectively, the active resistance and internal inductance of the conductor, taking into account the influence of the apparent TSE in them; R_0, L_0 are, respectively, the known values of active resistance and internal inductance of a conductor when DC flows through it [2, 28]; k_R, k_L are the dimensionless coefficients that take into account the influence of the transient mode of penetration of the external electromagnetic field into the conductor material, respectively, on the values of its active resistance and internal inductance.

It is interesting to note that according to data from [26, 27] for a non-massive continuous cylindrical conductor of radius b with pulsed axial current $i_p(t)$ of the form (1) with $b/\Delta_C \le 1$, the coefficients k_R and k_L in (3), (4) become equal to 1 and its pulsed electrical parameters R_{Na} and L_{Na} take values characteristic of DC in it. This circumstance, corresponding to the well-known provisions of theoretical electrophysics [2, 6], may additionally indicate the reliability of both the approach used in [26, 27] and the results obtained on its basis for the electrical parameters of the studied conductors with pulsed current $i_p(t)$.

In (3), (4), the electrical parameters of R_{Na} and L_{Na} are understood to be constant over the time interval $[t_s, t_e]$ the values of active resistance and internal inductance of the conductor under consideration, which by the time point $t_e > t_s$ cause in its material the same changes of energy of thermal (Joule) losses and magnetic field energy, as the time variable values of active resistance R_N and internal inductance L_N of the conductor. Note that in [28] for the case of a sharp manifestation of a stationary skin effect in a nonmagnetic massive solid cylindrical wire of radius b (see Fig. 2) with a variable sinusoidal axial current of frequency f, the following classical calculation relations were obtained for its current oscillations averaged over a half-period's area duration $0{,}5f^{-1}$ values of active resistance R_C and internal inductance L_C:

$$R_C = 0{,}5l(\pi b\gamma_C\Delta_C)^{-1};\qquad (5)$$

$$L_C = 0{,}25\mu_0 l\Delta_C(\pi b)^{-1}.\qquad (6)$$

For comparison at $\delta_p/\omega_p=0$ of the values of the active resistance R_{Na} and the internal inductance L_{Na} of the massive continuous cylindrical conductor of radius b with apulsed axial current $i_p(t)$, found taking into account the influence of the TSE, with the corresponding values of its active resistance R_C and internal inductance L_C, calculated in the stationary mode, at $b/\Delta_C >> 1$ the following relations can be used [26]:

$$R_{Na} / R_C = 2\Delta_C k_R / b;\qquad (7)$$

$$L_{Na} / L_C = 0{,}5bk_L / \Delta_C.\qquad (8)$$

Analytical and graphical dependencies for the coefficients $k_R>1$ and $k_L<1$ as applied to flow through the considered massive cylindrical conductor of pulsed axial current $i_p(t)$ of the form (1) are presented in [12, 26]. We now turn to the analysis of the effect of the TSE on the active resistance R_{Na} and the internal inductance L_{Na} of a nonmagnetic massive cylindrical conductor with pulsed axial current $i_p(t)$ according to (1).

The results obtained in [12, 26] for the conductor considered indicate that the averaged in the area of the first half-wave ($t_s=0$; $t_e=\pi/\omega_p$) of the damped sinusoidal current $i_p(t)$ of the form (1) values of the active resistance R_{Na} taking into account the linear TSE are much smaller, and the averaged in this area values of the internal inductance L_{Na} are larger than at the stationary skin effect in the material of such a conductor. So, at $b/\Delta_C=10$ and $\delta_p/\omega_p=0$ for a non-magnetic continuous cylindrical conductor with pulsed axial current $i_p(t)$, the ratio R_{Na}/R_C by (7) is numerically about 0.75, and the ratio L_{Na}/L_C by (8) takes a value numerically equal to about 1.14. It can be seen that for a massive cylindrical conductor, taking into account the influence of the linear TSE leads to a decrease (by about 25 %) of its average active resistance value R_{Na} and an increase (by about 14 %) of its average internal inductance L_{Na}. It is important to point out that according to the calculation data from [12, 26] for relatively thin (non-massive) cylindrical conductors ($b/\Delta_C \le 1$) with pulsed axial damped sinusoidal current $i_p(t)$ in the discharge circuit of the high-voltage EPHI, the transient electromagnetic process in their non-magnetic homogeneous material has practically no effect on the values of such integral electrical parameters as active resistance and internal inductance.

3.4. Influence on the quality factor of conductors of the discharge circuit of the EPHI. The quality factor (Q-factor) Q_N of the considered flat and cylindrical conductors with pulsed current $i_p(t)$ of the form (1) in the discharge circuit of the EPHI is understood as the physical quantity determined by the ratio of their internal reactances to their active resistances and calculated by the following expression [12]:

$$Q_N = \omega_p L_N / R_N.\qquad (9)$$

For a non-magnetic massive solid cylindrical conductor with a pulsed axial current $i_p(t)$ of the form (1), expression (9) according to [12] can be written as follows:

$$Q_N = 0{,}25b^2 k_L / (\Delta_C^2 k_R).\qquad (10)$$

Based on (9) and taking into account (5) and (6), for the specified massive ($b/\Delta_C >> 1$) cylindrical conductor at a stationary mode of manifestation in its non-magnetic material of the skin effect, the value of quality factor takes a numerical value equal to $Q_N=1$. This result corresponds to the well-known classical provisions of theoretical electrical engineering [28]. And how does the linear TSE, which manifests itself in their materials, affect the Q-factor Q_N of the considered conductors? From (10) and analysis of the results of theoretical studies of this skin effect in nonmagnetic massive conductors with pulsed axial current $i_p(t)$ of a temporary form (1), presented in [12, 26], it follows that for a massive solid cylindrical conductor with $b/\Delta_C=10$ (in the case of $\delta_p/\omega_p=0$) its Q-factor in the transient mode becomes numerically equal to about $Q_N=1.52$. It can be seen that linear TSE compared with the steady-state (stationary) skin effect leads to a significant increase (by about 52 %) of the value of Q-factor Q_N of the specified massive conductor with pulsed current $i_p(t)$, connected in the high-current discharge circuit of the EPHI. Note that a similar result for the quality factor Q_N was also obtained when calculating the integral electrical parameters for an infinitely thick flat conductor with a pulsed sinusoidal current in a transient mode [8]. From this we can conclude that in order to achieve in the discharge circuit of the powerful high-voltage EPHI that generates high pulsed currents and high pulsed magnetic fields on an electrical load, high values of Q-factor of its current-carrying busbar, in it (in this busbar) non-magnetic massive conductors must be used.

Conclusions.

1. From the presented data of the review, it follows that the linear transient skin effect in the metal conductors under consideration, compared with the stationary skin effect in them, in the first half-wave of the damped sinusoidal pulsed current $i_p(t)$ leads to a significant decrease (up to 33 %) on the outer surface of the conductors of the value of the strength of the pulsed electric field, a significant increase (up to 35 %) in the inner layers of the conductors of the value of the strength of the pulsed magnetic field, a noticeable increase (up to 37 %) in the depth of penetration of the external electromagnetic field into the conductor material, a decrease (up to 25 %) in the average active resistances of the conductors, an increase (up to 14 %) in the average internal inductance of the conductors and an increase (up to 52 %) in the Q-factor of the conductors, as well as to the flow in the discharge circuit of a high-voltage high-current electrical installation of a transient electromagnetic process with a duration of up to one and a half period of change of its pulsed current $i_p(t)$ of the specified temporary type.

2. The above-described features of the manifestation and influence of a linear transient skin effect in indicated non-magnetic homogeneous massive conductors of discharge electric circuits of high-voltage high-current electrical installations must be taken into account when designing and choosing the design of flat (cylindrical) busbar of discharge circuits of similar electrophysical installations, as well as when solving applied problems of obtaining on certain electrical loads of specified current (voltage) pulses with the specified parameters.

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