RESEARCH OF INFLUENCE OF CONSTRUCTION DESIGN PARAMETER VALUES OF THE ASYNCHRONOUS ENGINES ON THE RESULT OF DIAGNOSTICS OF THEIR INSULATION CONDITION

S.O. KHOMUTOV

According to the technique of diagnostics of a condition of windings in asynchronous engines (AE) during their operation [1] for reception of authentic results concerning a degree of degradation of electric insulation it is necessary, using known models of ageing, to carry out comparison of the measured value of test parameter with its reference value for a concrete type of the electric motor of known capacity. However, in practice, such comparison is not possible to carry out because the consumer lacks information on reference values of test parameter for AE series, which are widely used at industrial and agricultural enterprises. Thus, the purpose of the present research is to receive dependences of values of wave damped vibrations (WDV) parameters in AE winding on values of some factors determining design of the electric motor. The given dependences will precisely allow to determine reference values of the test parameter for engines of all standard sizes and, hence, to carry out authentic diagnostics and forecasting of the further change of condition of insulation in conditions of simultaneous use of various series and capacities of AE at enterprises.

It is known that number of the parameters describing design of asynchronous engines is great. Therefore, at the initial stage of the given research it is necessary to reduce their number by exclusion of those parameters, which influence on parameters of WDV in AE winding is insignificant, or absent at all.

There are experimental and effective ways of the solution of the above named task. However, results of experimental researches, though highly reliable, are marked by significant consumption of time and materials for their reception.

Therefore the given way is expedient to use at realization of special researches. Then, taking into account the aforesaid, by the further consideration of the task of limitation of amount of constructional parameters of AE, we shall use effective methods to receive required dependences.

The simplest way of the solution of the task in view is the method of expert estimations, which essence consists in experts' ranking parameters under research. As a result of the analysis of the data received from experts, two groups of AE design parameters were distinguished: parameters of the first group influence formation of wave damping process at diagnostics, and parameters of the second group render insignificant influence, or are absent in general.

Parameters of the first group are: slot configuration $Г_{паз}$, slot type $В_{паз}$, mark of magnet wires $М_{пр}$, diameter of magnet wires $d_{пр}$, thickness of insulation of magnet wires $h_{из}$, number of coils in a winding phase $n_{вит}$, winding type $В_{обм}$, number of pairs of poles p, length of stator $l_{стат}$, number of parallel conductors of stator winding m, number of stator slots Z_1, internal diameter of stator $d_{вн}$, external diameter of stator $d_{нар}$, gap width l_{δ}, material of slot insulation layer $М_{пи}$, number of layers of slot insulation $n_{пи}$, thickness of a layer of slot insulation $h_{пи}$, material of interlayer insulation $М_{мси}$, mark of steel $М_{ст}$, thickness of a sheet of steel $h_{ст}$, thickness of interlayer insulation $h_{мси}$, material of interphase insulation $М_{мфи}$, thickness of interphase insulation $h_{мфи}$.

Parameters of the second group are: type of interlayer insulation $В_{ст}$, diameter of a shaft $d_{вал}$, material of the wedge $М_{клин}$, mark of lead wire $М_{вп}$, insulation inside machine connections $М_{вмс}$, bearings $М_{подш}$ etc.

The following stage of theoretical research of influence of AE design parameters on change of the considered test parameter is construction of simple and convenient in use mathematical model of wave damped vibrations. Strictly speaking, in this case output capacity of mathematical model of the wave exhaustive processes proceeding in AE winding at voltage supply on its rectangular pulse stands for the test parameter.

Realization of the above named research phase assumes the use of an equivalent circuit, which can be made for any winding type. Thus, the assumption is made, according to which the distributed parameters of AE winding are replaced by lumped ones.

Generally, equivalent circuits of a stator winding in asynchronous electric motors depend on AE design with different number of poles of windings modification. The equivalent circuit of an elementary coil is represented in Figure 1.

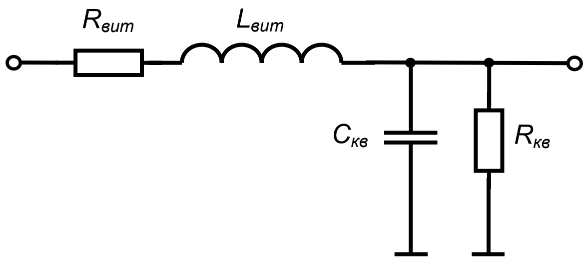

Fig. 1. Equivalent circuit of an elementary coil

In its turn, the equivalent circuit of the coil is a result of integration of equivalent circuits of coils and introduction of interturn insulation parameters. The given equivalent circuit of the coil has a lot of components and is inconvenient to analyze. For simplification of the circuit we shall be guided by the following reasons. As the coil represents a set of closed coils of a continuous conductor, its active and inductive resistance will be defined as the sum of, accordingly, active and inductive resistance of coils. Insulation capacitances of the coil toward the frame are joined in parallel among themselves, therefore the given parameter of the coil will be determined as

$$C_{\text{кк}} = \sum_{i=1}^{n} C_{\text{кв}i} \tag{1}$$

where $C_{\text{кв}i}$ - is capacitance of i-coil toward the frame;
n - is the number of coils.

Resistances of coils insulation toward the frame are also joined in parallel. Therefore, the expression holds true

$$R_{\text{кк}} = \sum_{i=1}^{n} \frac{1}{R_{\text{кв}i}} \tag{2}$$

where $R_{\text{кк}}$ - is the resistance of insulation of the coil toward the frame;
$R_{\text{кв}i}$ - is the resistance of i - coil insulation toward the frame

At the analysis of interturn parameters, which are included in the circuit, we shall make an assumption, that interturn resistance $R_{\text{в}}$ and interturn capacitance $C_{\text{в}}$ depend, first of all, on the distance between conductors.

Analytically it is expressed as

$$R_{\text{в}} = \frac{\rho \cdot d_{\text{в}}}{S}, \tag{3}$$

$$C_{\text{в}} = \frac{\varepsilon_{\text{в}} \cdot \varepsilon_0 \cdot S}{d_{\text{в}}}, \tag{4}$$

where ρ - is a specific resistance of interturn medium;
$d_{\text{в}}$ - is the distance between the coils;
S - is the surface area of the coils;
$\varepsilon_{\text{в}}$ - is dielectric permeability of interturn medium;
ε_0 - is the electric constant.

Analyzing expressions (3) and (4) it is possible to see that for identical marks of a wire, coil lengths (S=const) and constant structure of interturn medium $d_{\text{в}}$ remains the unique variable. The size of the given parameter renders opposite influence on change of $R_{\text{в}}$ and $C_{\text{в}}$ values: $R_{\text{в}}$ is increased, and $C_{\text{в}}$ is decreased and vice versa.

Thus, the establishment of dependence of influence of AE constructional parameters values on those of elements of an equivalent circuit of windings will allow to receive specific value of the test parameter formed, as it was already specified earlier, by wave exhaustive process, for various series of new electric motors or those which underwent an overhaul.. For normal functioning of the electric machine, it is essential to preserve integrity of insulation structure. Crippling of AE winding can happen between coils, the distance between which is minimal. Therefore, we shall consider in detail the properties of the specified parameters of the coils laying in immediate proximity from each other.

At mutual removal of conductors there is a falling capacity of $C_{\text{в}}$ and growth of $R_{\text{в}}$. As

$$X_{C_{\text{в}}} = \frac{1}{j \cdot \omega \cdot C_{\text{в}}}, \tag{5}$$

the resistance of a circuit of current drain through interturn insulation grows. Therefore even at insignificant removal of conductors from each other resistance of the considered circuit will increase by several times. Hence, it is characteristic for the conductors which are placed at greater distance from each other to have smaller interturn capacitance and the greater interturn resistance, than for nearby conductors. It is conditionally acceptable that circuit resistance of current drain through interturn insulation at significant distance between conductors is infinite. It means that at fulfilling of the given condition interturn resistance and interturn capacitance cause the break of the specified circuit and should be excluded from the equivalent circuit.

As a result of the analysis of conductors arrangement in a slot, as shown in Figure 2, we shall include interturn resistance and interturn capacitance, characteristic for pair of conductors with the minimal distance between them, in the equivalent circuit of the coil. Coils 5 and 6, increased by 11 times and represented on Figure 2, can serve as an example of such a pair.

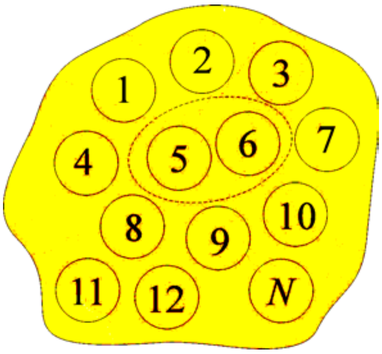

Fig. 2. Arrangement structure of conductors of the coil in a slot of the 4A100S2U3 engine for a part of slot section

By development of an equivalent circuit of the phase the following circumstances should be taken into account [2]. First, in electric machines it is enough to take into account mutual influences within the limits of each slot, containing two sections of a two-layer winding. The latter can refer to different phases or to different segments of one phase winding.

Second, each section has intercouplings not only within the limits of the given slot, but also outside of it, for example, in end windings. But as the coupling is very weak, its influence can be neglected.

As a result of the carried out researches, the equivalent circuit of a winding is received in Figure 3. The given circuit is similar to the one offered in [1].

Besides in [1] it is shown, that essential influence on WDV is rendered with parameters of the generator of pulses. Moreover, in the same work, modeling of WDV with the use of an operational method of calculation of transients is carried out in inductive resistor-capacitor contours. However, the given way of calculation is awkward, which causes inconvenience of its use in practical purposes. Therefore, an actual task is creation of simple and convenient in use parameter determination method of WDV.

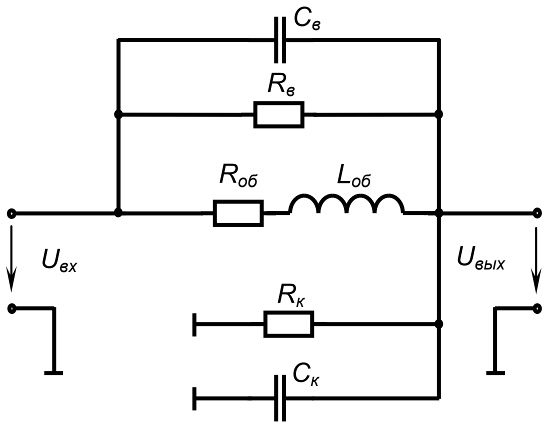

Fig. 3. Equivalent circuit of a winding of the electric motor

We shall construct mathematical model of WDV in AE winding by calculation of the transient arising with supply of an individual pulse on a winding, with the help of a classical method. Calculation of the transient is carried out separately for output parameters of the generator and for those of the equivalent circuit of a stator winding in the asynchronous electric motor. We are omitting the intermediate stages and presenting the final solution.

According to the circuit represented in Figure 3, diagram of the transient is determined by the equation:

$$U_{вых}(t) = U_{Ск.пр} + \frac{U_{Ск.пр}}{\sin(\nu)} \cdot e^{-\delta \cdot t} \cdot \sin(\omega_0 \cdot t + \nu). \quad (6)$$

The stator winding in the asynchronous electric motor, as well as windings of the majority of other electric machines, has a complex design on which its electric parameters depend. For calculation of electric parameters of AE winding, such as inductance, capacitance of insulation toward the frame, there exists a technique described in detail in [2]. In our case, at modeling of WDV in windings of low-voltage engines the following assumptions are accepted: a) the half-closed slot of the complex oval form is replaced with the round closed slot of the equal area; b) the random arrangement of conductors in a slot at with mesh winding is replaced with a regular one; c) materials of conductors and cores are accepted as homogeneous.

The interturn space of a winding of the electric motor consists of a multilayered dielectric: two layers of cover-coat enamel, one layer of impregnating varnish and various impurities. Dielectric permeability of complex dielectrics, represented as a mixture of several components with different dielectric permeabilities, can be at first approximation determined on the basis of the logarithmic law of mixture, which is generally applicable for calculation of various properties [3]:

$$\varepsilon_r^{\chi} = \sum_{i=1}^{n} \theta_i \cdot \varepsilon_{ri}^{\chi}, \tag{7}$$

where ε_{ri} - is relative dielectric permeability of i - component of the mixture;

θ_i - is volumetric concentration of i- component of the mixture;

χ - is a constant, describing distribution of components and accepting value from +1 to -1.

After the data on dielectric permeability of varnish is acquired, let's generate a complex of mathematical expressions to determine dielectric permeability of interturn space. For this purpose we shall accept the following assumptions:

- every insulation layer has homogeneous structure without extraneous inclusions (extraneous inclusions of conducting or semiconducting materials);
- enamel of wires has no mechanical damages and settles as a uniform layer all over the wire.

The executed calculations for PE939 (PE943) enamel and impregnating varnishes of FL-98, GF-996 and ML- 92 type show, that the size of dielectric permeability of interturn insulation depends mainly on thickness of the above-stated insulating covers.

Besides dielectric permeability, the important property of insulation is its specific conductance. As interturn insulation consists of multilayered dielectric, for definition of specific conductance we shall apply the logarithmic law of mixture for parallel inclusion of components:

$$\rho_{виз} = \frac{1}{\frac{\theta_{лак}}{\rho_{лак}} + \frac{\theta_{эм}}{\rho_{эм}} + \sum_{i=1}^{n} \frac{\theta_i}{\rho_i}}, \tag{8}$$

where $\rho_{эм}$, $\rho_{лак}$, ρ_i - are specific volumetric resistances of enamel, varnish and i-component of insulation designs;

$\rho_{виз}$ - is specific electric resistance of interturn insulation.

Dependence of specific resistance of interturn insulation on thickness of varnish and enamel makes it possible to come to the following conclusion: the value of specific resistance in great degree is caused by smaller value of specific resistance of the component included in insulation system. The electric capacity of interturn insulation is one of the key parameters describing a condition of insulation and influencing wave exhaustive process in a winding at diagnostics. Therefore the question of definition of these parameter values is topical.

For finding of values of interturn capacitances we shall apply the simplified physical model of interturn space, representing two parallel cylindrical conductors. We shall assume the conductors to be indefinitely long and determine capacity between their *l* length pieces, which in our case will be equated to the length of the coil of a stator winding in the appropriate electric motor.

The capacity between two solitary conductive bodies is equal to the relation of *q* charge of one of the bodies to the difference of their potentials φ_1 - φ_2. Hence, the capacity is equal to :

$$C_в = \frac{q}{\varphi_1 - \varphi_2} = \frac{q \cdot \pi \cdot \varepsilon \cdot \varepsilon_0}{\tau \cdot \ln \frac{d-r}{r}}. \tag{9}$$

As $q = \tau \cdot l$, the capacitance of two wires of the certain length is equal to:

$$C_в = \frac{\pi \cdot \varepsilon_0 \cdot \varepsilon_{из} \cdot l}{\ln\left[\frac{(\delta_{из} + 2 \cdot r) - r}{r}\right]} = \frac{\pi \cdot \varepsilon_0 \cdot \varepsilon_{из} \cdot l}{\ln\left[\frac{\delta_{из} + r}{r}\right]}. \tag{10}$$

That is, the capacity depends only on configuration of bodies, their sizes, distance between the bodies and electric properties of dielectric (values of dielectric permeability ε_r).

Except for dielectric permeability ε_l, for calculation of interturn capacitance under the formula (10), it is necessary to know the following magnitudes:

- length of one coil in a winding $l = \frac{l_0}{w}$, where l -is the full length of a wire in a winding, w - number of coils in a phase;

- radius of coils wires r,
- average distance between the two adjoining coils in a winding d.

Having established values of average distance between the two adjoining coils in a winding d, it is possible to find interturn capacitance $C_в$ of any dielectric structure of 4A electric motors with heights of an axis of rotation 63-250 mm and capacity of 0,55-55 kW using the following expression:

$$C_в = \frac{R_0 \cdot \pi \cdot \varepsilon \cdot \varepsilon_0 \cdot d_0^2}{4 \cdot \rho \cdot w \cdot M}, \quad (11)$$

where $M = \ln\left(\frac{\delta_л + \delta'_э + r}{r}\right)$ – is a variable. (12)

Analyzing the above mentioned dependences, it is possible to come to the conclusion, that interturn capacitance depends on the distance between coils. It is necessary to note, that the distance between coils is not a constant even in one electric motor. It, first of all, is expressed in distinction of compression force influencing various sections of winding coils, which are end windings and are stacked in slots. In the first case, smaller compression force take place, which is caused by the absence of the rigid technical devices to press coils to each other. In the second case, compressor force on the coil is rendered with metal walls of a slot. In this case, distances between coils will be less, than on coils sections, which are outside the slot. Another problem is that the slots sizes and diameter of coils wire conductors are different in individual engines.

In order to solve this problem, complex researches during which computer modeling of conductors' accomodation in slots and end windings of different electric motors were carried out.

The data received at computer modeling, were statistically processed, therefore it was established, that the distance between conductors depends on wire diameter. This dependence can be described with the help of expression

$$\delta_1 = \varpi \cdot d', \quad (13)$$

where d' - is the diameter of a wire with enamel, m;

ϖ - is the factor of interturn space.

Using the offered parameters determination method of physical model of insulation it is possible to find the reference value of interturn capacitance of a concrete dielectric system (DS). Thus, it is possible to define of the high value of key parameter (C_c), which describes property of interturn insulation in the beginning of its life cycle, and is appropriate to the highest durability of insulation.

In its turn, calculation of active resistance of interturn insulation is done in two stages.

At the first stage, calculation of insulativity is carried out.

At the second stage, calculation of resistance of interturn insulation with the help of insulativity ρ, is carried out, namely:

$$R_{из} = \frac{\rho_{из} \cdot \delta_{из}}{S}. \quad (14)$$

With reference to the considered case the formula (14) will look like:

$$R_в = \frac{\rho_{виз} \cdot \sum_{i=1}^{g} \delta_{вi}}{2 \cdot \pi \cdot r_1 \cdot l \cdot \psi}, \quad (15)$$

where δ is thickness of i- a layer of interturn insulation;

r, - is a radius of a wire without insulation;

g - is the number of layers of interturn insulation;

ψ - is the correction factor which takes into account the contact area of conductors among themselves and with walls of a slot.

Dependence of interturn resistance on thickness of varnish layer and varnish mark shows that as the distance between conductors increases, so does the value of resistance.

At calculation of values of interturn resistance it is established, that 0,55 - 55 kW electric motors capacity change them within the limits of 32-63 kOhm.

In practice of the enterprises engaged in repair of electric machines, such cases are frequent when at rewinding of stator windings instead of the wires, stipulated by specifications for the given AE type, other wires are used. Then value of inductance will differ from the table one. For estimation of influence of such changes in design of a winding on wave exhaustive process it is also necessary to have a technique of determination of inductance. The subsequent calculation of inductance will be made for 0,55-55 kW AEs of 4A series.

Inductance of a winding of the electric machine can be generally calculated under the formula

$$L_{об} = \frac{X_{11}}{\omega} = \frac{X_{11}}{2 \cdot \pi \cdot f}. \quad (16)$$

where X_{11}, - is inductive impendance.

At change of a design of a winding during overhaul its resistance can be calculated on the following expression

$$R_{об} = \frac{\rho \cdot l_{ср} \cdot n_{в}}{s_{эл} \cdot n_{эл} \cdot a}, \quad (17)$$

where ρ - is volume resistivity of a conductor, Ohm-m;
$l_{ср}$ - is the length of a coil, m;
$n_{в}$ - is the number of coils in a winding, pcs;
$s_{эл}$ - is the section of an effective conductor, m^2;
$n_{эл}$ - is the number of elemental conductors in the effective one , pcs;
a - is number of parallel winding paths, pcs.

It is possible to determine the quantity of resistance of winding insulation toward the frame by consideration of a multilayered dielectric construction design. Assume that there is one equivalent conductor in a slot instead of a high number of them. Insulation of a winding of the electric motor toward the frame consists of a multilayered dielectric: a layer of cover-coat enamel, a layer of impregnating varnish and several layers of fibrous dielectric materials (varnished cloth, cloth-based laminate, paper-based laminate).

By consideration of characteristics of winding insulation toward the frame we shall accept the following assumptions:

- every insulation layer has homogeneous structure without extraneous inclusions (extraneous inclusions of conducting or semiconducting materials);
- enamel of wires has no mechanical damages and is disposed as a uniform layer all over the wire.

We shall take into consideration the simplified model of multilayered insulation, where thickness of varnish $\delta_{лак}$ varies within the limits of 0 to 0,7 mm, and thickness of other components of insulation construction designs are equal to normalized ones for the given type of electric motors.

Resistance of insulation toward the frame can be determined on the expression

$$R_{к} = \frac{\rho_{киз} \cdot \sum_{i=1}^{f} \delta_{кі}}{4 \cdot \pi \cdot r_1 \cdot n \cdot l_{паз} \cdot \psi}, \quad (18)$$

where n - is the number of conductors, adjoining to the walls of the slot;
$l_{паз}$ - is the length of the stator core.

Calculation of values of the frame resistance has shown, that for AEs under research they make 320-1000 MOhm. The capacitance toward the frame of one winding coil, considering assumptions, can be determined under the formula

$$C_{кат} = \frac{\pi \cdot \varepsilon_0 \cdot \varepsilon_{киз} \cdot 2 \cdot l_{паз}}{\ln \dfrac{\delta_{лак} + \delta_{эм} + \sum_{i=1}^{m} \delta_{кі} + r_{экв}}{r_{экв}}}. \quad (19)$$

Then the capacity of one phase toward the frame is calculated as follows:

$$C_{ф} = k_2 \frac{n}{6} C_{кат}, \quad (20)$$

where n – is the number of stator slots;
$n/6$ - the number of coils in a phase;
k_2 - the factor, which takes into account the correction for the fringe effect (K_2 = 1,0- for machines of open construction and K_2 = 1,05-1,07 for the closed machines). In conclusion it is necessary to note, that the carried out researches have allowed to receive a number of the additional expressions, which take into account the influence of concentration of substances, which are found in the environment, on parameters values of the equivalent circuit. Generally, using the theoretical approach to describe the condition of DS and taking into account its real heterogeneity, defectiveness of insulation can be presented as the factor of porosity $K_{пор}$ determined by expression

$$K_{пор} = \frac{V_{пор}}{V_{из}} = \frac{\pi \cdot \varepsilon_{возд} \cdot \varepsilon_{эм} \cdot \varepsilon_{лак} \cdot l \cdot \varepsilon_0}{\ln\left[\dfrac{\delta_{из} + r}{r}\right] \cdot C_{в} \cdot \varepsilon_{эм} \cdot \varepsilon_{лак}} - \frac{V_{эм} \cdot \varepsilon_{возд}}{V_{из} \cdot \varepsilon_{эм}} - \frac{V_{лак} \cdot \varepsilon_{возд}}{V_{из} \cdot \varepsilon_{лак}}. \quad (21)$$

The expression (21) reflects defectiveness of dry insulation, the pores of which are filled with clean air. In case of dampening or pollution of the pores in materials of multilayered insulation construction design the expression (21) will look like

$$K_{пор} = \frac{V_{пор}}{V_{из}} = \frac{\pi \cdot \varepsilon_{зс} \cdot \varepsilon_{эм} \cdot \varepsilon_{лак} \cdot l \cdot \varepsilon_0}{\ln\left[\frac{\delta_{из} + r}{r}\right] \cdot C_в \cdot \varepsilon_{эм} \cdot \varepsilon_{лак}} - \tag{22}$$
$$- \sum_{i=1}^{k} \frac{V_i \cdot \varepsilon_{зс}}{V_{из} \cdot \varepsilon_i},$$

where $\varepsilon_{зс}$ - is dielectric permeability of the mixture, filling pores;
ε_i - dielectric permeability of i- layer of insulation;
k - is the number of layers of insulating materials.

Interturn capacitance at presence of polluting impurities can be determined by the expression

$$C_в = \frac{\pi \cdot \varepsilon_0 \cdot V_{из} \cdot \prod_{i=1}^{k} \varepsilon_i \cdot l}{\sum_{i=1}^{k}\left[V_i \cdot \left(\prod_{\substack{j=1 \\ j \neq i}}^{k} \cdot \varepsilon_j\right)\right] \cdot \ln\left[\frac{\delta_{из} + r}{r}\right]}. \tag{23}$$

Interturn resistance at presence of impurities in a winding

$$R_в = \frac{\left(V_{лак} \cdot \rho_{лак} + V_{эм} \cdot \rho_{эм} + \sum_{i=1}^{n} V_{зci} \cdot \rho_{зci}\right)}{2 \cdot V_{из} \cdot \pi \cdot r_1 \cdot l \cdot \psi} \times \tag{24}$$
$$\times \sum_{i=1}^{g} \delta_{вi},$$

where $V_{зci}$ is the volume of i- component of the polluting mixture;
$\rho_{зci}$ - specific resistance of i- component of the polluting mixture.

However, besides chemical factors, at execution of the appropriate calculations it is also necessary to take into account influence of some physical factors. Thus we shall assume, that during diagnosis of parameters value equivalent circuits do not change, that is, time of diagnosis is little in comparison to the time, necessary for the change of physical and chemical properties of insulation construction design.

In the given restrictions the basic physical factor, which value is subject to the account, is the temperature of a winding. Reception by theoretical way of dependence of both parameters of equivalent circuit and test parameter on the temperature represents a very laborious task. Therefore, temperature dependence of $П_{из}$ test parameter was found during experimental researches. The given dependence looks like:

$$П_{из.t} = \frac{П_{из}}{1 + 0{,}0004 \cdot \frac{П_{из.эт}}{П_{из}}(t - 20)}, \tag{25}$$

where $П_{из.эт}$ - is reference value of $П_{из}$;
$П_{из.t}$ - value of $П_{из}$ at 20°C.

Thus, on the basis of the aforesaid, the result of the executed researches is the found opportunity of detemining reference values of $П_{из}$ test parameter for each type of AE. Calculation is carried out with the use of the described above model of wave damped vibrations, and the initial data are values of parameters of the equivalent circuits found above. Besides, substitution of the received reference values of test parameter in dynamic stochastic model [4] will allow to receive nominal service life of dielectric systems of concrete type of AE in the given conditions of operation.

The results of research given in the present publication allow to make the following basic conclusions:
- an establishment of quantitative interrelations between parameters of equivalent circuit of a stator winding and a number of parameters of AE design is possible only in an implicit kind;
- connection of WDV parameters and parameters of equivalent circuit can be established with the help of the offered mathematical model of WDV in a winding taking into account design factors of AE insulation systems;
- dielectric permeability of DS directly depends on dielectric permeabilities of the components included in it and their volumetric propotion;
- interturn capacitance is inversely proportional to the value of porosity factor of a winding and depends on properties of the material, filling pores;
- values of test parameter are increased with growth of capacitance and the number of AE poles.

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Altai State Technical University

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