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# The Analysis Main and Differential Dissipation of The Inductances Windings Stator an Energy Method

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**Abstract:** In article are brought methods of the calculation main and differential dissipation of the inductances, which allows to take into account all factors, influencing upon inductances, except influences of unevenness of the air clearance between steel still part and rotor and демпфирующего influences current, directed in secondary sidebar by fields high spatial harmonic, created by winding статора machines of alternating current. The Proposed methods of the calculation is founded on models of the field of the air clearance of the electric machine of alternating current.

**The Keywords**: Differential dissipation of the inductances, steel still part, air clearance, machine of alternating current, energy and harmonic analysis.

The main and differential scattering inductance of the stator winding are the main parameters due to the field of the main air gap of modern AC electric machines. They are complex functions of the radial size of the air gap between the stator and rotor cores, the number of slots per pole and phase, the pitch, the number of phases and winding zones, the width of the slot of the slot, the tooth pitch, the magnetic state of the steel sections of the stator and rotor magnetic circuits and the damping effect of currents in the secondary circuits of the machine[1]. We present a methodology for calculating the main and differential dissipation of inductances, which allows us to take into account all the above factors affecting these inductances, except for the influence of the unevenness of the air gap between the stator and rotor cores and the damping effect of currents induced in the secondary circuits by fields of higher spatial harmonic generated by the stator winding of the AC machine. The proposed calculation method is based on the model of the air gap field of an AC electric machine.

In the model, it is assumed that the total current of the stator slot is concentrated in a thin layer located along the arc of the circle of the smooth surface of the stator bore and the width of the even width of the slot of the slot, which corresponds to the internal spatial angle $2\alpha$. The radial size of the air gap $\delta$ between the ferromagnetic cores of the stator and the rotor of the machine is assumed to be uniform.

As you know, the differential leakage inductance is the difference between the winding inductance due to the actual field in the air gap and its fundamental wave. The main field wave determines the main inductance of the winding. Inductors can be determined for the case of supplying each phase of a polyphase winding separately, for the case of a polyphase supply, as well as for zero sequence currents. The issue of the computational determination of the main and differential dissipation of inductances for a single-phase winding and for currents of positive sequence of three-phase windings is considered. Usually, when calculating the reactivities due to the magnetic field of the main air gap of AC machines, energy and harmonic analysis methods are used. Let us apply the first of these methods, based on the energy method for determining inductances.

When applying the method for one phase of polyphase stator windings, the expressions (double-layer windings with integer q), (single-layer windings with integer q) can be used, (two-layer windings with fractional q with a fractional base equal to two) and similar expressions (for any fractional values of q) [2].

The expression for the strength of the magnetic field in the air gap of the machine, created by the three-phase stator winding, is compiled for one of the instantaneous values of its current. In particular, for the moment in time, when the current in one of the phases of the three-phase two-layer winding is zero, and in the other two phases the currents are equal in magnitude and opposite in sign, the expression for the field strength has the form

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$$H_m = \sqrt{3} w_1 a_1 \sum_{n=1}^{\infty} K_n \kappa_{об n} \kappa_{pqn} \left\{ \sin n \left[ \varphi - \frac{(2p-1)}{p} \frac{\pi}{2} \right] - \right.$$
$$\left. - \sin n \left[ \varphi - \frac{(2p-1)}{p} \frac{\pi}{2} - \frac{2\pi}{3p} \right] \right\}, \quad (1)$$

where $a_1$ - number of parallel branches of the stator winding; $w_1$ - the number of effective turns of one phase of the winding: $w_1 = \frac{2pqw_\kappa}{a_1}$.

After some transformations from (1) we get

$$H_m = 2\sqrt{3} w_1 a_1 \sum_{n=1}^{\infty} K_n \kappa_{об n} \kappa_{pqn} \cos n \left[ \varphi - \frac{(6p+5)}{6p} \pi \right] \sin n \frac{\pi}{3p}. \quad (2)$$

Differential leakage inductance

$$L_\partial = L - L_г, \quad (3)$$

where is the inductance of the winding due to the actual field in the gap, $L_г$ - main inductance.

As you know, the inductance of the winding is associated with the electromagnetic energy of the real field by the expression

$$L = \frac{2}{i^2} W, \quad (4)$$

where $W$ - electromagnetic energy of the actual field in the machine gap.

Like (4) main winding inductance

$$L_г = \frac{2}{i^2} W_г. \quad (5)$$

where $W_г$ - electromagnetic energy of the main working field in the machine gap.

Taking into account (4) and (5) from (3) we obtain the expression for the differential leakage inductance of a single-phase winding:

$$L_{\partial o} = L_o - L_{го} = \frac{2}{i^2}(W_0 - W_{го}). \quad (6)$$

where $W_0$ - electromagnetic energy of the real field of a single-phase winding in the machine gap, $W_{го}$ - electromagnetic energy of the main working field of a single-phase winding.

Similarly (6), the differential leakage inductance of one phase of a three-phase winding when powered by a three-phase current

$$L_{\partial m} = L_m - L_{гm} = \frac{4}{3i^2}(W_m - W_{гm}), \quad (7)$$

where $W_m$ - electromagnetic energy of the real field of a three-phase winding;

$W_{гm}$ - electromagnetic energy of the main working field of a three-phase winding.

In (6) and (7), the designations “o” and “т” in the indices correspond to single-phase and three-phase windings. On the other hand, the electromagnetic field energy is in the air gap.

$$W = \sum_v \mu_0 \frac{H^2}{2} dV, \quad (8)$$

where $H$ - the effective value of the magnetic field strength, V is the volume of the air space between the stator and rotor cores of the machine.

$$V = \int_0^{2\pi} l_\delta \delta \frac{b+c}{2} d\varphi, \quad (9)$$

where $l_\delta$ - calculated length of the air gap.

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With regard to single-phase and three-phase windings, expression (8), taking into account (9), can be written

$$W_o = \frac{\mu_0 l_\delta \delta(b+c)}{4} \int_0^{2\pi} H_o^2 d\varphi, \qquad (10)$$

$$W_{го} = \frac{\mu_0 l_\delta \delta(b+c)}{4} \int_0^{2\pi} H_{op}^2 d\varphi, \qquad (11)$$

$$W_m = \frac{\mu_0 l_\delta \delta(b+c)}{4} \int_0^{2\pi} H_m^2 d\varphi, \qquad (12)$$

$$W_{гm} = \frac{\mu_0 l_\delta \delta(b+c)}{4} \int_0^{2\pi} H_{mp}^2 d\varphi, \qquad (13)$$

where $H_{op}$, $H_{mp}$ - basic harmonic strengths of magnetic fields of single-phase and three-phase windings.

The values $H_{op}$ and $H_{mp}$ are obtained by substituting $n$=p (1) and (2), respectively and others.

$$H_{op} = 2 w_1 a_1 K_p \sin p\left[\varphi - \frac{(2p-1)}{p}\frac{\pi}{2}\right], \qquad (14)$$

$$H_{mp} = 3 w_1 a_1 K_p \cos p\left[\varphi - \frac{(6p+5)}{6p}\pi\right], \qquad (15)$$

$$K_p = \left[C_{\delta n}\rho^{(p-1)} - D_{\delta n}\rho^{-(p+1)}\right]\frac{\sin p\alpha}{\alpha} \sin p\frac{\beta}{2} \frac{\sin pq\frac{\alpha_z}{2}}{q \sin p\frac{\alpha_z}{2}} \cos p\pi .$$

Substituting (14) and (15), respectively, in (11) and (13) and performing the integration, we obtain

$$W_{го} = \pi \mu_0 w_1^2 l_\delta \delta(b+c) K_p^2,$$

$$W_{гm} = \frac{9\pi}{4}\mu_0 w_1^2 l_\delta \delta(b+c) K_p^2 .$$

Integration in (10) and (12) with a large number of harmonics in the composition $H_o$ and $H_m$ difficult, and in some cases practically impossible [3]. Therefore, the quantities $H_o$ and $H_m$ can be replaced with equivalent values $H_{oэ}$ and $H_{mэ}$, which are found graphically by dividing the corresponding field curve into s equidistant ordinates $h_1$, $h_2$, $h_3$ and others by expressions.

$$H_{oэ} = \sqrt{\frac{1}{s}\left(h_{o1}^2 + h_{o2}^2 + h_{o3}^2 + \ldots + h_{os}^2\right)}, \qquad (16)$$

$$H_{mэ} = \sqrt{\frac{1}{s}\left(h_{m1}^2 + h_{m2}^2 + h_{m3}^2 + \ldots + h_{ms}^2\right)}. \qquad (17)$$

Substituting $H_{oэ}$ and $H_{mэ}$ instead of $H_o$ and $H_m$, respectively, (10) and (12) and integrating we have

$$W_o = \frac{\pi}{2}\mu_0 \delta l_\delta (b+c) H_{oэ}^2,$$

$$W_m = \frac{\pi}{2}\mu_0 \delta l_\delta (b+c) H_{mэ}^2 .$$

Note that when dividing the field curve, to find $H_{oэ}$ and $H_{mэ}$ for (16) and (17), for equidistant ordinates, for armature windings with integer q, it is enough to limit one pole division, and for windings

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with fractional q, you need to use the field curve within the part of the stator winding repeating in its structure. With an even base of fractionality, the repeating part of the winding occupies the number of pole divisions equal to the base of fractionality, and with an odd base, twice the base of fractionality.

As noted earlier, the above expressions for calculating the main and differential inductance dissipation are valid for two-layer windings with an integer q.

Calculations of the main and differential dissipation of inductances are carried out on a computer for a four-pole alternating current machine with a two-layer armature winding at

$a$=0; b=0,1241м; $\rho$=$c$=0,125; d=0,184 м; $\alpha$=0,028 рад; $\alpha_z$ =0,1496 рад; $\beta$=1,3464 рад; q= $3\frac{1}{2}$; $W_1$ =56. These values basically correspond to a three-phase salient pole synchronous generator of the type MCA 72/4, 15 кВА (12кВт), 230 В, connection diagram of the stator winding "star", 1500 rpm. The differential leakage inductance of one phase with three-phase power supply in the range of variation of the relative value of the magnetic permeability of the steel parts of the stator and rotor magnetic circuits from 200 to 4000 remains practically unchanged and decreases only at those values $\mu$ which correspond to deep saturation of the magnetic circuit. At the same time, the main inductances of the windings, both with single-phase and three-phase power supply, depending on the value $\mu$ vary within fairly wide limits. The differential leakage inductance with a single-phase supply varies over a wider range than with a three-phase supply.

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