The Development of Windings Diagnostic Methods of the Electric Equipment

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Abstract. The influence of the short-circuited contour (SCC) on magnetic characteristics of a material of the transformer core and also on parameters of damping electrical oscillations in windings of electrical machines are considered.

Introduction

A reliability of an electrical equipment is determined to a large degree by a state of its windings, for example, a probability of a formation of short circuits in them. It is known, that an objective progressing development of SCC with induced in them currents of considerable magnitude due to an influence of operating conditions of electrical equipment takes place.

1. Examination of Influence SCC on Magnetic Characteristics of a Material of a Magnetic Circuit

A magnetic field $\overline{H}_c$ of SCC with a current, opposing to a magnetic field $\overline{H}_w$ of windings, reduces to changing a field of magnetization $\overline{H}_{mag}$, which is the sum of fields: $\overline{H}_{mag} = \overline{H}_w + \overline{H}_c$. Therefore, SCC directly influences, due to a natural magnetic field $\overline{H}_c$, on processes of alternating magnetization in a core and on its magnetic characteristics. Examination of this effect was carried out on a twisted core of anisotropic electrical steel (Fig. 1). The reading winding 2 of length l_r, the exciting one 3 of length l_e and SCC 4 in the form of separate closed winding of a wire have been reeled on the magnetic core 1. During examinations a wire section in SCC was varied, that caused a change of a current magnitude

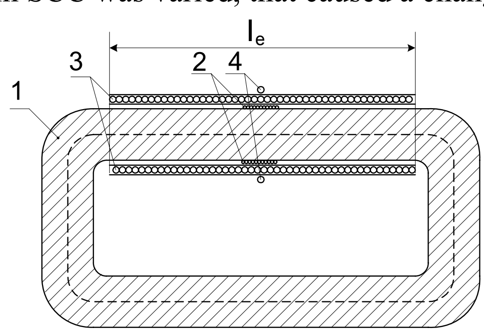

Fig. 1 - The disposition of windings and SCC on a magnetic core.

induced in it and of a magnetic field strength $\overline{H}_{\mathrm{c}}$. The alternating voltage with frequency of 50 Hz was impressed on a magnetizing winding 3. The magnetic field strength H_{w} in a winding 3 was calculated on a current magnitude in it, amplitude values of a magnetic induction in material of a magnetic core were found on electromotive force value, induced in a reading winding 2. The winding 2 placed in area where a magnetic field strength H_{w} and a magnetic induction in material in the absence of SCC were homogeneous since $l_{\mathrm{e}} >> l_{\mathrm{r}}$. The magnetization curves ($B_{\mathrm{m}} - H_{\mathrm{mw}}$) of magnetic core material in the absence and in the presence of SCC are presented in Fig.2. A comparison of these curves shows influence of the magnetic field $\overline{H}_{\mathrm{c}}$ as dimagnetization factor, opposing a magnetic field of a winding $\overline{H}_{\mathrm{w}}$.

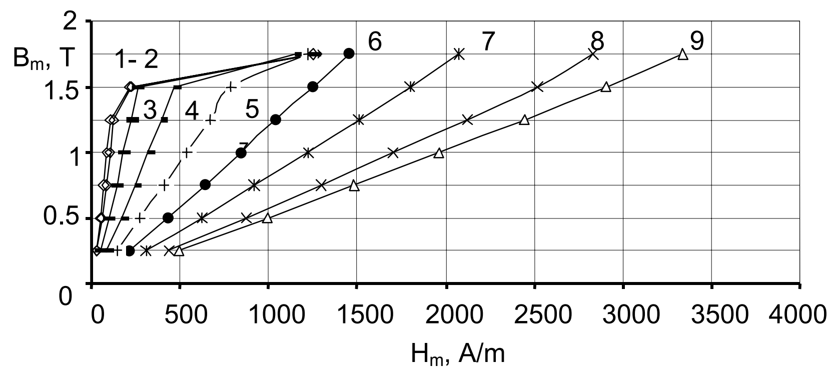

Fig. 2 - Magnetization curves of a magnetic core material at various values of section S of wire in SCC: 1 - without SCC; 2 - $S = 0{,}03$ mm^2; 3 - $S = 0{,}11$ mm^2; 4 - $S = 0{,}25$ mm^2; 5 - $S = 0{,}53$ mm^2; 6 - $S = 0{,}78$ mm^2; 7- $S = 1{,}19$ mm^2; 8 - $S = 1{,}79$ mm^2; 9 - $S = 2{,}06$ mm^2.

From Fig. 2 it is seen, that at magnification of a wire section in SCC the amplitude value of a magnetic field strength of the winding H_{mw} at a given value of amplitude of a magnetic induction B_m increases. The analysis of dependencies in Fig. 2 shows, that influence of SCC is the most essential over the values range of the magnetic induction B_m, corresponding to area of the greatest magnetic permeabilities of magnetic core material.

2. Influence SCC on Transients in Windings of Electric Machines

2.1 Basic Positions

We consider oscillating contour $C_1L_1R_1C_2L_2R_2$, where L_2 is a tested winding, R_2 is the measuring resistor, $\bullet_2$ is the high-voltage capacitor, R_1 is the current resistor, L_1 is the damping coil, $\bullet_1$ is the additional capacitor (Fig. 3). Let's define transitive values of a current and a voltage in the circuit of interest at when acting upon it a voltage of a sine wave form at switching a key K from 1 in 2. Let us assume that a tested coil L_2 contains SCC. It, as follows from above mentioned results, causes a reduction of an inductance of the coil L_2 by size $\bullet$L. Before switching a key K from 1 in 2 the sine wave current proceeds in the circuit.

$$i = I_m \sin(\omega t - \varphi) \tag{1}$$

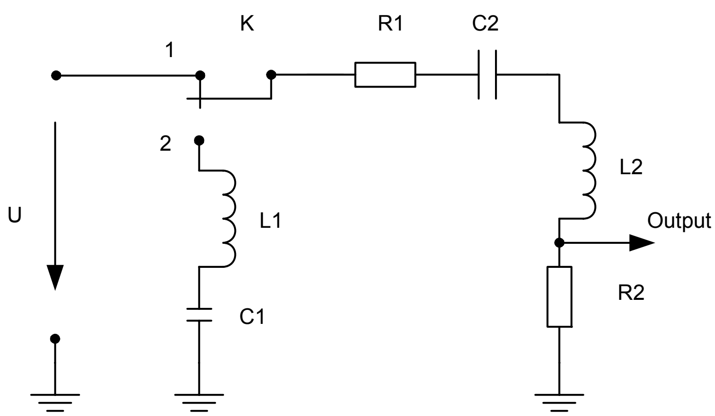

Fig. 3 – The circuit of excitation of damped electric oscillations

The voltage on plates of capacitor S_2 changes under the law

$$U_{C2} = X_{C2} I_m \sin\left(\omega t - \varphi - 90^0\right) \tag{2}$$

Transitional process in contour $C_1L_1R_1C_2L_2R_2$ after switching a key K in position 2 can be described by the Ohm's law in the operational form. Let at the moment of time t_0 a current and a voltage of transient are accordingly equal i_0 and U^0_{c2}. There is not external source of an electromotive force in the contour and we can write an internal electromotive force as:

$$E(p) = (L_2 - \Delta L)\ i_0 - \frac{U^0_{C2}}{p} \tag{3}$$

An operational resistance of a contour

$$Z(p) = R_1 + R_2 + p(L_1 + L_2 - \Delta L) + \frac{C_1 + C_2}{pC_1C_2} \tag{4}$$

Keeping in mind that $L_2 - \Delta L >> L_1$, and entering designations $R = R_1 + R_2$, $C = \frac{C_1C_2}{C_1 + C_2}$, we can write Ohm's law in the operational form as:

$$I(p) = \frac{E(p)}{Z(p)} = \frac{C\,p\,L_2\ i_0 - U^0_{C2} C - C\,p\,\Delta L\ i_0}{RC\,p + C(L_2 - \Delta L)p^2 + 1} \tag{5}$$

For finding current image $I(p)$ from (5) $I(p)$ the second theorem of decomposition [1] is applied:

$$I(p) = \frac{P(p)}{Q(p)} \bullet\!=\!\bullet \sum_{k=1}^{2} A_k e^{\alpha_k t}, \tag{6}$$

where $A_k = \frac{P(\alpha_k)}{Q'(\alpha_k)}$, $Q'(p) = \frac{dQ(p)}{dp}$, α_k are simple roots of a denominator of rational fraction in (5). Solving the equation $Q(p) = 0$, we shall receive expressions for α_1 and α_2:

$$\alpha_1 = -\frac{R}{2(L_2 - \Delta L)} + \frac{j}{\sqrt{C(L_2 - \Delta L)}} \tag{7}$$

$$\alpha_2 = -\frac{R}{2(L_2 - \Delta L)} - \frac{j}{\sqrt{C(L_2 - \Delta L)}}, \tag{8}$$

where j is imaginary unit. Calculating A_k with the account (7) and (8), we shall receive from (6) expression for the original of a transient current:

$$i(t) = \frac{P(\alpha_1)}{Q'(\alpha_1)} e^{\alpha_1 t} + \frac{P(\alpha_2)}{Q'(\alpha_2)} e^{\alpha_2 t} = e^{-\frac{R}{2(L_2 - \Delta L)} t} \left(i_0 \cos \frac{t}{\sqrt{C(L_2 - \Delta L)}} - \left(\frac{CRi_0}{2\sqrt{C(L_2 - \Delta L)}} + \right. \right.$$

$$\left. \left. + \frac{U_{C2}^0 C}{\sqrt{C(L_2 - \Delta L)}} \right) - \sin \frac{t}{\sqrt{C(L_2 - \Delta L)}} \right) \quad (9)$$

In a case when the winding L_2 has no SCC expression (9) becomes simpler and looks like:

$$i(t) = e^{-\frac{R}{2L} t} \left(i_0 \cos \frac{t}{\sqrt{CL_2}} - \left(\sqrt{\frac{C}{L_2}} \frac{R}{2} i_0 + \sqrt{\frac{C}{L_2}} U_{C2}^0 \right) \sin \frac{t}{\sqrt{CL_2}} \right) \quad (10)$$

The comparison (9) and (10) shows, that SCC reduces characteristic resistance ($\rho = \sqrt{\frac{L}{C}}$) of the tested coil, and so, a goodness ($Q = \frac{\rho}{R}$) of the whole of the oscillating contour. A damping decrement $\alpha = \frac{R}{2L}$ increases. Hence, speed of transient damping in a considered oscillating contour grows.

2.2 Experimental Researches

Transients in stators windings of three and single-phase electric motors were investigated. In each groove of a stator the only one turn which could be closed and disconnected was put as additional, simulating different number of SCC in a winding. In this case the stator winding with an inductance L_2 has been included in the oscillating contour $C_1L_1R_1C_2L_2R_2$ (Fig. 3) in which free oscillations excited. Oscillograms of damping oscillations in the given contour at various number of SCC in winding L_2 and at their absence are submitted in Fig. 4. In Fig. 5 oscillograms of the signals received as difference between damping oscillations in

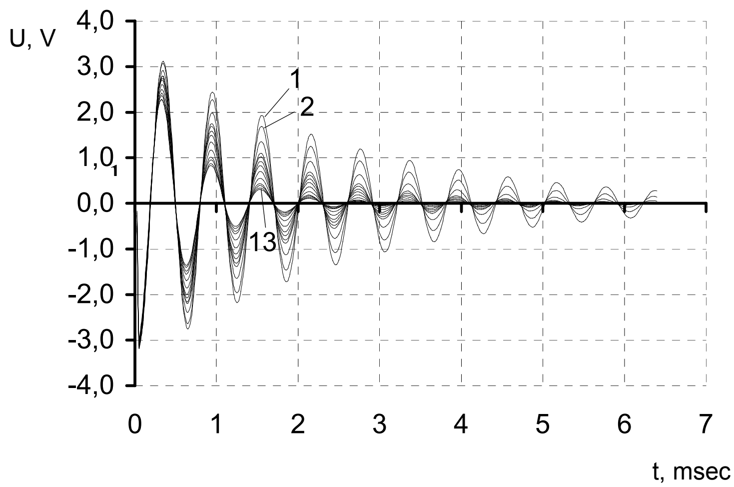

Fig. 4 – Damping oscillations in a contour at: 1 - absence SCC; 2 - 1 SCC; …; 13 - 12 SCC.

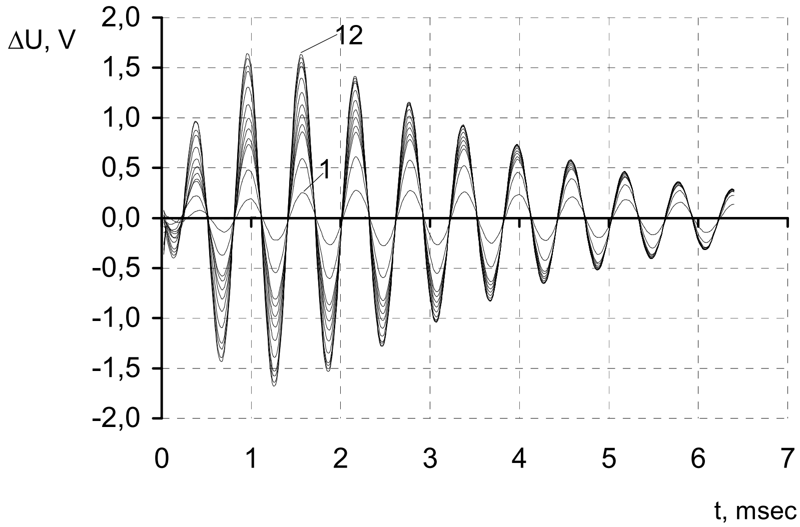

Fig. 5 – Difference signal of damping oscillations in the contour at: 1 - 1 SCC; …; 12 - 12 SCC.

a contour at absence of SCC and at presence of various number of SCC in stator winding L_2 of the electric motor (difference signals) are submitted. From Fig. 5 it is visible, that curves of difference signals directly caused by influence of SCC on damping oscillations in the contour, have maxima. These are areas of maximum sensitivity of transients to influence of SCC in the oscillating contour. Amplitude values of difference signal curves of damping oscillations with the different number of SCC are presented in Fig. 6. From this figure it is visible, that areas

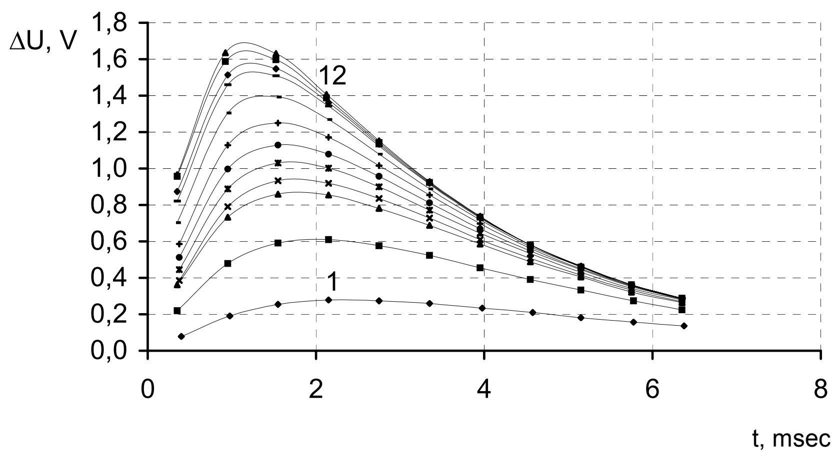

Fig. 6 –Amplitude values of difference signal damping oscillations at: 1 - 1 SCC; …; 12-12 SCC.

of maximum sensitivity of transients to influence of various number SCC are shifted on a t-line from each other.

3. Conclusions

- It's experimentally shown that presence of SCC, linked to the basic magnetic flow the core, results in reduction of its dynamic magnetic permeability. This reduction is the most essential in a range of values of the magnetic induction, corresponding to an area of the greatest magnetic permeabilities of core material.

- It is by calculations and experimentally shown, that presence of SCC results in growth of speed of transients damping in windings of electric motors.
- It is experimentally established, that values of the component of transients in windings of electric motors, caused by influence of SCC (difference signal) depend on number of SCC and have on the maxima shifted from each other t-line which are areas of the greatest sensitivity of transients to influence SCC.

Results of work create preconditions for development of methods of detection of SCC in windings of an electric equipment with the purpose of increase of their sensitivity and information.

References

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