REDUCING THE LOSSES LEVEL OF THE COLLECTOR SYSTEM USED WITHIN THE TRANSFORMERS PROVIDED WITH ROTATING SECONDARY WINDING

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REZUMAT. Lucrarea prezintă utilizarea unui model matematic generalizat pentru calculul rezistenţei echivalente a traseului conductor în vederea stabilirii nivelului pierderilor provocate de curenţii de inducţie în cadrul sistemului colector cu tole de jug cu joncţiuni suplimentare al unui transformator cu înfăşurare secundară rotitoare.

Cuvinte cheie: pierderi, înfăşurare secundară rotitoare, sistem colector.

ABSTRACT. This paper present a generalized mathematical model for calculating equivalent resistance of the conductive route in order reducing the level of heat losses in the yoke laminations of collector system with additional junction used it is used in the transformers provided with rotating secondary winding. The heat losses at issue is due to induction currents established in the circuits consisting of yoke laminations pairs of shorted by collectors elements.

Keywords: collector system, losses, rotating secondary winding.

1. INTRODUCTION

The content of this paper is part of a current research area and an obvious theoretical and practical interest, linked to analytical treatment based on adequate mathematical models of sliding contacts and experimental approaches including the development of new solutions to improve the duration of life of the transformers and the autotransformers used to regulate voltage of the electricity distribution systems. Industrial installations sensitive to voltage variations and laboratory installations that is required to maintain the voltage, as a condition specifically required by the rules, are areas of major interest to justify the development of sources of medium and even large power, capable of to permit fine adjustment of the step or continuous load voltage.

Is also required for such sources and other conditions: to be static, to adapt without major difficulties to control systems and automatic voltage stabilizer, do not produce distortions of the sinusoidal variation in time of the voltage supplied, to have high reliability, etc.

Some of the above conditions are met with some precision by the autotransformers and the transformers with regulation steps of the voltage ratio, where the regulations steps are integer multiples of control voltage turns. If adjustment is required to be taken continuously under load it is necessary a construction involving a sliding contact on the spiral route of the adjustment winding and a mobile connection crossing the magnetic circuit, "*last turn*" include a continuously variable number of magnetic field lines.

One solution for this problem is to use a rotating secondary winding of insulated copper in continuous contact with a conductive brush sliding on a movable vertical shaft which is a terminal and the second terminal is a rotating brush in contact with a package of yoke laminations which is also the current path. This current path consisting of ferromagnetic laminations is manifested by an equivalent electrical resistance whose precise assessment is approached in this work.

2. ANALYTICAL MODEL FOR EQUIVALENT ELECTRICAL RESISTANCE

The aspects on the construction optimization of the transformers provided with rotating secondary winding are linked, directly, of the problem of losses and efficiency.

As it results from specialty literature, losses associated collector system can be divided into two main categories:

- Joule-Lenz losses noted with P_C and it are caused by adduction currents flowing through the conductor route of the collector system [3] (the collector brush

PC, yoke laminations associated of the collector system, the plate collectors PK);

- losses noted P_{SC} due to induction currents established in the circuits constituted by the pairs of laminations yoke shorted by collectors elements PR and PK [3].

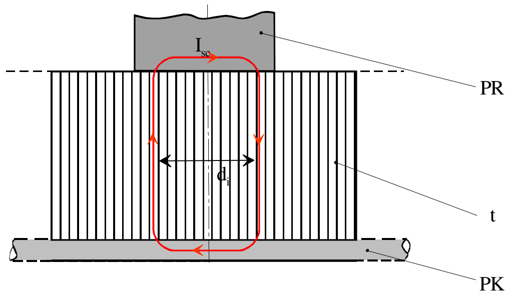


Fig. 1 Detail on the establishing of induction currents through laminations package shorted by the contact elements associated collector system

PR - rotating brush, PK - plate collectors, t- laminations of the front yoke; d_i - the distance between the axes of laminations pairs analyzed

The analysis of losses P_{SC}, caused by induced current in the circuit of the laminations shorted by contact elements of the collector system, is reduced, when applying the simplifying hypothesis $R_{c1}=0$; $R_{c2}=0$ (R_{c1} - contact resistance between the PR brush and laminations, R_{c2} - the contact resistance between the collector plate PK and laminations), at the relation:

$$P_{SC} = \sum_{i=1}^{n} R_{Ei} \cdot I_{sci}^{2} \qquad (1)$$

where: R_{Ei} - equivalent resistance of the conductive route established through laminations considered in "i" conductive circuit; I_{sci}- induced current in the circuit consists of the order "i" pair of laminations shorted by the collectors elements PR and PK of the collector system.

$$I_{sci} = \frac{4{,}44 \cdot f \cdot d_i \cdot l_t \cdot B_{jm}}{2 \cdot R_{Ei}} \qquad (2)$$

where: f- frequency, [Hz]; d_i - the distance between the axes of the laminations pair analyzed, $d_i=2g\cdot(i-1)$,[mm]; g-laminations thickness,[mm]; i-order of the laminations pair considered in the study; l_t - width of laminations package [mm]; B_{jm} - maximum amplitude of magnetic induction in the transformer yoke, [T]; R_{Ei}- equivalent resistance of the conductive route established through laminations of the magnetic system, [Ω].

Equivalent resistance of the conductive route established through the yoke laminations afferent of the collector system is calculated with the relation:

$$R_{Ei} = \frac{\rho_t \cdot l_{te}}{g \cdot \left(\frac{1}{n_e \cdot x \left(k_1 l_{te} + k_2\right)} + \frac{1}{n_e \cdot x_e \left(k_1' l_{te} + k_2'\right)} + l_p \right)} \qquad (3)$$

where: ρ_t - electrical resistivity of the sheet-steel laminated-steel laminated, $\left[\Omega \cdot mm^2/m\right]$; l_{te} - equivalent length of the sheet-steel laminated, [m]; l_p - electrical sockets width [mm]; g - thickness of the magnetic system sheet-steel laminated, [mm]; n_e - parameter which dependent by the sheet-steel laminated- width; x_e - length dispersion area; k_1, k_2, k_1', k_2' - constants.

The analysis of speciality literature led to the following conclusions:

- reduce the width of yoke laminations is directly proportional to the decrease current I_{sci}, due to the reduction in flow due chained circuit faction consists of pairs of shorted laminations;
- placing collector elements at extremity of yoke laminations lead to decrease of the value current I_{sci}, simultaneously with the increase the equivalent resistance R_{Ei}.

3. SOLUTIONS FOR THE REDUCING LOSSES LEVEL

Order to verify the main technical solutions identified for reducing the losses P_{SC} has been investigated the following cases:

– *case 1:* the use of sheet-steel laminated-steel with width l_t $=0.1m$, collector elements PR and PK are placed coaxial, the distance between collector elements axle and the yoke laminations extremity is higher than the equivalent maximum width of dispersion area ($x=x'>L_{dmax}$; $l_t=0,1m$; $B_{jm}=1,2T$);

– *case 2:* the use a sheet-steel laminated width reduced to half, ie $l_t=0.05m$, collector elements PR and PK are placed coaxial, the distance between collector elements axle and the yoke laminations extremity is higher than the equivalent maximum width of dispersion area ($x = x'>L_{dmax}$; $l_t = 0,05m$; $B_{jm} =1,2\ T$);

– *case 3*: the use a sheet-steel laminated width $l_t=0.05\ m$, collector elements PR and PK are placed at one extremity of sheet-steel laminated the distance between brush PR axle and the yoke laminations extremity is higher than the equivalent maximum width of dispersion area, ($x>L_{dmax}$; $x'=0$; $l_t=0,05m$; $B_{jm}=1,2T$)

Reducing the width l_t of the yoke laminations (which is possible by reducing their height) involves two apparently contrary effects. Is obtained a decrease of a fraction of the magnetic flux established through laminations pair shorted and as a result of reduction I_{sci} induced currents in these circuits. In other words, this leads to decreasing of resistance which determine increasing of currents value I_{sci}.

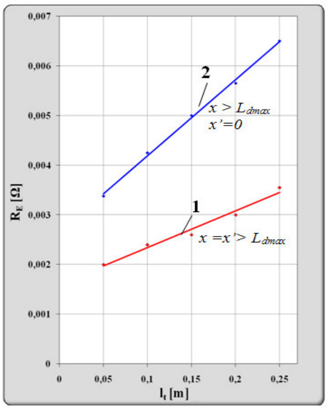
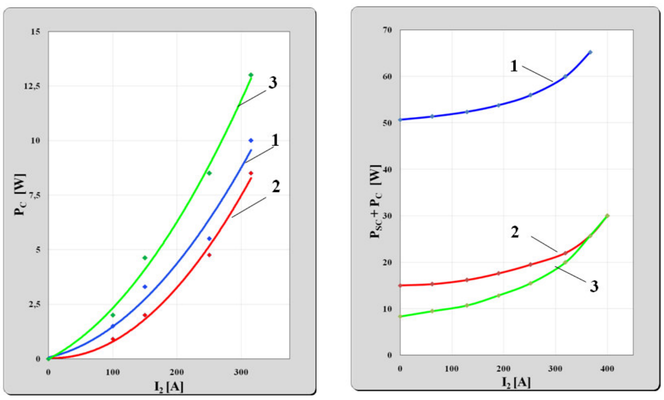


Fig. 2 Characteristics $R_{Ei} = f(l_t)$

The two contrary effects can lead to false premise, of reciprocal compensation, resulting a minor change to currents value I_{sci}. In fact, parameter l_t changing leads to modification, in a proportion much less, of the resistance R_{Ei}, which is expressed in figure 2 by the characteristics $R_{Ei}=f(l_t)$. If the collector elements is located in the sheet-steel laminated middle (characteristic 1 in figure 2) is found that at a decreasing by five times of the yoke laminations width l_t lead to diminution only by 1.73 times of the resistance R_{Ei} and only by 1.93 times in case this are located at extremity (characteristic 2 in figure 2).

In figure 3 are presented the characteristics $P_C=f(I_2)$ and $P_C+P_{SC}=f(I_2)$ for the three cases initially admitted.



a) b)

Fig. 3 Characteristics
a - $P_C =f(I_2)$; b- $P_C+P_{SC}=f(I_2)$

Is found that reducing the width for laminations of yokes frontal leads to reducing the losses P_{SC}, and at to decreasing the losses P_C, which is a consequence of reducing the resistance R_{Ei} of conductive route through the sheet-steel laminated (characteristics 1 and 2).The decrease of losses P_C percentage is more reduced than that of decrease losses P_{SC} because, as noted, the reduce width of laminations does not lead to a decrease, in the same proportion, of resistance $R_{Ei.}$ In this context, the solution of magnetic systems with reduced height yokes is recommended to use. At the magnetic systems in the sheath, the decreasing of yokes height can be achieved by replacement of rectangular section with the square section in the columns achievement.

The solution of resistance increasing R_{Ei} should be treated with caution taking into account the transformer load, because this fact it leads to reducing losses P_{SC} but involves an increase of the losses P_C (characteristic 3 in figure 3a). It is possible that at heavy loads, the total losses sum $P_C+P_{SC'}$ to grow, making this solution inefficient. The utility of this solution is obvious in the case of rotating brushes with large diameters.

To indicate the the maximum possible level for losses P_{SC}, corresponding to the most severe operating conditions, the resistances between collector elements and yoke laminations were considered null ($R_{c1}=R_{c2}=0$). Under normal conditions these resistances, which depend on contact type, by the materials used and the contact force, are different from zero.

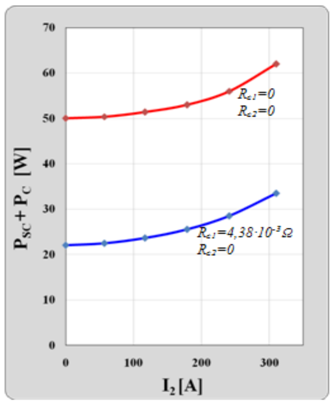


Fig. 4 Characteristics $P_C+P_{SC}=f(I_2)$

In figure 4 are presented the characteristics $P_{SC}+P_C=f(I_2)$ for cases $R_{c1}=R_{c2}=0$ and $R_{c1}=4{,}38\cdot10^{-3}\Omega$, $R_{c2}=0$. It is noted that of contact resistance R_{c1} between the collector elements of yoke laminations lead to a decrease losses P_{SC}.

Simultaneously, it produces and an increase of Joule - Lenz losses at contact the rotating brush PR with yoke laminations. In these conditions is required optimal value of the contact resistance, which for a given operating system, lead to the minimum values of sum P_C+P_{SC}. For a given contact, the optimal value of contact resistance R_{c1} can be obtained by properly adjusting of the pressing force of rotating brush. PR.

Another practical way to increase of resistance R_{Ei} consists in eccentric placement of collector elements on both sides of the front yoke, which represents an increase of equivalent laminations package width which is shorted without change the fraction value of magnetic field flux established through laminations. This new solution consists in additional cutting of yoke laminations through additional oblique junctions in adjacent areas of the rotating brush route

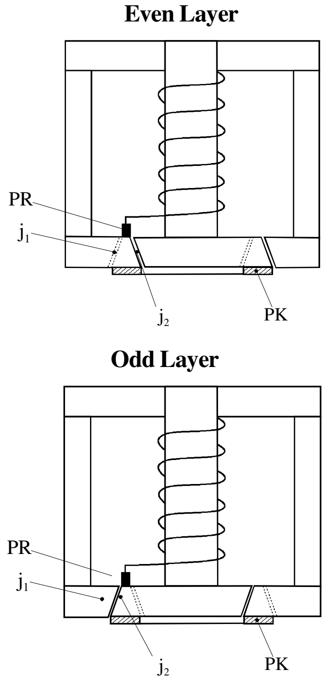


Fig. 5 Collector systems with additional oblique junctions
PR- rotating brush, PK- collector plate, j_1, j_2- oblique junctions

Authors fail through this solution to bring together two remarkable advantages: the increase resistance of the conductive route by placing the collector elements at the extremity sheet-steel laminated and at the same time by increasing the equivalent width of sheet-steel laminated, while the fraction of magnetic flux remains unchanged.

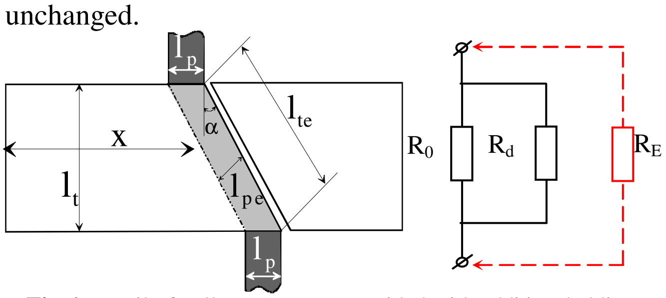


Fig.6. Detail of collector system provided with additional oblique junctions

Immediate result of the solution is increase of the equivalent width of sheet-steel laminated which is calculated with relationship:

$$l_{te} = \frac{l_t}{\cos\alpha}; \tag{4}$$

where: l_{te} - equivalent width of sheet-steel laminated, [m]; l_t - actual width of sheet-steel laminated, [m]; α - angle of the oblique junction, [°].

The result is followed by the following practical effects:

– linear resistance R_0 increase due to increase length of linear conductive area;

– linear resistance R_0 increase due to reducing width of linear conductive area, according to the equation:

$$l_{pe} = l_p \cdot \cos\alpha \tag{5}$$

where: l_{pe} - equivalent width of linear conductive area, [mm]; l_p - actual width of linear conductive area, [mm]; α - angle of the oblique junction, [°].

Therefore, the linear resistance R_0 is computed with the relation:

$$R_0 = \rho_t \cdot \frac{l_{te}}{g \cdot l_{pe}} = \rho_t \cdot \frac{l_t}{g \cdot l_p \cdot \cos^2\alpha} \tag{6}$$

and the dispersion resistance with the relation:

$$R_d = \rho_t \cdot \frac{l_t}{g} \cdot n \cdot x^{(k_1 \cdot l_t + k_2)} \tag{7}$$

and the equivalent resistance R_{Ei} with the following equation:

$$R_{Ei} = \frac{R_0 \cdot R_d}{R_0 + R_d}$$

Study on the influence of junction inclination on the values: the equivalent width of sheet-steel laminated, equivalent width of the linear conduction area, linear resistance, resistance, dispersion equivalent resistance of the conductive route was performed on five samples of laminations and the result is presented, in a form synthetic, as the name operating characteristics of collector system, in figure.

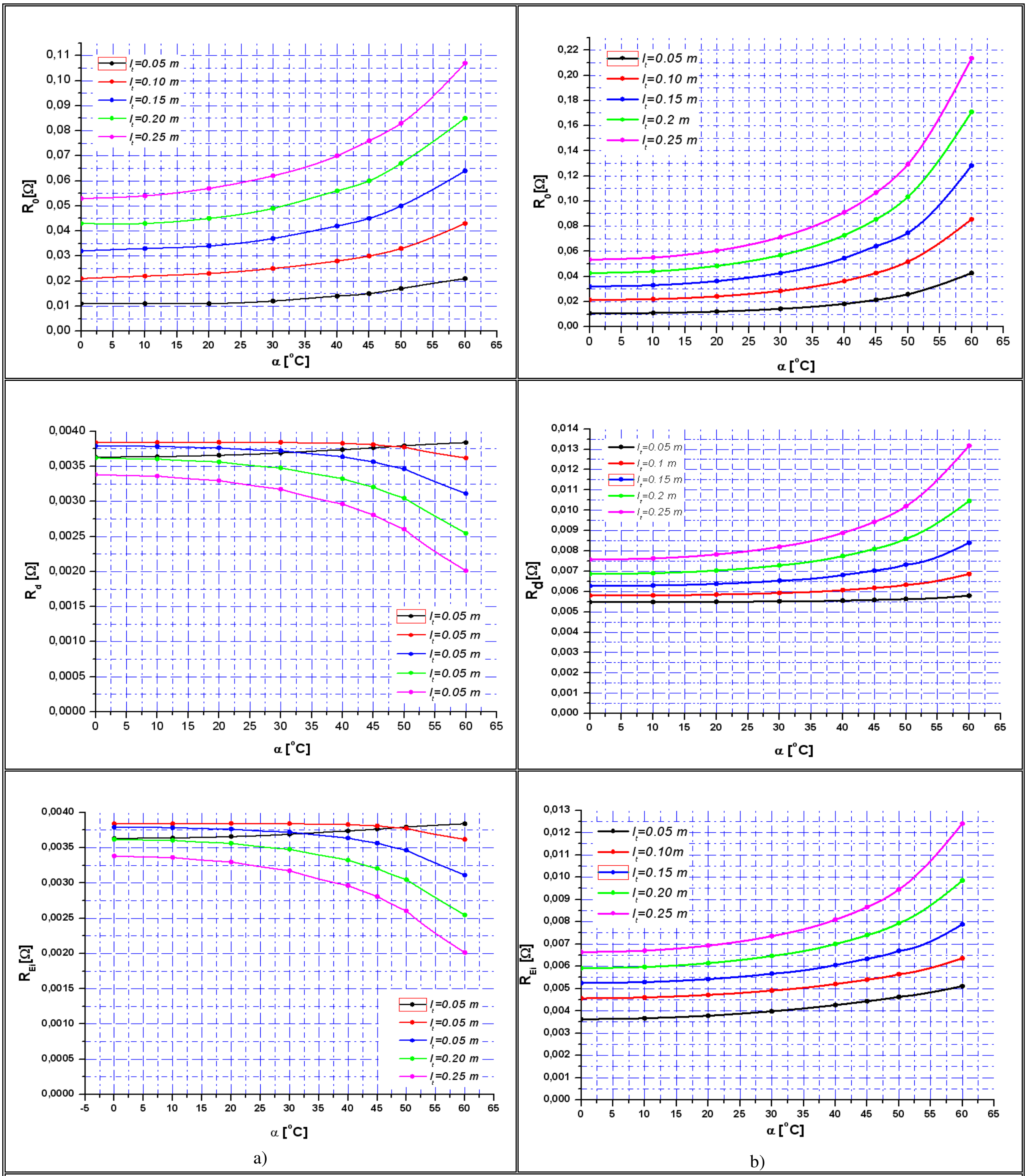


Fig. 7 Operating characteristics of collector system provided with additional oblique junctions

a- for the interval $0 < x \le 0{,}2l_t$; b- for the interval $0{,}2l_t < x < 0{,}6l_t$

CONCLUSIONS

The study of characteristics $R_0=f(\alpha)$ - where α is the angle of additional junction considered in the experiment - indicates that the conduction resistance increases for all five dimensions of sheet-steel laminated considered in the experiment.

The analysis of the curves $R_d=f(\alpha)$ shows the influence of dispersion area width, where for the range $0.2l_t<x<0.6l_t$, the feature $R_d=f(\alpha)$ shows a trend increasing exponentially as a route for all dimensions of sheet-steel laminated considered in experiment. For the interval $0<x\leq 0.2l_t$. the curve $R_d=f(\alpha)$ shows a decreasing trend for the dimensions of sheet-steel laminated used in the experiment with one exception identified for $l_t = 0.05\ m$

Analysis of the $R_E = f(\alpha)$ characteristics leads, in fact, to similar conclusions. The observed dependence of the dispersion width of observing that the interval of $0.2l_t<x<0.6l_t$, feature $R_E = f(\alpha)$ shows a trend upwards, with exponential data for all five dimensions of sheet-steel laminated used in the experiment. Mentioned evolution changes when the range $0<x \leq 0.2l_t$ when small leaf sizes: is increasing and the size of sheet-steel laminated is slightly decreasing.

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