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**ROLLING CURRENT COLLECTOR IN DIRECT CURRENT MACHINES**

V.D. Avilov, D.I. Popov

Omsk state university of means of communication  
E-mail: emoe@omgups.ru

*The new method of rolling current collector has been developed. Its theoretical research was carried out. The operating model sample of the current collecting device using the rolling contact was made.*

Considerable difficulties at adjusting switching of the direct current machines (DCM) are connected with known disadvantages of rolling contact of brush-collector and its limiting switching capacity.

Absence of influence of mechanical factors as well as discharged atmosphere or mordant environment on rolling current collector makes it rather perspective for using in reduced conditions.

The analysis of the existing current collecting devices (CCD) for the direct current machines using the rolling contact shows that all similar devices do not possess switching capacity the same as the rolling contact possesses.

In this connection a new method of rolling current collector was proposed [1]. The matter is in using additional link – rolling rollers (circles) providing electric contact between rotating collector and stationary «brushes» (Fig. 1).

In order to provide the switching capacity of such device its «brushes» should be compound with increasing resistances of their elements to the leaving edge [2, 3].

In Fig. 2 the typical examples of dependences of «brushes» resistances on the place of contact with them for reversible (solid line) and irreversible machines (dotted line) are introduced.  $R_{min}$  and  $R_{max}$  note minimal and maximal resistances of «brush» components (C),  $b_{ш}$  is the «brush» width.

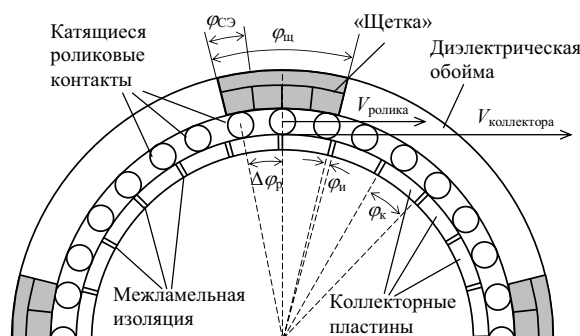


Fig. 1. Current collecting device for DCM

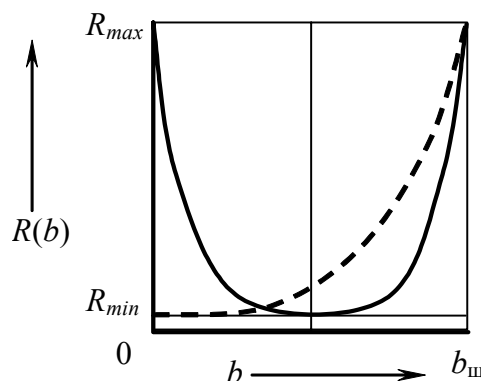


Fig. 2. «Brush» resistance from the place of contact with roller

The term «brushes» is used in quotes as they have different engineering execution (may be made of metal plates connected by resistors) in a new device than in traditional carbon brushes and they function in a different way. Increase of resistance of «brush» contact with a trailing plate is provided not by decreasing the area of their reciprocal contact but increasing the resistance of extreme C. The reduced construction of «brushes» may provide a control of switching capacity of the new device.

The analysis of a new CCD construction allowed determining minimal values of the amount of rollers ( $N_p$ ) and C ( $N_{c3}$ ) required for providing its efficiency connected with the parameters of CCD elements by the following ratios:

$$\left\{ \begin{array}{l} N_p > \frac{360^\circ I_m k}{\varphi_m I_{p, \text{дон}}}; \\ N_p > \frac{360^\circ}{\varphi_k}; \\ N_p \approx K(i + 0,5); \\ \left( N_{c3} > \frac{\varphi_m}{\varphi_n} \right) \text{ или } \left( \frac{\varphi_m}{\Delta\varphi_p} < N_{c3} < \frac{\varphi_m}{\varphi_n} \right); \\ N_p, N_{c3} \rightarrow \min, \end{array} \right. \quad (1)$$

where  $I_m$  is the brush current;  $k$  is the coefficient taking into account irregularity of roller load;  $I_{p, \text{дон}}$  is the rated temperature-rise current flowing through the roller;  $K$  is the number of the commutator segments;  $i$  is any natural number;  $\varphi_m, \varphi_k, \varphi_n, \Delta\varphi_p$  are the angular sizes of CCD elements by the Fig. 1.

For estimation of optimality of switching process conditions the criterion accepted by many leading researchers [4–6] is used. It is determined by current failure in opening «brush» contact with the commutator bar beforehand the switching termination:

$$i_{c6} \approx 0, \quad \frac{di_{c6}}{dt} \approx 0, \quad t \rightarrow T_p, \quad (2)$$

where  $i_{c6}$  is the leaving edge of «brush» in the moment  $T_p$  of contact opening;  $t$  is the time.

Condition (2) may be checked by the form of the current curve of switching section.

In a general case at any variants of brush coverage and simple anchor winding with two parallel branches

the equivalent circuit of switched section has a form introduced in Fig. 3.

In Fig. 3 the following notations:  $i_a$  is the current of parallel branch of anchor winding;  $i_1, i_2, \dots, i_{(N_c+1)}$  are the currents flowing through the «brush» contact with the commutator bars of corresponding numbers;  $R_1, R_2, \dots, R_{(N_c+1)}$  are the electric resistances to flow of currents  $i_1, i_2, \dots, i_{(N_c+1)}$ ;  $N_c$  is the number of sections switching during one concerned moment;  $L$  is the section inductance;  $i_{c1}, i_{c2}, \dots, i_{cN_c}$  are the currents in sections with corresponding numbers are introduced.

Let us introduce the following ratios:

$$t = xT, \quad i_{cj} = 2i_a y_{cj}, \quad E_{Lcp} = L \frac{2i_a}{T}, \quad (3)$$

where  $x$  is the value of relative time;  $T$  is the time of collector turn from the position of the earliest possible close to the position of the latest possible opening of the switched section at different initial positions of rollers;  $j=1, 2, \dots, N_c$  are the numbers of currents and resistances in the equivalent circuit;  $i_{cj}$  is the current of  $j$  section;  $i_a$  is the current of the parallel branch of anchor winding;  $y_{cj}$  is the value of the relative current of  $j$  section;  $E_{Lcp}$  is the value of average emf of self-induction for the period of switching;  $L$  is the section inductance.

If the equations for the equivalent circuit are written down by the Kirchhoff's laws and the substitutions (3) are applied then the following system of differential equations with nonlinear coefficients describing the switching process

$$\left\{ \begin{array}{l} \frac{dy_{c1}}{dx} = \frac{T}{L} [(y_{c2} - y_{c1})R_2 - (y_{c1} + 1)R_1] + \\ + \frac{E_{k, \text{cp}}}{E_{Lcp}} \quad (\text{for } j=1); \\ \frac{dy_{cj}}{dx} = \frac{T}{L} [(y_{c(j+1)} - y_{cj})R_{(j+1)} - (y_{cj} - y_{c(j-1)})R_j] + \\ + \frac{E_{k, \text{cp}}}{E_{Lcp}} \quad (\text{for } j=2, 3, \dots, N_c - 1); \\ \frac{dy_{cN_c}}{dx} = \frac{T}{L} [(1 - y_{cN_c})R_{(N_c+1)} - (y_{cN_c} - y_{c(N_c-1)})R_{N_c}] + \\ + \frac{E_{k, \text{cp}}}{E_{Lcp}} \quad (\text{for } j=N_c), \end{array} \right. \quad (4)$$

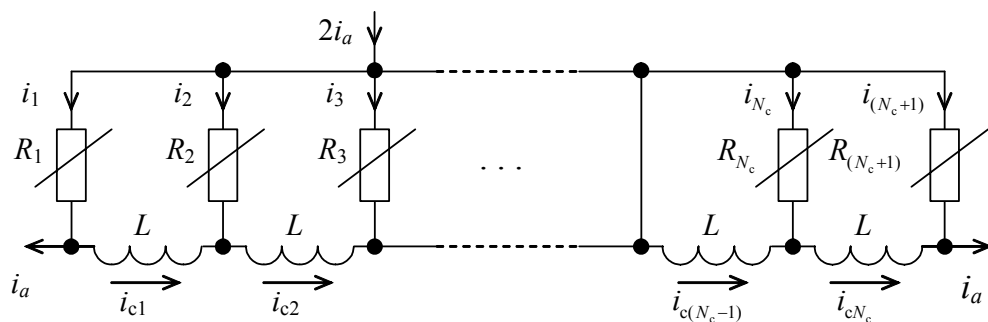


Fig. 3. The equivalent network of switched circuits

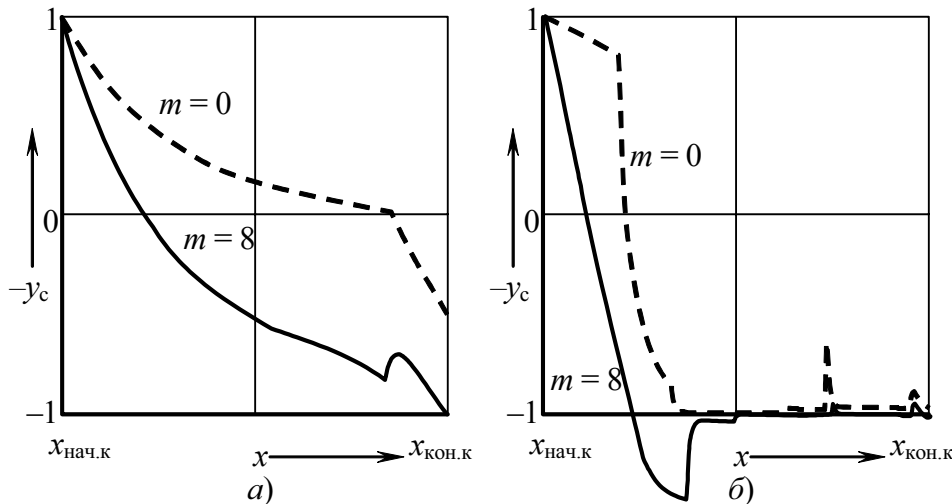


Fig. 4. Curves of switched section current: a) at minimal switching duration, b) at maximum switching duration

may be obtained, where  $E_{k,cp}$  is the value of average emf produced by interpole field for the switching period;  $R_1, R_2, \dots, R_{(N_c+1)}$  are the electric resistances of the equivalent circuit elements by the Fig. 3.

Nonlinearity of coefficients in the equation system (4) is conditioned by abrupt change of resistances of «brush» contact with commutator bars  $R_j$  at appearance and disappearance of rolling lamel contact with each C.

Resistance of «brush» contact with  $j$  commutator bar may be determined from the expression:

$$R_j(x) = \frac{1}{\sum_{i=1}^{N_{ca}} (KSchR_{i,j}(x) \cdot Y_{ca,i})},$$

where  $Y_{ca,i}$  is the conductivity of  $i$  C;  $KSchR_{i,j}(x)$  is the logic function the value of which equals a unit if there is a roller contact between the  $i$  C and  $j$  lamel; and equals zero if there is no contact.

Logic function of  $KSchR_{i,j}(x)$  is determined in terms of motion equations of rollers and edges of commutator bars at introduction of angular coordinate system.

The given theoretical researches allowed designing and manufacturing a working sample of a new current collecting device for production direct current machine of PBST type (rated capacity is 1,2 kW, voltage is 110 V), instead of a brush assembly set on it before. The parameters of the produced CCD were obtained from the ratio (1) and checked in mathematical model against the criterion of optimality of switching conditions (2) by calculating the curves of section current (Fig. 4).

Section currents without ( $m=0$ , dotted line) and with switched emf  $E_k$  ( $m=E_k/E_{Lcp}=8$ , solid line) are shown in Fig. 4. According to the curve form one can say that the developed construction of CCD may meet the demands of switching optimality at certain adjustment of the machine and, therefore, may be used for developing the efficient model sample.

The collector was processed before manufacturing the CCD element. The slots between lamels were filled in with plastic of protacryl type self-solidifying at room

temperature. After plastic solidification the collector was turned at turning lathe and canted on the angle of  $45^\circ$  for providing CCD arrangement.

In connection with high cost of manufacturing roller contacts for CCD their quantity in the model was reduced to the minimally required ( $N_p=92$ ). Thin-wall (wall thickness is 0,2 mm) bronze rings were applied as the roller contacts. They were uniformly spaced on collector in four lines and assembled in separators. In this case all lines are uniformly shifted on a circle relative to each other (Fig. 5).

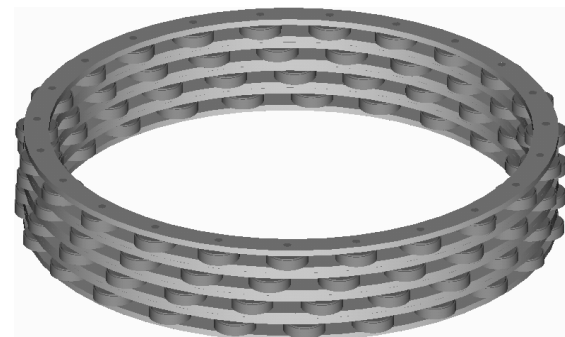


Fig. 5. Rollers assembled in separators

«Brushes» from six copper C isolated from each other and connected with resistors of nichrome wire of different length possessing the resistances:

$$R_i = (0,1; 0,1; 0,9; 8,1; 75; 75) \Omega,$$

where  $i=1,2,\dots,6$  are the numbers of C from entering to leaving edge of the «brush» were used in the model (Fig. 6).

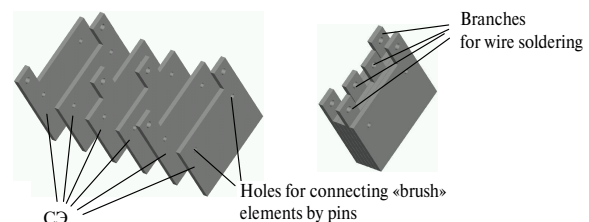
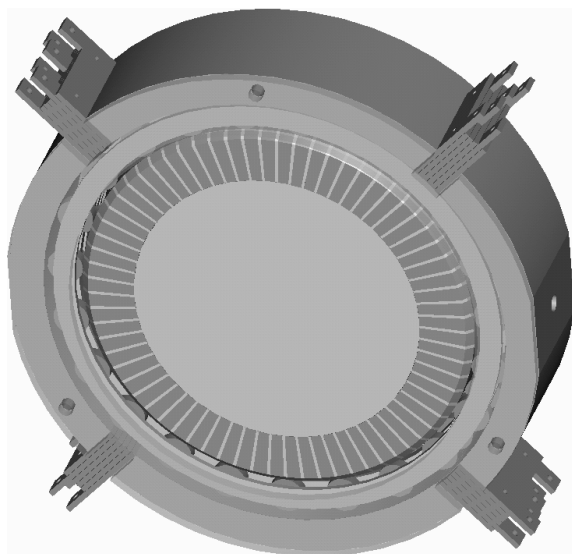


Fig. 6. «Brush» construction



**Fig. 7.** Current collecting device

«Brushes» were pasted in gaps of cylindrical yoke turned of textolite; rollers were put inside of this yoke

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and this construction from the end was placed on collector by step-by-step knurling under pressing (Fig. 7).

After assembling the CCD the «brushes» were adjusted along the line of geometric neutral terminal and the yoke and the cross bar were held rigidly.

The model of the electric machine with the developed current collecting device was tested in generator mode and motor operation. In this case the current load and CCD rate of rotation were adjusted.

The results of the carried out research:

1. New engineering solutions allowing implementing rolling current collection in DCM were developed.
2. The ratios of the parameters of CCD elements determining minimally required values of the amount of rollers and C for providing machine availability were determined.
3. The mathematical model allowing obtaining the curve of the switched section current when using a new current collecting device was developed.
4. One of the variants of manufacturing CCD elements and their further assembly was proposed and implemented.

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