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OPTIMIZATION OF SLIDING CONTACT PARAMETERS FOR DC ELECTRICAL MACHINE BY METHODS OF ARTIFICIAL INTELLIGENCE

Summary. The paper deals with parameter optimization of a sliding contact equivalent diagram for a DC machine by the methods of artificial intelligence, especially by a generic algorithm. The emphasis is put on reaching the maximum of sparking and the minimum of losses.
Firstly, the equivalent diagram of DC machine sliding contact used is described, and its mathematical model is analysed. Secondly, a numerical calculation is performed. In conclusion, the sliding contact is optimized by means of generic algorithms. The parameters are selected for the optimized solution, a purpose (criterion) function is created and the results of optimized values are obtained and discussed.

Key words: optimization, electrical machine, commutation, sliding contact, artificial intelligence, genetic algorithm

1. PROBLEM OF COMMUTATION FOR DC ELECTRICAL MACHINES

Correct commutation is one of the quality criteria for DC electrical machine. Commutation limits the output of DC electrical machine. Therefore, it is very important to specify commutation conditions as precise as possible so that the machine being designed can be useful in operation. Much effort is mostly made to achieve linear commutation that produces uniform current density on the surface of a brush, and thus it provides adverse conditions for the occurrence of sparking with a commutator. Therefore, an analysis of circumstances in the commutation zone is usually performed provided that commutation is linear. Correct commutation requires, in addition to electromagnetic conditions, absolutely perfect mechanical and thermal conditions for a friction node. A commutator has to be precisely cylindrical in shape, without any bulges even at the maximum operating speed. Lamellar insulation must not protrude so that brushes cannot bounce. It should have the same wear as lamellar copper so that a commutator wears uniformly. Carbon brushes have to slide freely in their holders and may not get stuck. If pressure is too high, carbon brushes wear too fast. If pressure is too low, carbon brushes bounce away from the commutator. The correct hardness of carbon brushes is very important not only with regard to contact resistance and contact losses but also with regard to commutator friction and friction losses. The pitch of brush-holder studs should correspond with the pole pitch as precise as possible so that commutation conditions are identical for all brush rows. At the same time, brush-holder studs have to be parallel with the commutator axis so that all brushes of the same row commute simultaneously. The heat load of the commutator surface and the friction area of brushes have to be minimum in order to provide adverse conditions for arc striking. The atmosphere near brushes is also very important. In some cases it is useful to create such atmosphere by enclosing a commutator in a space filled with appropriate gas or by supplementing carbon brushes with those substances that are missing in the atmosphere.

1.1. Simplification of a reserve diagram for sliding contact

A complete reserve diagram for sliding contact consists of a series chain of circuit parameters R,L,C – see Fig. 1.

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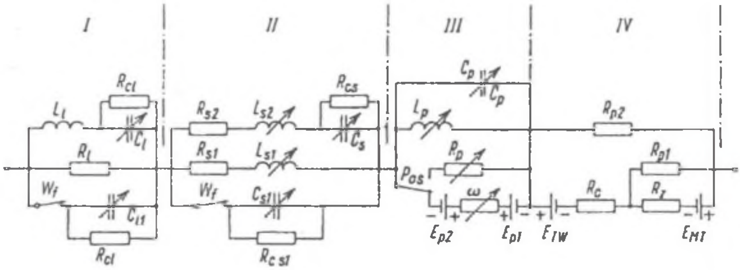

Fig.1. Diagram for sliding contact consists of a series chain of circuit parameters R,L,C

This chain involves 4 parts:

1.Groove parameters, 2.Brush parameters , 3. Contact space parameters , 4.Polish parameters.

It follows from the literature available that the complete reserve diagram is very problematic, and therefore in the next part we are going to analyze only the simplified diagram according to Fig. 2 which takes into considerations only brush parameters and contact space parameters.

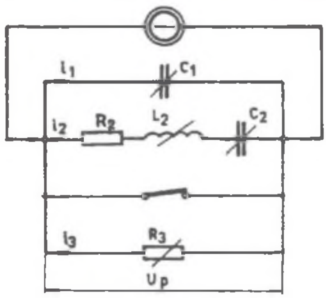

Fig. 2. Simplified diagram

1.2. Mathematical model of sliding contact for DC electrical machine

After consideration of the circuit parameters for a brush and a contact space, the parameters of the simplified circuit diagram shown in Fig. 1 take the following form:

$$C_1 = \frac{(L_{s1} + L_{s2})^2\, C_s\, C_p}{(L_{s1} + L_{s2})^2 C_s + L_{s1}^2\, C_p} \quad [F] \tag{1}$$

$$L_2 = \frac{\left[(L_{s1} + L_{s2})^2 c_s + L_{s1}^2\, C_p\right]^2}{(L_{s1} + L_{s2}) L_{s1}^2\, C_p^2} \quad [H] \tag{2}$$

$$C_2 = \frac{L_{s1}^2\, C_p^2}{(L_{s1} + L_{s2})^2 C_s + L_{s1}^2\, C_p} \quad [F] \tag{3}$$

2. CALCULATION OF SLIDING CONTACT BY A NUMERICAL METHOD

The parameters of the reserve diagram were calculated first by a numerical method. Even though this calculation is very time consuming, complete calculation was done which was necessary for the constructional design of sliding contact for DC electrical machine. Some of the quantities are mentioned below:

•Brush acceleration, •Distance of brush displacement relative to the commutator surface, •Slot length between the sliding surfaces of a brush and a commutator ,•Electric resistance of a contact space, •Capacity of a contact space, •Brush inductance, •Current running through a contact space, •Voltage drop at the impedance of a contact space .

An example of the numerical calculation for the selected brush parameters is described below:

1)Calculation of parameter C_1.

Quantity values entered (according to the available literature):

$L_{s1} = 25.76 * 10^{-9}$ H, $L_{s2} = 25.76 * 10^{-9}$ H, $C_s = 94.54 * 10^{-9}$ F, $C_p = 15 * 10^{-9}$ F,

$$C_1 = \frac{(L_{s1} + L_{s2})^2 C_s \cdot C_p}{(L_{s1} + L_{s2})^2 \cdot C_s + L_{s1}^2 \cdot C_p} = \ldots\ldots\ldots = 14.42 * 10^{-9}\ \text{F}.$$

2)Calculation of parameter C_2.

$$C_2 = \frac{L_{s1}^2 \cdot C_p^2}{(L_{s1} + L_{s2})^2 \cdot C_s + L_{s1}^2 \cdot C_p} = \dots\dots\dots\dots = 57.2 * 10^{-9}\,F.$$

The values obtained by a numerical method correspond approximately to the real values that exist in practice.

3. CALCULATION OF SLIDING CONTACT BY GENETIC ALGORITHMS

3.1. Description of the design of sliding contact

When designing sliding contact, we started from the mathematical model for a commutator and a brush. Individual values of the brush and commutator parameters were taken from real values that characterize the particular element. In case it was impossible to determine any parameter value precisely, its approximate value was estimated.

3.2. Programme synthesis

A programme was generated for the optimization of sliding contact. This programme utilizes for its activity one of the methods of artificial intelligence - genetic algorithms. The programme applies the method of genetic algorithms to calculate sliding contact, and tries to find a solution for which all the optimized values are within acceptable limits. This programme consists of two parts:

1) Calculation of sliding contact during which its mathematical model is described.
2) Genetic algorithm during which the demanded sliding contact parameters are directly optimized.

Considering that sliding contact was optimized for minimum sparking between a brush and a commutator, the following parameters were chosen to calculate the optimum solution.

Table 1

Parameter	Symbol	Dimension	Lower limit	Upper limit
Inductance	L_{s1}	H	10^{-8}	10^{-9}
Inductance	L_{s2}	H	10^{-8}	10^{-9}

3.3. Objective (criterion) function

An objective function is the most significant part of a genetic algorithm. It represents, in general, a function that evaluates the design quality of the recently selected solution and assigns a real number to it which becomes then a measure of its quality. The higher the value of this number, the bigger the error of the actual solution and the farther away it is from the global minimum of this function. A criterion function shows a concrete form, in contrast to the genetic algorithm itself which is identical for all optimized tasks.

Most cases of optimization tasks are concerned with an approximation to a certain demanded value. The identification of the parameters for the reserve diagram of a motor is a typical example of this type of task. The error of the solution can be determined according to relation (4) as the sum of the differences of real square values and demanded square values.

$$\varepsilon(GR_i) = k_I\,(G_1^2 - G_{1n}^2) + \dots + k_P\,(G_P^2 - G_{Pn}^2). \qquad (4)$$

The essence of the optimization of the design of a friction node consists in achieving the best parameters, which means the maximum or the minimum value of the chosen quantity and not its concrete amount as in the previous situation. Therefore, an objective function was chosen as the sum of absolute values of the differences of real values and best values multiplied by an appropriate weight coefficient – see relation (5). With this form of an objective function, the error decreases in a linear way, proportionally to the increase in the quality of individual parameters, which is very useful for this type of task. A criterion function was chosen in the form:

$$\varepsilon(GR_i) = abs(k_1(G_1 - G_{1n})) + \dots + abs(k_P(G_P - G_{Pn})). \qquad (5)$$

Not only the form of this function but also the selection of optimized parameters are most important for solving the task. The selected parameters must adequately describe the quality solution of a particular problem. The following parameters, which are most important for attainable results, were chosen for the optimization of the design of sliding contact.

• Brush capacity C_1[F], • Brush capacity C_2[F], • Brush inductance L_2[H]

A corresponding definition of a criterion function is as follows:

$$\varepsilon(GR_i) = abs(k_1C_1 - C_1) + abs(k_1C_2 - C_2) + abs(k_1L_2 - L_2). \qquad (6)$$

Thus, the total error is expressed as the sum of individual partial errors for each controlled parameter. Weight coefficients influence the effect of each of them on the result obtained. If more emphasis is placed on one of the parameters, the relevant weight coefficient increases, which results in achieving its improvement in the final design. However, the values of other parameters decrease at the same time. Thus, finding the optimum adjustment of weight coefficients is one of the most essential and most difficult problems of the task. The term 'optimum' means such adjustment of parameters for which friction node parameters are chosen with regard to minimum sparking and/or loss.

3.4. Results of optimization

A genetic algorithm for relevant values was programmed according to the previous section. The circuit parameters of the reserve diagram serve as input values: L_{s1}, L_{s2}.
Those parameters that are essential for the correct operation of an electrical machine were chosen as the output of a genetic algorithm: C_1, C_2, L_2.
The following parameters were chosen for the adjustment of a genetic algorithm:
Number of estimations: 1, Population size: 160
Total accuracy demanded for the termination of a genetic algorithm: 0.00000001
Maximum number of cycle recurrences after which a genetic algorithm will be terminated: 15000
Number of genes: 2, Number of mutations: 140
The results of optimized values obtained by a genetic algorithm:

Table 2

Calculation No.	C_1	C_2	L_2
1	$1.5*10^{-8}$	$3.3*10^{-10}$	$4.7*10^{-5}$
2	$1.4*10^{-8}$	$7.8*10^{-10}$	$2.2*10^{-5}$
3	$1.4*10^{-8}$	$5.6*10^{-10}$	$3.5*10^{-5}$
4	$1.3*10^{-8}$	$1.7*10^{-9}$	$6.6*10^{-6}$
5	$1.0*10^{-8}$	$5.3*10^{-10}$	$3.5*10^{-5}$

From the values determined by the method of a genetic algorithm, it is obvious that the calculated values are almost identical, except for C_2 and L_2 whose values differ by one order. This problem can be eliminated only by properly selected ranges of input values that are entered into a genetic algorithm.

As some of sliding contact parameters are not available, we can only assume that these values are correct. It should be useful to measure relevant sliding contact in a laboratory or directly in a plant and then to compare the results obtained with each other.

4. CONCLUSIONS

The present paper outlined the possibility of using genetic algorithms in the optimization of the constructional design of sliding contact for electrical machines. It is obvious from the results obtained that the application of the methods of artificial intelligence is very prospective also in this sphere, for it is possible at the present state of computer art to select optimum solution according to customer's demands in a relatively short period of time.

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