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**НЕКОТОРЫЕ ВОПРОСЫ ИССЛЕДОВАНИЯ ПРОЦЕССА  
КОММУТАЦИИ В КОЛЛЕКТОРНЫХ МАШИНАХ  
SOME ISSUES OF RESEARCH OF THE COMMUTATION  
PROCESS IN COLLECTOR MACHINES**

**Аннотация.** Данная работа посвящена комплексному исследованию процесса коммутации в машинах постоянного тока, который играет ключевую роль в обеспечении их эксплуатационной надежности и эффективности. Двигатели постоянного тока благодаря своим пусковым свойствам и регулировочным характеристикам получили широкое применение во всех видах электрического транспорта, в судовых электродвигателях, в приводах прокатных станов на металлургических предприятиях. Несмотря на то, что в благодаря развитию силовых полупроводниковых преобразователей, асинхронные двигатели вытесняют двигатели постоянного тока, электромагнитные нагрузки мощности МПТ продолжают расти, что обуславливает актуальность исследований, направленных на повышение коммутационной устойчивости МПТ.

**Abstract.** This work is devoted to a comprehensive investigation of the commutation process in DC machines, which plays a crucial role in determining their operational reliability and efficiency. Direct current machines (DC machines) are widely used due to their favorable starting properties and regulation characteristics in all types of electric transport, in ship electric drives, and in the drives of rolling mills at metallurgical plants. Despite the fact that, due to the development of power semiconductor converters, induction motors are gradually replacing DC machines, the electromagnetic loads and power ratings of DC machines continue to increase. This determines the relevance of research aimed at improving the commutation stability of DC machines.

**Ключевые слова:** Машины постоянного тока, коммутация, искрение под щетками, контакт «щетка-коллектор», переходное сопротивление; добавочные полюса, устойчивость коммутации, электромагнитные и механические факторы, диагностика технического состояния.

**Keywords:** DC machines, commutation, brush sparking, brush-commutator contact, transitional resistance, interpoles, commutation stability, electromagnetic and mechanical factors, condition monitoring and diagnostics.

The causes of inadequate commutation can be divided into two main groups: mechanical and electromagnetic. However, this division should be considered conditional. The non-uniformity of the



commutation process associated with electromagnetic causes depends on the ratio between the commutating EMF and the reactive EMF, as well as on the transient voltage drop in the brush–commutator contact. The commutation process in DC machines is determined by a large number of various electromagnetic and mechanical factors.

Mechanical factors include the following: roughness and deformation of the commutator surface, its runout, oval shape, protrusion of the inter-lamella insulation, the pressure of the brush on the commutator surface, vibration of the brush–contact assembly, and others. These factors lead to brush vibration, which worsens the contact between the brush and the commutator segments and causes sparking under the brushes. Even when the brush–commutator contact is in an almost ideal mechanical condition, electromagnetic factors may result in inadequate commutation accompanied by sparking under the brushes, which can damage the trailing edge of the brushes as well as the working surface of the commutator. Such damage, in turn, causes additional brush vibration and further intensifies sparking associated with mechanical causes. Measures aimed at reducing sparking and increasing commutation stability provide a significant technical and economic effect.

Failure analysis of electric motors shows that 23% of all failures are due to the occurrence of circular sparking on the commutator, faults of the brush–contact assembly, and the appearance of scoring on the commutator surface. Considering that traction motor failures in electric locomotives account for about 54% of all failures, it can be concluded that the problem of diagnosing the technical condition of the machine is highly relevant.

The parameters determining the commutation process in DC machines vary over time, since this process is dynamic in nature. Almost all researchers studying commutation use, in one form or another, a system of first-order nonlinear differential equations to analyze the commutation process. The most critical stage of commutation is its final stage. During this time interval, the influence of the transition resistance of the brush contact is most pronounced. It follows that the brush is an active element of the commutated circuit and significantly affects the nature of commutation. The volt–ampere characteristic (V–I characteristic) of the brush–commutator contact layer reflects the dependence of the transient voltage drop in the contact on the current density:

$$\Delta U_b = f(J_b). \quad (1)$$

This type of characteristic can have different forms. Line *a* in Fig. 1 (solid line) represents the most typical form of the volt–ampere characteristic.

It should be noted that almost any change in the operation of the brush contact affects the average value of the sparking intensity.

The volt–ampere characteristic of the brush contact changes significantly with temperature. The degree of this change is determined by the type of electrobrush used. For some brushes, this influence is more pronounced, while for others it is weaker. For example, for EG-74 brushes, with increasing temperature,  $\Delta U_b$  decreases significantly and the slope of the characteristic decreases, approaching a straight line ( $rb = \text{const}$ ).

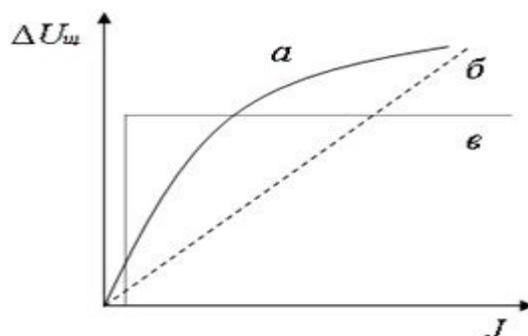


Figura 1



However, for EG-2A brushes, temperature changes have a much smaller effect. It is obvious that changes in the volt-ampere characteristic cause changes in the nature of commutation in DC machines.

$$\begin{cases} L_1 \frac{di_1(t)}{dt} + \sum_k \left( M_k \frac{di_k(t)}{dt} \right) = D_f(J_{1lead}(t)) - D_f(J_{1out}(t)) - i_1(t)R_{S1} - e_{k1}(t); \\ L_2 \frac{di_2(t)}{dt} + \sum_k \left( M_k \frac{di_k(t)}{dt} \right) = D_f(J_{2lead}(t)) - D_f(J_{2out}(t)) - i_2(t)R_{S2} - e_{k2}(t); \\ L_n \frac{di_n(t)}{dt} + \sum_k \left( M_k \frac{di_k(t)}{dt} \right) = D_f(J_{nlead}(t)) - D_f(J_{nout}(t)) - i_n(t)R_{Sn} - e_{kn}(t); \end{cases} \quad (2, 3, 4)$$

Here  $-L \frac{di(t)}{dt}$  - EMF of self-induction,  $-\sum_k \left( M_k \frac{di_k(t)}{dt} \right)$  - EMF of mutual induction,  $D_f(J_{1lead}(t))$  и  $D_f(J_{1out}(t))$  - transient voltage drops under the leading and outgoing edges of the brush,  $R_{S1}$  - resistance of the commutated section

The wear rate of the commutator is determined by many different operating factors. This process has a rather complex physical nature. As a result of significant commutator wear, additional intensification of sparking under the brushes usually occurs. The wear intensity of the elements of the brush-contact assembly is largely determined by the presence and properties of the polishing film, the correctness of commutation adjustment, the presence of burn marks on the commutator surface, as well as the presence of abrasive particles in the contact layer. Changes in both rotational speed and load can lead to an increase in the non-uniformity of commutation cycles, which in turn causes time variations in sparking intensity. The commutating properties of the interpoles are determined by their ability to reduce the level of sparking under the brushes by improving commutation. At present, they are the most effective and widely used means of improving commutation.

Based on known studies in commutation theory and on practical experience in adjusting commutation in DC machines, it can be concluded that the sparking process under the brushes is non-uniform. A number of causes determining the nature of the commutation process and, consequently, the intensity of sparking under the brushes are known. The exact position of the spark arcs and the sparking intensity continuously change over time.

The main purpose of the present work is to conduct a comprehensive investigation of the commutation process in DC machines, which is a critical phenomenon governing their operational reliability and efficiency. Commutation quality directly influences the occurrence of sparking at the brush-commutator interface, which in turn affects energy losses, electromagnetic interference, thermal stresses, and mechanical wear of both brushes and the commutator surface.

This study aims to analyze the commutation process as a dynamic and nonlinear system determined by the interaction of electromagnetic and mechanical factors. Special attention is devoted to the influence of the brush-commutator contact characteristics, including transitional resistance, volt-ampere behavior, temperature dependence, and surface condition of the commutator. The work also considers the role of additional poles (interpoles) and their contribution to improving commutation by compensating reactive electromotive forces.

Another important objective of the study is to identify the principal causes of non-uniform commutation and brush sparking under various operating conditions, such as changes in load, rotational speed, and temperature. By examining these effects, the work seeks to establish quantitative relationships between commutation parameters and observable indicators of sparking intensity and contact degradation.

Furthermore, the study is directed toward the development and justification of practical measures for enhancing commutation stability. These measures include optimization of brush contact conditions, improvement of electromagnetic compensation, and refinement of commutation adjustment procedures. In addition, the obtained results may be applied to diagnostic systems for assessing the technical condition of DC machines based on commutation behavior.



In summary, the purpose of this work is not only to deepen the theoretical understanding of the commutation process in DC machines but also to provide a methodological basis for reducing brush sparking, minimizing wear of commutation components, and increasing the operational reliability and service life of DC machines used in industrial and traction applications.

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