Measurement of sparking voltage in electric machines based on their transient functions

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Abstract. The article proposes a method for measuring the sparking voltage in DC electric machines based on the transient functions of these machines connected to bipolar brushes. Knowing the resulting response of the system to an impact in the form of a series of pulses obtained experimentally, it is possible to determine the response of the system to an arbitrary input action from a real spark in the sliding electrical contact of an electric machine. Using real transitional parameters of the anchor circuit of an electric machine will eliminate the systematic error of the method for estimating the level of switching sparking using a signal with bipolar brushes of this machine.

1. Introduction
The relevance of the issue of electromagnetic compatibility of collector machines with on-board devices and high-frequency systems is unquestionable, due to the widespread use of DC motors in the process.

There is much detail that must be considered if safe and interference free operation is to be assured, even relatively innocuous details can have a significant effect on the systems installed EMC performance. It is necessary to obtain an in depth view of qualification methods, test results, equipment and installation designs, platform characteristics and intended operational use to be able to provide an EMC assessment with a justifiable degree of confidence [1,2].

Currently, there are many ways to reduce the amplitude and duration of sparking, attempts to create new structural models of engines, various mathematical software systems have been developed for assessing the intensity of sparking, monitoring the state of switching. However, there is no unambiguous solution to all the issues of switching the invention, due to the complexity of the study of all manifestations of this physical process.

DC motors are designed to provide rotational or linear motion in electromechanical systems and complexes. DC motors are the main components of control systems, and are widely used in industry (both components of robotics, and in low and medium power machines, etc.).

An engine is a module due to which the system will function in principle. However, even despite an extensive study of all the parameters of these machines, they have inherent non-linear properties that affect the quality of work, the usefulness and reliability of using such machines. Their control requires the installation of increasingly complex control systems, regulation, which is difficult to implement.
2. Problem statement
The problem is how to analyze system situation without using sensors [3], and do not interfere with the design of the DC motor.

Despite the difficulties arising in the process of diagnosing the parameters characterizing the switching ability of electric micromachines, in recent years, in their work, the authors adhere to some conditional classification of the methods of switching stability.

So, well-known methods for improving switching can be divided into two main groups:
1. Ways to improve switching stability, the implementation of which is associated with the introduction of structural changes in the elements and nodes of the DC machine.
2. Methods that implement the accepted control algorithms and are based on a direct effect on the electrical parameters that directly or indirectly determine the quality of the switching process in the DC machine.

The first group of methods include such methods that improve switching by compensating reactive EMF (electromotive force) in the switched section with additional poles. Switching creates electromagnetic oscillations with a frequency of 1000 - 3000 Hz, which propagate through an electrical network connected to an electric machine. These vibrations cause radio interference that impedes the operation of electronic equipment. To reduce these disturbances produce balancing rotor chain of the machine, i.e. the winding connected in series with the armature, including winding and additional poles, is divided into two parts, which connects the to bipolar brushes. This method is considered one of the most famous, and is widely used in practice. However, after the fabrication of the DC machine, it is not possible to regulate the air gap over the additional poles; accordingly, it is not possible to provide satisfactory switching stability. A rather weak dependence of the switching stability on the configuration of the tip of the additional poles was also noted.

Switching sparking leads to failure of the elements of the sliding contact of the collector electric machine and the violation of its electromagnetic compatibility with electronic devices. To control the level of sparking during production and operation, many instrumental methods have been developed. They have their advantages and disadvantages.

A known group of methods of non-contact (without changing the design of the machine) control of the intensity of sparking, which is an attempt to record and analyze the spectral characteristics of the light energy released during the sparking process. These photoelectric methods make it possible to evaluate sparking by averaging the photocurrent value, however, a feature of this method is the need to incorporate photocells into the collector of the machine, which indicates the difficulty of producing such structures in mass production. In addition, the light flash is only part of the allocated energy of the electric discharge, and most of the energy, including heat, remains unaccounted for.

A method for evaluating the intensity of sparking by the level of radio interference of electromagnetic radiation under electric brushes can also be attributed to the non-contact method. To implement this method, you need a receiver with a number of parameters for sensitivity and noise immunity, the band of perceived frequencies and others.

Another group of methods is based on interfering with the design of the machine, for example, by connecting an additional resistance in the section of the armature winding of the machine, and registering electrical signals through additional contact rings using an oscilloscope. In this case, it is possible to register the curve of the current flowing in the section, or to record the EMF curve induced by the change in current. The disadvantage of this group of methods is the difficulty of implementation and the need for structural changes in the collector machine.

The simplest hardware method for assessing the level of sparking can be called using a signal from bipolar brushes. The signal from the bipolar brushes is provided through isolation capacitors to the input of the high-pass filter, then it is provided to the rectifier bridge and a DC microammeter, which measures the average value of the high-frequency voltage components associated with the switching process. The advantages of devices of this type are the absence of any primary converters and the ability to assess the level of sparking of the whole machine. This allows you to use a signal from bipolar brushes to assess the intensity of sparking during control tests in mass production.
Taking into account all the positive aspects of the last method for assessing the intensity of sparking, some disadvantages should be pointed out. Firstly, it is a subjective factor that forces the researcher to choose the main measurement parameters, excluding some components of the signal that are clearly not related to sparking. Secondly, the effect on the measurement results, which are not revealed here, of the parameters of the series-connected elements of the anchor circuit of the collector electric machine, although sparking appears only in the contact of the brush with the collector.

Work of interest Design of an electronic odometer for DC motors [3] where propose to detect the changes of the armature’s impedance caused by non-zero size of the commutator brushes. During each period, each brush shorts one or more winding coils for a while. This results in periodic decreasing and increasing of the armature’s impedance, which causes spikes in supply current. Thus, it is possible to detect current pulses, and having built the transient response of the motor, get the result in the form of a response, which allows you to analyze the operation of the system.

3. Proposed Solution
To eliminate the last drawback, it is necessary to exclude the influence on the measurement results of parameters of series-connected elements of the anchor circuit of a collector electric machine, for example, by taking these parameters into account when deciding on the actual degree of sparking. For this purpose, taking into account the non-stationary nature of the switching process, it is possible to use the transition characteristic of the anchor circuit of the machine as a passive two-terminal network. At the same time, in order to isolate the sparking signal precisely at the brush contact with the collector, it is necessary to subtract from the signal received from the bipolar brushes of the machine the voltage drop signal on the series-connected transitional conductivity of the armature circuit elements of the collector electric machine.

To use the transition characteristic of the circuit, the Duhamel integral method is used, which allows one to determine the response of a linear system to an input action that varies arbitrarily with time. This integral is based on the principle of superposition, therefore it is necessary to accept the assumption of the electrical linearity of the anchor chain. This assumption seems fair, since the values of switching sparking signals and the range of their variation are small compared with the operating voltages and currents of the collector electric machine.

It is proposed to use a series of rectangular pulses \( u_{\text{pulse}}(t) \) from a special electronic generator as a measuring signal. The parameters of these pulses must satisfy the requirements of the calculation method of the Duhamel integral, i.e., have time parameters corresponding to the time constants of the transient process of the anchor chain. Thus, transients will occur in the machine. From the influence of these pulses, the measuring electric current \( i_k(t) \) will flow along the anchor circuit of the machine. The latter is recorded, and the law of variation of this current is approximated by analytical functions.

In Figure 1, an electric circuit is presented that simulates the armature circuit of a DC machine, with inductance \( L_a \), armature coil resistance \( R_a \), electromotive force \( E_{a} \), resistance of bipolar brushes \( R_{\text{brush}} \), \( C_{\text{sep}} \) isolation capacitors (to exclude the influence of armature EMF on the circuit operation) and potential spark EMF.
Initially, the circuit starts in idle mode, and it reads the EMF value of the armature $E_a$ without arcing, $e_{\text{spark}} = 0$. The circuit resistance

$$r(t) = \frac{e_{\text{measure}}(t)}{i_{\text{measure}}(t)}$$  \hspace{1cm} (1)

is found.

Then, the circuit (Figure 2.) starts under load, where the spark is not equal to zero, $e_{\text{spark}} \neq 0$. A series of rectangular voltage pulses $u(t)$ is applied. The EMF of the spark is found by

$$e_{\text{spark}}(t) = u_{\text{hp}}(t) + i_a(t) \cdot r(t),$$  \hspace{1cm} (2)

where $u_{\text{hp}}(t)$ is the voltage from the bipolar brushes. Using a current sensor, the output current is taken. The ratio of $i(t)$ output to $u(t)$ output will give the magnitude of the transition resistance of this circuit.
Figure 2. The second stage of mathematical modeling of sensorless measurement of spark voltage. Including sparking.

Then, using a mathematical converter, the ratio of the current $i_k(t)$ to the voltage amplitude $u_{input}(t)$ is found, as a result, the transient conductivity $g(t)$ of the electric machine is obtained, as a two-terminal device.

In the future, knowing the response of the system to the action in the form of a series of pulses obtained experimentally, it is possible to determine the response of the system to an arbitrary input action from real sparking in the sliding contact of an electric machine.

Thus, taking into account the real transient parameters of the armature circuit of an electric machine will eliminate the systematic error in the method for estimating the level of switching sparking using a signal from bipolar brushes of this machine.

4. Conclusions
This paper has presented a new sensorless method to estimate the voltage sparking of brushed dc motors. The ability to analyze the operation of the system makes it possible to accurately predict the operation of DC motors, remote control the system, and eliminate the probability of observer error.

References
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