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Physical Peculiarities of Corona-Discharge Motors

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Abstract—This work is aimed at the study of the corona-discharge motor (CDM), whose torque is produced due to the electric dipole moment, which appears at the corona discharge. The physical mechanisms and features of the CDM operation that allow us to form a calculation base for the design and construction of the CDM, are identified and discussed. The motor power consumption, dipole moment generation, rotor torque as well as some specific effects inherent to this type of motor, arising from numerical calculations which take the pulse character of the supply voltage of the corona discharge into account, are considered. It is found that the motor rotation at a constant angular rate and a synchronous rotation with the torque are impossible. The obtained results can be used as a prerequisite for engineering calculations of the corona-discharge motors.

Keywords: corona discharge, electrostatic motor, dipole moment, torque, sector capacitor

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INTRODUCTION

The first electric motor was electrostatic, and an electromagnetic motor appeared [1] 100 years later. Despite the fact that they had rather a simple construction, electrostatic motors were soon replaced by electromagnetic ones. These had a more complex construction, but ensured a higher rotational moment. Another important factor in the replacement of electrostatic motors by electromagnetic was the necessity of a high voltage supply to the latter. The situation started to change in the early 1960s. The change occurred after the well-known lecture given by R. Feynman at a California Technological Institute during a session of the American Physical Society. After this, the tendency towards the miniaturization of technologies was noted. In searching for the solution to the miniaturization problem, the value of the voltage supply was reduced to hundreds of volts. One reason for the increasing interest in electrostatic motors was that with a decrease in the spacious sizes, the ratio of the Coulomb force value to the volume of its action (a volumetric density of force) increases. As a result, at a microlevel, the electrostatic motor ceased to be replaced by the electromagnetic one, and with its simplicity of construction, it substantially surpassed the latter. The electromagnetic motors will clearly maintain the predominant position, however, among advanced engineering models and in operation under special conditions, the positions of the two may change [2].

From the viewpoint of the motion of the working element, electrostatic motors can be divided into linear and rotor. The first [3, 4], are extensively used in precision positioning and microfluidics. Their principle of operation is based on the repulsion of the mobile elements of the motor (similarly charged) or attraction (charged oppositely), and the construction is often similar to a comb. When it comes to the method of supplying the charge to the rotor, electrostatic motors can be divided into contact, spark, electretic, condenser, and corona. The latter [5–8], compared to other types of electrostatic motors [9], differ by a higher rotational moment. They are made in the form of a cylindrical rotor from dielectric material with a coating plated at a certain step of conducting longitudinal strips and a number of electrodes in the form of blades. The electric field near such electrodes is strongly nonuniform, which is favorable for their corona producing and for injecting the charges onto the rotor.

This work studies the rotors, which are somewhat different from the existing models, which must be referred to as the "corona-discharge motors" (CDM), rather than just "corona" motors, which emphasizes the predominating role of the discharge-current force in a general expression for the density of pondermotor (electromechanical) force. The aforementioned is supported by the very concept of the corona discharge of the constant voltage as *unipolar* in accordance with the formulas of electro-gas- dynamics [10]:

$$\vec{j} = k\rho\vec{E} \Rightarrow \vec{f} \equiv \rho\vec{E} \Rightarrow \vec{f} = \vec{j}/k,$$

where $\vec{j}$, ρ, $\vec{f}$ are the current densities of unipolar charge and the mentioned Coulomb force; k is the mobility of ions, which induce the volume charge ρ. The formula shows the determining role of the *dis-*

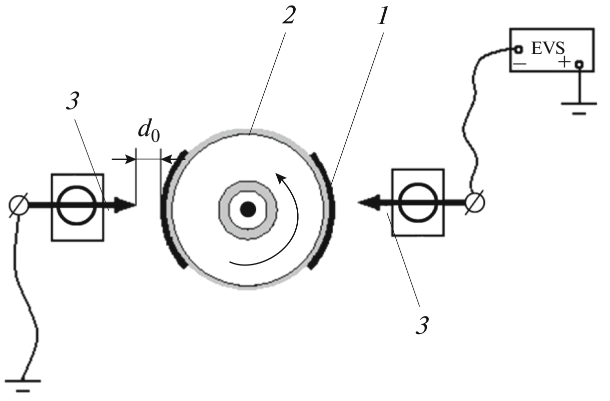

Fig. 1. Corona-discharge motor: (*1*) foil strips; (*2*) dielectric gap; (*3*) corona-producing electrodes.

charge current in the electrohydrodynamic (EGD) phenomena [11]. The principal of operation of the proposed motor is the same as of the existing ones, which is reminiscent of the EGD effect of the rotational motion of the dielectric film in the crossed electric fields [12, 13]. The data on the process of accumulation of charges on the surfaces, which are interfaces in the electric field, as well as the problems of mechanical stability of these surfaces can be found in [14, 15]. The distinguishing features of the constructive arrangement and physical version of the principal of its operation are described in [16].

Rotor (the basic component of the motor, Fig. 1) is a thin-walled $d = 2r_0 = 80$ mm diameter cylinder, $L = 120$ mm long and with a general mass of $m = 27.5$ g, made of a dielectric material. Along the diametrically opposed components of the cylinder there are symmetrically attached metal foil strips *1*, each is $L_0 = 80$ mm long, $a_0 = 82$ mm wide and $\delta = 0.02$ mm thick. Dielectric gap *2* between the longitudinal edges of the strips is b_0, so that $2a_0 + 2b_0 = 2\pi r_0$ opposite, symmetrically and in parallel to the cylinder components there are two electrodes in the form of thin hard plates *3* with the sharpened brims- blades. The latter are turned *normally* to the cylinder surface, but not tangentially, unlike in the other types [1]. The distances from the edges of the blades to the cylinder surface along the *normal* are $d_1 = d_2 \equiv d_0$ (Fig. 1).

The character of direction of the beginning of rotation should be attributed to a drawback of the symmetric CDM. This disadvantage, however, is unprincipled and removable at the level of an appropriate arrangement. However, the use of a two-electrode symmetric "stator" system allows us to charge rotor capacity *1* most efficiently, it considerably simplifies the construction and physical interpretation of the results of the CDM study and its calculation. The device is fed from the source of a high constant voltage, which ensures a bipolar symmetric corona discharge. When the electrodes are supplied the high constant voltage U (to 33 kV) and the latter reaches a certain electric value U_{cr} the corona discharge occurs. The cylinder, which is set on a fixed axis (relatively to the cylinder) starts to rotate, performing the motor rotor function (the maximum angle rate of rotation was 28 rot/s). The starter role is performed by the hard high voltage corona-producing electrodes-blades *3*. Simultaneously they also act as electrodes, which create *external* (relatively to the rotor) electric field with intensity $\vec{E}$ (Fig. 1) accepted as constant, equal to a certain mean value U/d. Thus, the stator includes the electrodes plus the external electric field produced by them, which rotates the "dipole-rotor" (electrically isolated from the other components of the CDM).

Certain peculiarities of the general character of the motor consist in that it, firstly, operates only after generating the corona *discharge* in the external electric circuit, (which is clear), because this condition directly shows the presence of the electric power consumption ($IU \neq 0$), which makes it possible to obtain the mechanical energy. Secondly, the seeming possibility of the cylinder rotation by the "electric wind" (EW) from the corona-producing electrodes [17], becomes futile because of the complete symmetry of the corona-producing system of electrodes and created by it the EHD flows, and, as a consequence, the equality to zero of the total kinetic moment. Thirdly, in the absence of the metal strips on the cylinder surface the rotation effect still exists, but it is incomparably weaker. All these allow us to assume that the crucial role in the phenomena under study, as already mentioned, belongs to the *corona discharge*, which being a bipolar, charges electrically the cylinder surface from two opposite sides with the charges of opposite signs. Thus it generates *a dipole electric moment* $\vec{P}_e$ on the cylinder, which is mechanically unstable, since it is opposite to the external field $\vec{E}$, i.e., $\vec{P}_e \uparrow\downarrow \vec{E}$, [16]. As to the metal strips presence on the cylinder surface and, due to it, a considerable enhancement of the effect observed, the strips serve as the charge integrators and introduce significant *quantitative* changes in the phenomenon under consideration. In this situation, the important role belongs to the direct capacitive charging of the dipole (of the capacitor). The fact of the effect's existence in the absence of the metal strips attests to a certain role of the surface charge, which stuck to the dielectric surface of the cylinder and accompanying the corona discharge near the rotor by air.

Further on, the attention is given to revealing and discussing the physical mechanisms and peculiarities of the CDM operation, which allows us to create the calculation basis required for their design and construction. We study the consumption energy of the motor, dipole moment and its arising, rotational moment of the rotor, as well as certain specific effects peculiar to this type of motors.