

## COMPUTER MODELING OF THE CHARACTERISTICS AND MAGNETIC FIELD OF SINGLE - PHASE COMMUTATOR MOTOR

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**Abstract:** The article presents some calculation results of dynamic characteristics of the single – phase series – excited commutator motors and magnetic field analysis.

Single – phase commutator motors in up – to – date literature are called universal motors, because they can be used in both alternating current (AC) and direct current (DC) systems. The single – phase AC small power commutator motors are widely used in different vacuum cleaners, electric tools, drives of household, electrical, medical and hygienic equipments and portable electrical hand tools. However, the principal defect of those motors is worse commutation with sparking between brushes and the collector, and high enough level of radio interferences on wide frequency range.

In this article obtained expressions compounds the mathematical model of the single – phase series – excited commutator motor. The model of the dynamic processes of the motor and its block diagram are compiled according to the differential equations which were derived from the equations of voltage balance. The software of Matlab/Simulink is applied here which has integrated the methods of the solution of differential equations for the motor.

For modeling the magnetic field of a AC series – excited commutator motor there was used the software JMAG. The program is compiled by means of finite elements, by attaching on the computer separate geometric figures their titles and characteristics. Since the magnetic field in the air gap between the salient poles and armature is not homogeneous, so the density

of the grid has to be the highest. The obtained results of modeling describe a very complicated structure of a magnetic field of a commutator motor for the analysis of which are required new and comparatively accurate mathematical models.

### 1. INTRODUCTION

In manually operated devices, where high velocities of (20 – 40) thousands r/min and a comparatively small masses are required, there are applied universal commutator motors. These motors are mostly applied as single – phase alternating current (AC) in series – excited motors. However, motors themselves as well as manual tools and devices with commutator drives not always comply with modern requirements in the field of electromagnetic compatibility, environmental protection and radio interferences reduction. Moreover, there are problems in relation with the application of electronic digital control systems, application of control and braking systems for commutator drives. From that point of view, the investigation of the following issues, namely the magnetic field of commutator motors, calculation of their characteristics, optimization of the design as well as reduction of radio interferences are considered to be very relevant issues for analysis.

Recently, there have appear scientific works dealing with the analysis of the problems concerning the theory of commutator type electric motors and their practical application. In the author's presented list of literature (Putnicki, 2000, based on the achievements of modern technologies, there have been solved very significant problems of automatized designing, structure optimization and synthesis as well as search for an optimal version of low capacity commutator motors. The long – lasting ex-

perience of the author is summoned here concerning the designing, manufacturing, experimental research of such motors.

In article (Karaliunas, 2005) there are presented the findings on the magnetic field of single – phase commutator motors in order to achieve the reduction of the intensity of radio interferences caused by such motors. The methodology for calculating the characteristics of alternating current (AC) commutator motors is submitted in article A group

of authors in their report (Jack et al., 2000) analyse the magnetic system of a salient pole stator of universal motor, in which the poles tips is manufactured from a special material – Somaloy 550. The authors state that in this case the manufacture of the magnetic circuits of the motor is simpler and cheaper. In article (Tuncay et al., 2001) there are presented the results of modelling characteristics of universal motors with different capacities. The authors presents the patterns of distribution of the magnetic flux lines in the magnetic system of the motor and the diagrams of dynamic characteristics. It is not possible to install the usual measures of commutation improvement such as additional poles and the windings of compensation in the low capacity commutator motors due to space shortage. That is why the decisive influence on the commutation processes of the current, the intensity of sparking and the intensity of radio interferences in such motors make the specific type of disturbance appearing in the air gap of the magnetic

field. The mentioned above issues have not received the required attention in the scientific literature so far. That is why the purpose of the work is to investigate the magnetic field

of the single – phase series excited commutator motors and to analyze their dynamic characteristics.

## 2. THE MAIN EQUATIONS AND THE BLOCK DIAGRAM

When simulating, there are applied the differential equations of the exciting circuit and armature circuit, derived from the equations of voltage balance. In the mentioned above equations there are evaluated the mutual inductance of both the circuits and the excitation currents as well as the change of armature current at the moment of starting the motor. For the excitation circuit it is possible to write the following:

$$u_e = i_e r_e + L_e \frac{di_e}{dt} + M_{ea} \frac{di_a}{dt}; \quad (1)$$

where  $u_e$ ,  $i_e$ ,  $r_e$  – is the voltage of the series excitation winding, the current and active resistance;  $L_e$  – is the self – inductance of series excitation winding;  $M_{ea}$  – is the mutual inductance of series excitation winding and armature winding;  $i_a$  – is the armature winding current.

The following equation is received for the armature circuit:

$$u_a = i_a r_a - \omega i_a L_{a1} + L_{a2} \frac{di_a}{dt} + \omega i_e M_{ea1} + M_{ea2} \frac{di_e}{dt}; \quad (2)$$

where  $u_a$ ,  $r_a$  – is the voltage of armature winding and active resistance;  $\omega$  – is the angular velocity of armature rotation;

$L_{a1}$  and  $L_{a2}$  – are self – inductances of parallel branches of armature winding.

The equations (1) and (2) are modelled together with the main equation of motion of commutator drive:

$$J \frac{d\omega}{dt} = T_e - \varepsilon \omega - T_1; \quad (3)$$

where  $J$  – is the torque of armature inertia;  $T_e$  – is electromagnetic torque of the motor;  $\varepsilon \omega$  – is the component of the resistance torque due to the friction in the bearings and in the commutator brushes sliding contacts;  $T_1$  – is the load torque of the motor.

Electromagnetic torque of the single – phase commutator motor is proportional to the instantaneous power and could be calculated in the following way:

$$T_e = \frac{e_a(t) \times i(t)}{\omega}; \quad (4)$$

where  $e_a(t)$  – is the instantaneous value of electromotive force induced in the armature winding.

Expression (4) indicates that the torque of the motor is generated not only by the rotational, but by the transformer armature electromotive force. Then after determining the expressions of electromotive forces and inserting them into (4), we derive that the electromagnetic torque consists of four components:

$$T_e = T_{rv} + T_{trv} + T_{rk} + T_{trk}; \quad (5)$$

where  $T_{rv}$  and  $T_{trv}$  – is the average components of the torque caused by the rotational and transformer electromotive forces;  $T_{rk}$  and  $T_{trk}$  – is the alternating components of the torque, which varies with double frequency of the network.

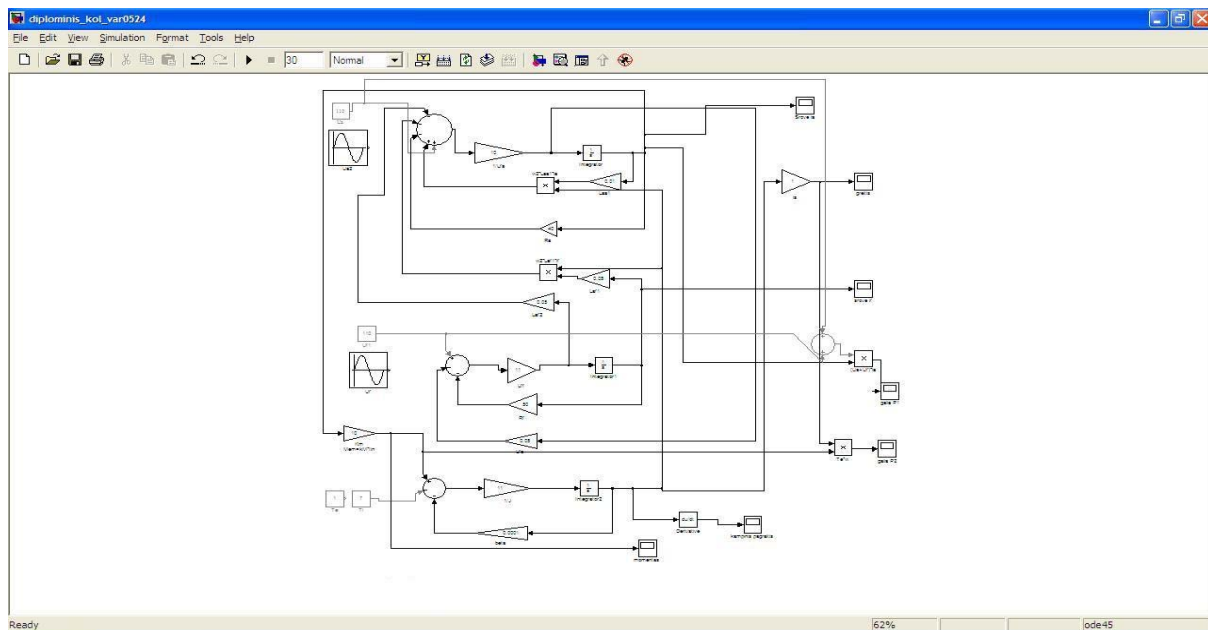


Fig. 1. Matlab/Simulink model of a single – phase commutator motor

For calculating the several components of the torque the following expressions were obtained:

$$T_{rv} = \frac{pN}{4\pi a} \Phi_m I_m \cos\gamma \cos\beta; \quad (6)$$

$$T_{uv} = \frac{w_a \omega_1}{2\pi\omega} \Phi_m I_m \sin\gamma \sin\beta; \quad (7)$$

$$T_{rk} = \frac{pN}{4\pi a} \Phi_m I_m \cos\gamma \cos(2\omega_1 t - \beta); \quad (8)$$

$$T_{uk} = \frac{w_a \omega_1}{2\pi\omega} \Phi_m I_m \sin\gamma \sin(2\omega_1 t - \beta); \quad (9)$$

where  $p$  – is the number of pairs poles of the motor;  $N$  – is the number of the armature conductors;  $a$  and  $w_a$  – are the numbers of parallel branches and coils of armature winding;  $I_m$  and  $\Phi_m$  – is the amplitudes of excitation current and magnetic flux;  $\gamma$  – is the angle of bend of brushes sliding from the geometric neutrality;  $\beta$  – is the angle of motor losses;  $\omega_1 = 2\pi f_1$  – is the angular frequency of excitation current.

Having the equations (1) – (3) and the expressions of torque (6) – (9) it is possible to get all the transver functions required for compiling the computer model. The software Matlab/Simulink is used, where the methods of differential equations solution are integrated there. Then in the Simulink desktop there are connected separate subsystems to form block diagram of which is presented in Fig. 1.

### 3. MAGNETIC FIELD MODELING

For modelling the magnetic field of a commutator motor there was applied the software JMAG. The software for modelling was compiled by the method of finite elements, when in the computer to the separate sectors of the magnetic system, there were attached their titles, characteristics and other parameters.

In Fig. 2 there is presented the finite element model of the magnetic circuit of the motor together with the inductor and the scheme for connecting both the armature windings and commutator.

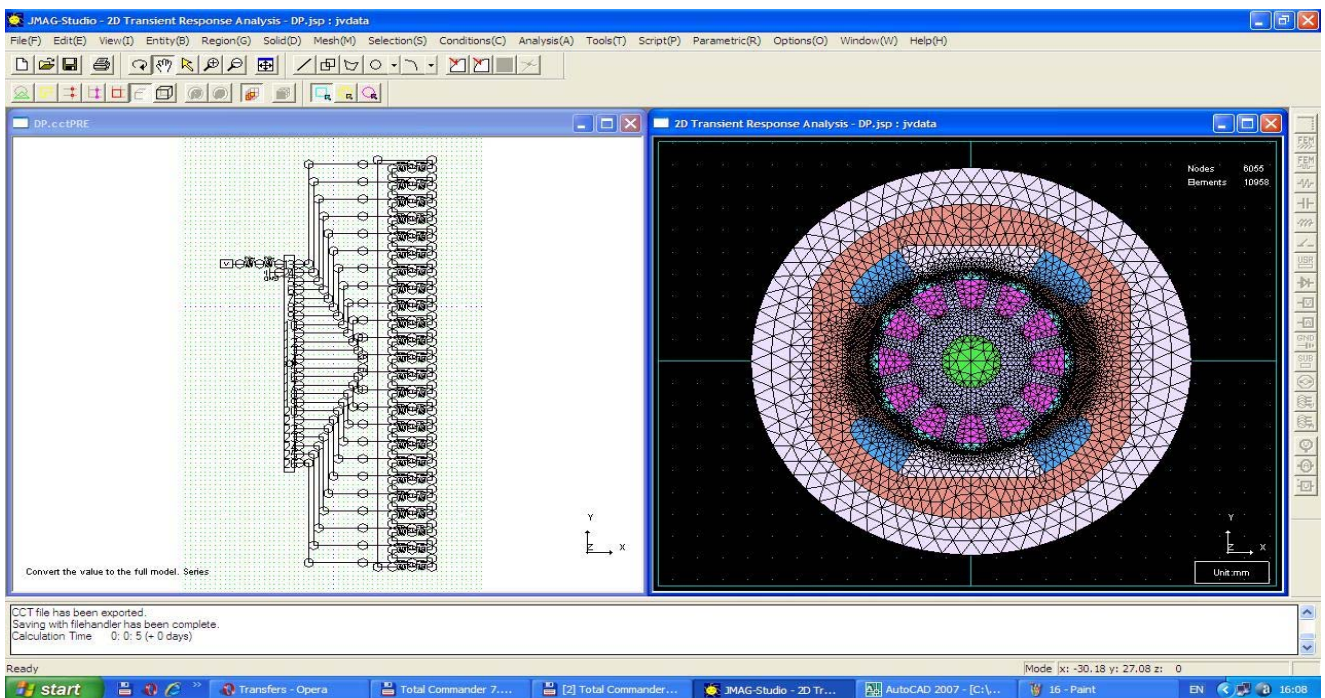


Fig. 2. The model of the magnetic system of commutator motor with the logical scheme of windings connecting

### 4. RESULTS OF MODELING

By using Matlab/Simulink model presented in Fig. 1, there were obtained the patterns of the velocity, acceleration, electromagnetic torque, currents and dynamic characteristics. The variation of the electromagnetic torque in time is presented in Fig. 3. Distribution of magnetic induction in the motor is presented in Fig. 4.

The results of modelling indicate, that the character of transitional processes of high speed single – phase commutator motors is similar to the transitional processes of the practically tested motors. Judging from the results

presented in Fig. 4 the conclusion is derived stating that in the operating motor there appear the demagnetization effect of the reactions of an armature. Due to that the highest density of the magnetic flux is observed not at the poles of the excitation, but they are shifted by a certain angle from the longitudinal axis of the motor. That is why in non – reverse commutator motors the brushes have to be turned from the geometric neutrality by the same angle, namely from the cross – sectional axis of the motor. This measure allows increasing the coefficient of efficiency of a motor, to reduce the sparking and the intensity of radio interferences.

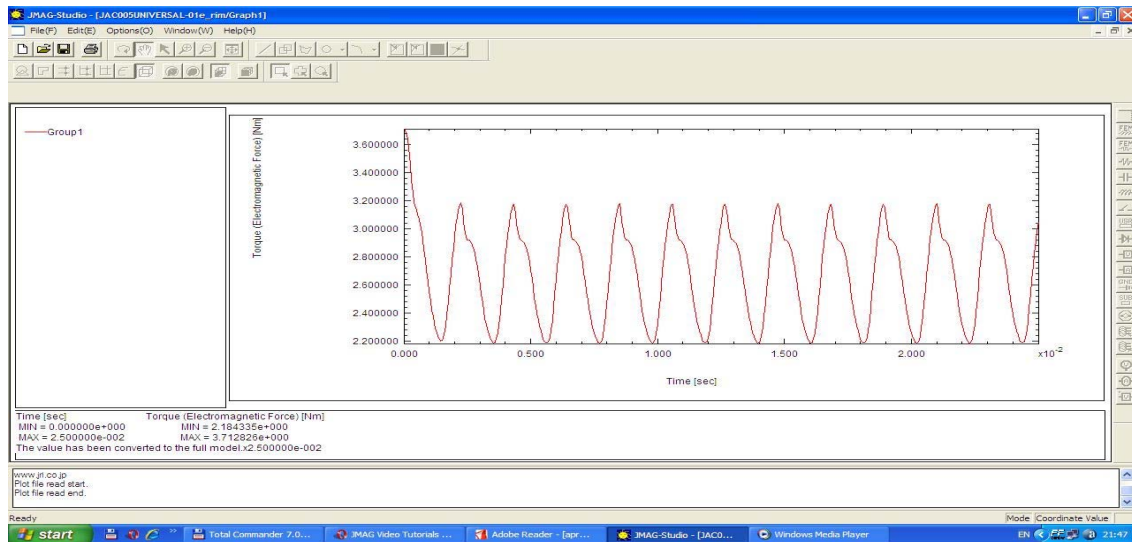


Fig. 3. Variation of electromagnetic torque in time

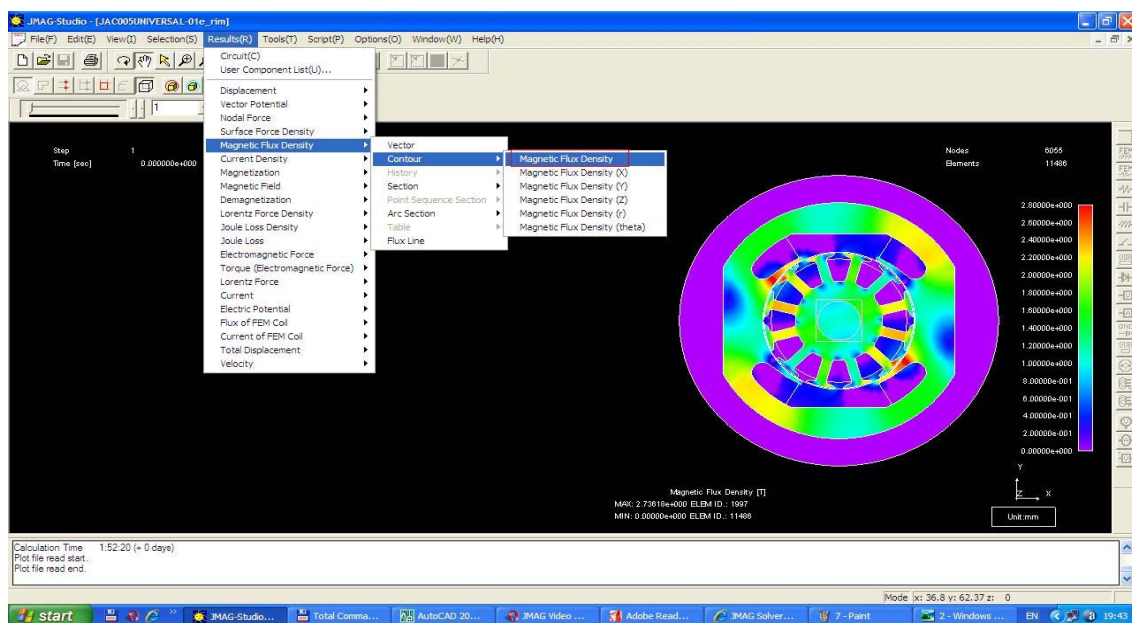


Fig. 4. Distribution of magnetic induction in a commutator motor

## 5. CONCLUSIONS

The new simulation model of transitional processes and dynamic characteristics is derived for a alternating current single – phase series excitation commutator motor.

The results of modeling indicate that the type of transitional processes of velocity, acceleration, torque and currents for low capacity single – phase commutator motors coincide with the results of the experimental research of the practically tested motors.

Modeling and calculation results of dynamic characteristics and magnetic field help to find constructive means which reduce transverse magnetic flux and intensity of the radio interferences. It is recommended to symmetrize of magnetic circuit of the small power commutator motors and the elements of interferences reduction must be placed as close as possible to sparking sources.

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