Sectional approach to researching of two-phase BLDC motor

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Abstract. An approach to researching of two-phase brushless DC motor, based on winding's section is proposed. A classification of control methods by section connection kind and commutation methods is developed. An example in case of independent windings' layout is given. Torque-speed curves are obtained. A comparative analysis of them is carried out and recommendations to drive systems' developers are given.

1. Introduction
Two-phase BLDC motors have a lot of properties which three-phase ones do not. Due to their orthogonal winding layout, sections do not affect one another (ideally), it enables to organize motor handling by two orthogonal independent axes.

The existence of an additional winding section in the two-phase motor gives rise to a great lot of additional connection and commutation methods. Thus, a description, representation and consideration conventionally applied to a three-phase motor is not sufficient for the two-phase one. For the last, when a winding has only one section, it has no sense to divide it into sections. But, such an approach leads to consideration a multi-sectional unit as one phase, that does not enable to research interaction processes happening between sections.

Because of this, the conventional phase-based approach cannot satisfy the tasks of this research, a necessity appears to consider the motor and to create its mathematical description based on a section, not on a phase.

By many Researchers torque-speed curves calculation methods for a certain kind of motors were proposed, attempts to create a classification of phase connection and commutation methods were made [1, 2]. Therefore, the meanings "phase" and "section" were stood into the same level, their equation was admitted.

Due to it, nowadays an approach is absent in which a section were selected as a basic (an elementary) calculation unit, an approach which enables do determine affection of a certain method selection to motor's characteristics and to compare them each other.

In this paper an approach to researching of two-phase BLDC motor, in which a winding section is considered as an elementary calculation unit, is proposed. This approach enables to determine time relations of voltages and currents between the sections, contribution of each section to armature magnetic field and by means of them their affection to the motor's characteristics.

For torque-speed curves calculation an automated method based on an imitation model of two-phase BLDC motor with phase windings consisting of two sections is proposed. The model is based on an equivalent circuit in which the sections are represented explicitly, it enables to carry out calculations with any kind of section connection and commutation. The model is designed in MATLAB/Simulink.
environment and belongs to a program complex, the model's working process is controlled by automation scripts written in MATLAB language.

2. Control Method Classification

2.1. Terms and Definitions

According to the proposed approach, following terms are supposed:

Section — a part of the armature winding, having its own leads to connect to external circuitries.
Elementary section vector — an armature magnetic induction vector formed by one certain section when it is energized by full supply voltage value and the back-EMF is absent (by initial torque). This vector's amplitude is considered as an elementary unit, amplitudes of all other vectors are calculated respecting to it.
Base vector [of armature magnetic field] — armature magnetic field vector acting during the intercommutation interval. This vector is produced as result of elementary section vectors' addition during this interval.

2.2. Armature equivalent circuit

The mathematical description and modeling of the motor, according to the sectional approach proposed, is based on an armature's equivalent circuit in which a section is supposed as an elementary calculation unit(figures 1).

Figure 1. Equivalent circuit.

Large letters show phase leads, i.e. connection points to the power amplifier (inverter), small --- individual leads of each section. By composing the diagram following assumptions are made:

- Resistances and inductances of all sections are equal.
- Collinear sections have opposite back-EMF direction.
- Mutual inductance between sections is neglected.

Torques of each section are summed respecting to its angle position in electrical coordinates.

2.3. Control method classification

In the proposed classification motor control methods are identified by section connection kind, among them the following are distinguished:

- independent layout;
radial connection with common point (connected to any pole of the power supply unit);
radial with neutral point (not connected);
ring connection — bridge ("square").

Each commutation method is characterized by base vector system without back-EMF (at initial torque). Commutation methods do not depend on connection kind, all of them can be in any of them. Methods are grouped by participation of a certain section in a base vector during a certain intercommutation interval. Among methods the following are distinguished:

- separate — sections laid out along one axis are participating;
- joint — sections laid out orthogonally on both axes;
- combined — is a combination of the first two ones;
- without section — on both leads of a certain section the same potential is present, there is no current, therefore, no magnetic field, the section does not participate in the work;
- without phase — induction vectors of two collinear sections are directed opposite one another, magnetic fields of the sections compensate each another, both sections do not participate in the work.

By number of sections participating in the base vector forming the methods are denoted as:

- section — only one section is participating;
- phase — more than one section.

Thus, the name of a control method contains information about the formed base vector system and position sensor allocation required to implement it.

3. Program Complex

The program complex enables to obtain torque-speed curves, information and power signal waveforms, thus it enables to detect motor's work modes during the phase voltages' period. The calculation results are used to research processes of energy interchange between the power supply unit, the motor and the load; they enable to determine the affect of the connection kind and commutation method to the motor's characteristics.

The proposed program complex is based on the one developed in [3]. It is adapted for the modeling of two-phase motor by application of the sectional approach. The calculation automation became further developing. In its ground a principle is laid: to input all initial data one time in a unique place; to put their preparing and processing work on the computer. A batch calculation procedure is inserted: curves for each control method are calculated consequently. Modules for automated building of comparative torque-speed curves are added.

The program complex performs preparing of the initial data to the calculation, its carrying out on available processor cores with the parallel computing method and analysis of the results. Based on the initial data put in, the complex selects the model automatically, calculates its launch parameters, forms diagram descriptions and a filename for the results saved. Due to this approach, errors by putting in initial data and identification diagrams with results are reduced.

4. Simulation Results

The proposed sectional approach was used to obtain and compare torque-speed curves for the motor with independent phases. A comparative analysis was carried out by parallel, serial and in the case when the base vector is formed by only one section.

For each connection kind three commutation methods are tested: separate, joint and combined.
Figure 2. Torque-speed curves.

The figure 2 shows that the torque-speed curves are grouped by section connection kind. The torque and speed are shown in relational units based on the “Independent, separate section” control method.

It is determined that in comparison with the separate method, at the joint one, the initial torque grows up $\sqrt{2}$ times, the idle speed — about 1.18 times. At the parallel one, they lie higher, at the independent, have higher slope, at the serial, lie below.

Minimal torque-speed curves slope takes place at the parallel connection of collinear sections and the separate commutation and allows to recommend this control method for the greatest torque at high loads. If curves of high slope are needed, the “separate section” method is suitable.

References
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