https://www.proconference.org/index.php/gec/article/view/gec26-01-011
DOI: 10.30888/2709-1783.2023-26-01-011

UDC 519.6: 681.5

FEATURES OF THE FORMATION OF STEPPER MOTOR CONTROL SIGNALS IN THE MICRO-STEP MODE

Kryvoruchko I.P.
Postgraduate
ORCID: 0000-0003-2848-5348
G.E.Puhov Institute for modeling and energy engineering, Kyiv, Naumova,15,03164

Abstract *The micro-step operation mode of the stepper motor (SM) allows more accurate positioning of the rotor (working body) of the SM. The method of discretization of phase voltage signals given in some works is analyzed. A modification of the known method of discretization is proposed for the generation of control signals of the microstep operation mode of the SM. The method presented in the work makes it possible to form a phase-uniform step-variable signal from an input sinusoidal signal. The simulation results of the proposed method using the Simulink model are given. The advantage of this method in comparison with the existing ones and those given in some information sources is shown.*

Keywords*: stepper motor, micro-step mode, electromagnetic moment*

Introduction

A stepper motor is similar to synchronous motors in that each control pulse corresponds to a specific fixed displacement or motion. The widespread implementation of SM was facilitated by the simplified compared to other types of control engines, as it required only a flow of pulse signals, which means that they could easily interface with computer equipment. To accurately reproduce the given law of movement of the working body of the electromechanical system based on the SM, a microstep mode is used. The work is focused on the specifics of the formation of control signals for the microstep mode of operation.

Main text

The mathematical model of HSM operation consists of the Maxwell-Kirchhoff equations for two stator windings and the equation of the rotational motion of an inertial body [1]. *Ua, Ub* – the voltage on the first and second stator windings.

The same mathematical model is used to simulate the operation of the HSM in the Simulink computer simulation environment and is implemented in the SM block of the package library. Signals Ua and Uв are used to power the SM, which are connected to separate stator windings. According to [2], one of the simplest ways to obtain a microstep mode of operation is to energize the SM stator windings with a trapezoidal current in such a way that at each moment of time the current in one winding has a maximum value, and in the other it changes linearly. But under such winding supply conditions, the total moment also changes linearly and cannot change step by step. Accordingly, the moment modulus also changes over time. In the full step mode, it is sufficient to alternately supply current pulses in a certain order to rotate the rotor: A+, B+, A-, B-. Each current pulse of the corresponding magnitude causes the rotor to rotate by one step. Thus, one period of control voltage Ua (Uв) corresponds to rotation of the rotor by 4 steps. The "half-step" mode differs from the previous mode by additional rotor positions between the main states. The invention of the microstepping mode of operation of the SM made it possible to fix or orient the rotor not only in one intermediate state, but also in a larger number depending on the control algorithm. For this, as Ua and Uв, step-variable sinusoids, shifted relative to each other by an angle of π/2, are used. The greater the positioning accuracy we want to achieve, the smaller the step size should be. Reducing the size of the step leads to "smoothing", the control signal, it becomes more similar to a sinusoid. To obtain such a sine wave, work [3] suggests using the Simulink Quantizer block, which forms a step signal with specified quantization levels from the input signal. A similar approach is proposed in [4]. For this, it is suggested to use the formula:

$$U_a = \mathrm{U} \cdot \mathrm{q} \cdot \mathrm{round}\left(\frac{\sin\left(\frac{\pi}{2} \cdot \mathrm{f} \cdot \mathrm{t}\right)}{\mathrm{q}}\right) \tag{1}$$

where ***U*** is the driver supply voltage, q is the quantization step, ***f*** is the frequency of the supply voltage, the round(x) function returns the elements of the X array rounded to a integer. For example, for the argument interval of this function is 7.18º - 22.02º, the function value is 0.25. The other component of the total voltage on the other stator winding for angles 0 - 28.96º is equal to 1. And the value of the module of the total voltage is 1.03. Similarly, it is possible to calculate the value of the modulus for other angular intervals. Figure 1 shows the results of modeling both supply voltages Ua and Uв, as well as the modulus of the resulting vector of these voltages, calculated according to equation (1). Calculations were performed for the ¼ microstep mode. As can be seen from the figure, the amplitude value of the resulting voltage vector changes over time. The maximum deviation reaches 12%. Obviously, the instability of this parameter causes additional variability of the M_E. As the degree of discretization of the main step increases (decreasing q), the deviation value decreases.

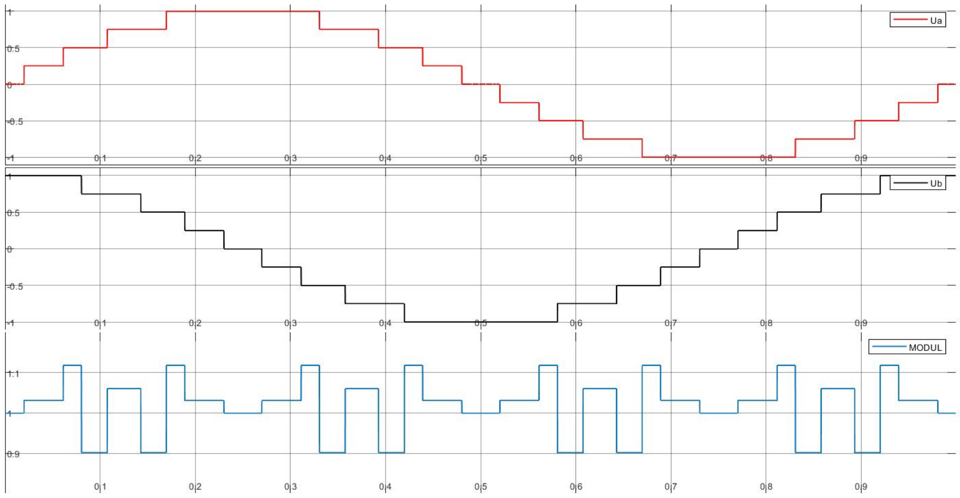

Figure 1. The shape of the control signal and the amplitude of the total control vector according to formula (1).

To eliminate this undesirable effect, the following method of forming the shape of the power supply voltage of the stator windings of the SM is proposed. The main idea is to divide the oscillation period into 2N equal segments and fix the average value within each segment. We use the function y=round(X) not for the sinusoid, but for its phase:

$$\text{Angle} = \left(\frac{\pi}{2}\right) \cdot q \cdot \text{round}(2 \cdot \text{asin}(S)/\pi \cdot q) \tag{2}$$

where S is a sinusoid with a unit amplitude, q=1/N. In this case, the interstep time intervals become equal. The next step is to calculate the step-variable sine wave for the calculated phase:

$$Sr = \sin\,(\text{Angle}) \tag{3}$$

If the frequency of the sinusoid *f* changes over time, the size of the step intervals will also change according to the same law.

Figure 2 shows the graphs of the phases, supply voltages of both phases of the SM and the resulting module of the voltage vector, calculated according to the proposed method. On the last graph for the module of the total vector of the supply voltage, its magnitude is no longer observed. The graphs shown in Figure 1 and Figure 2 were obtained with the use of simulink models shown in Figure 3. Blocks Sine and Sine1 generate sinusoidal signals shifted in phase by an angle π/2. The block Constant (microStep[N]) sets the required microstep value.

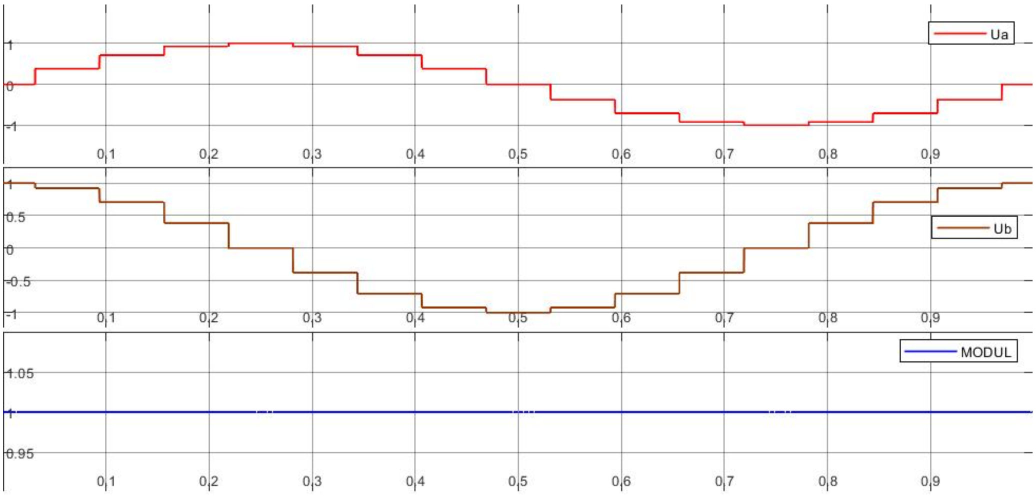

Figure 2. The shape of the control signal and the amplitude of the total control vector according to formula (2,3).

Calculation of equations (1-3) is performed in MatLab fcn blocks. Blocks Sc1, Sc2 and Sc3 are used to visualize the output measured values, which are presented in the corresponding figures 1 - 4. In order to check the obtained results, we use the Simulink stepper motor model with the following parameters: step size – 1.8º, J = 36.5e-6kg·m^2, L =4.2mH, R =1.25Ω, Ψ_m =0,0036 V·s, V_r = 25 VDC, where Vr is the rated supply voltage of the stator windings, Tdm =0.1 N•m. The frequency of control signals Sine and Sine1 is equal to 6.28 rad/s. The simulation results are shown in Figure 4 and 5, respectively, for generated control signals according to formulas (1-3).

A comparison of the diagrams in Figures 4 and 5 shows a more pronounced "stepping" (periodicity) of the signals. This is especially evident from the graphs for changing the angle of rotation of the rotor over time. In the first case, the angle increases gradually, but not synchronously with the control signal.

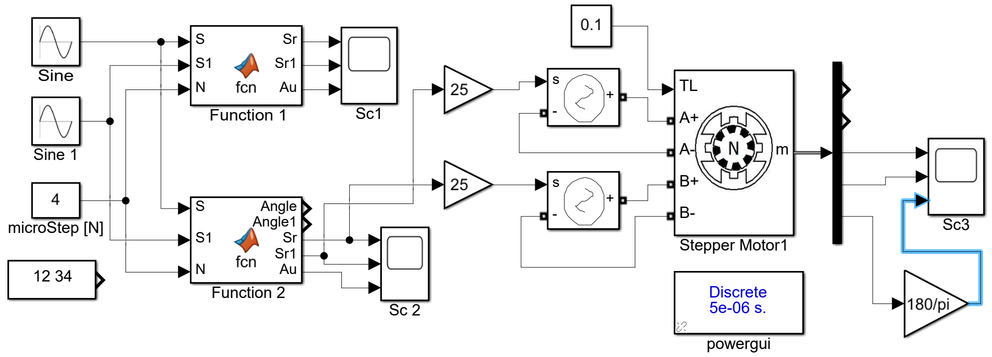

Figure 3. Block diagram of the model in the MatLab/Simulink

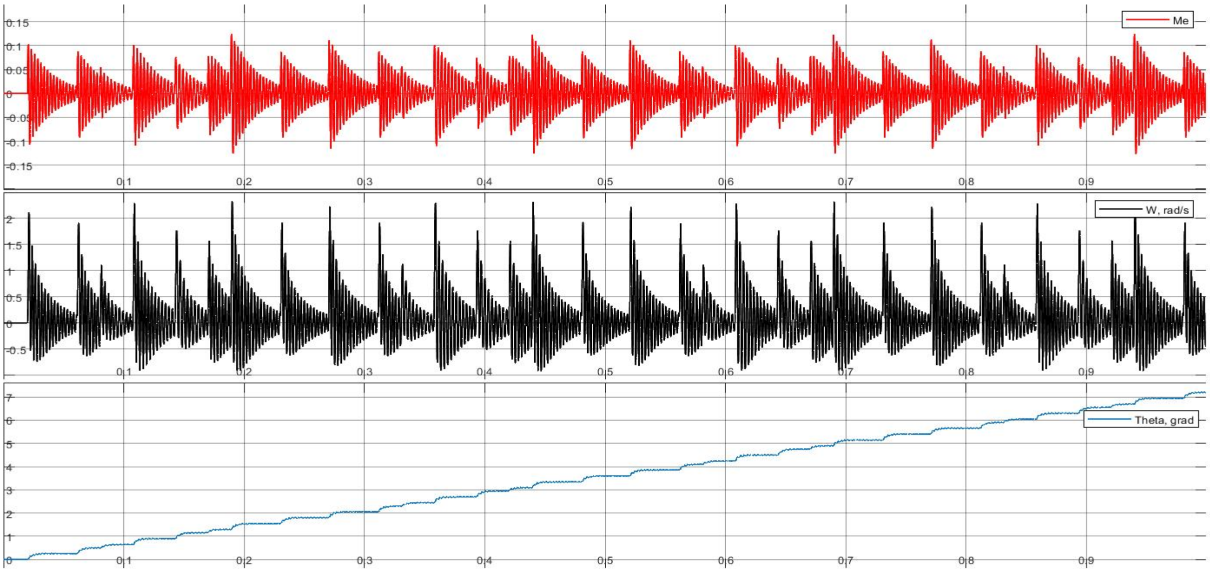

Fig. 4 Diagrams of the total torque, angular velocity and rotor rotation angle for the case of generating control signals according to formula (2)

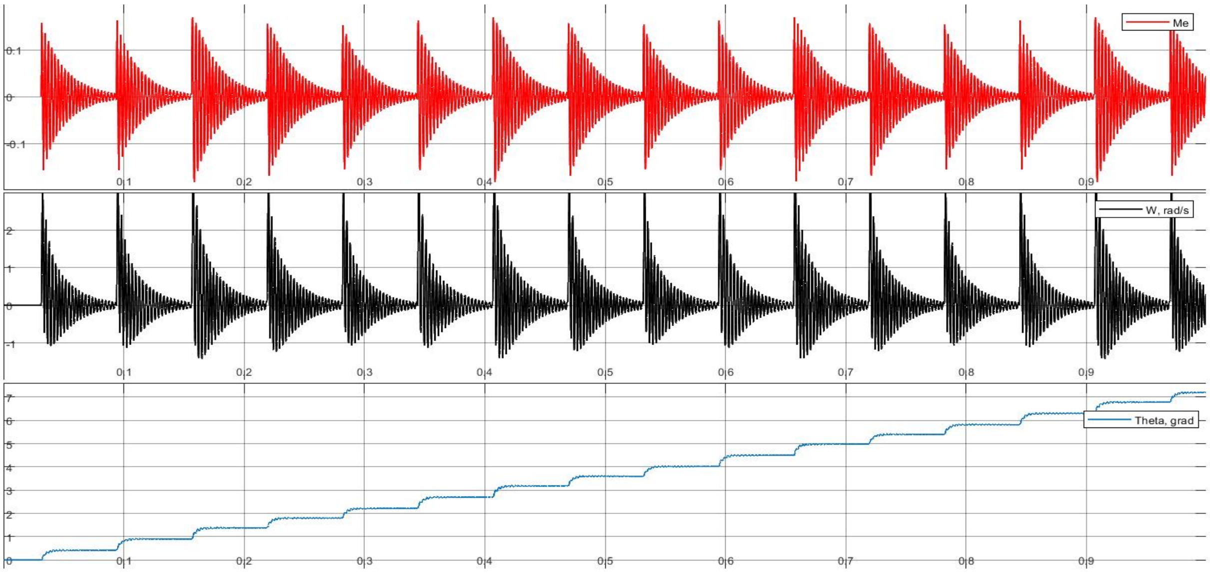

Figure 5. Diagrams of the total torque, angular velocity and rotor rotation angle for the case of generating control signals according to formulas (4,5).

In addition,intermediate angular positions of the rotor appear that are not predicted by the control algorithm. In the second case, the value of the angle increases gradually, with a value of ¼ step (0.45º).

Summary and conclusions.

The methods of generating control signals of the SM in the microstep mode are analyzed. The method used in some sources has disadvantages manifested in undesirable fluctuations of the electromagnetic moment even in the mode of uniform rotation.

A modification of the known method of generating control signals for the microstep mode of the SM is proposed. Modeling the operation of the SM using this method shows the stability of the module of the total vector of the active stator voltage, as well as the mechanical moment. The proposed formulas (2,3) can be used to generate control signals for the SM for the implementation of movement of an arbitrary nature with the involvement of the relationship between the displacement generator and the frequency *f* of the signal *S*.

References:

1. Kenio T. Step motors and their microprocessor control systems. Moscow: Energoatomizdat; 1987. 200 p. (In Russ.)
2. Osadchyi V.V., Nazarova O.S., Tobolkin S.Yu. Research of a positional electric drive based on a stepper motor in the microstep mode// Elektrotekhnicheskie i kompyuternye sistemy № 19 (95), 2015 p.24 – 27. (In Russ.)
3. Stepochkin A.O. Simulation of the operation of a stepper electric motor of a hybrid type in the Simulink package. Izvestiya of the Tula State University. Technical science. - 2018. - №8. p. 308 – 315. (In Russ.)
4. Kavalerov B.V., Falaleev D.V. Linearization of the mathematical model of a hybrid stepper motor // Bulletin of PNIPU. Electrical engineering, information technology, control systems. – 2021. - №40. p.130-148. (In Russ.)

Scientific adviser: Doctor of Technical Sciences,
Vladimirsky A.A.