

Design of Rotor with Unequal Turns and Unequal Pitches for Brushless Doubly-fed Motor

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Abstract—Brushless doubly-fed motors are widely used in real life due to their excellent starting and speed regulation performance as well as extremely high safety. In order to better explore the electromagnetic distribution of brushless doubly fed motors under asynchronous operating conditions, this paper uses finite element simulation software to conduct two-dimensional electromagnetic simulation of brushless doubly fed motors. The focus is placed on analyzing the magnetic flux density distribution, the magnetic field line distribution and the air-gap magnetic flux density waveform. On this basis, two motors with different rotor winding forms are established, and a comparative simulation analysis is carried out for the whole process of motor operation. The emphasis is laid on exploring the impact of the rotor winding pitch on the motor operation process.

Keywords—Air gap magnetic field, Brushless doubly-fed motors, Natural synchronous speed, Magnetic flux density

I. INTRODUCTION

THE BRUSHLESS doubly fed motor is different from ordinary permanent magnet motors and three-phase squirrel cage motors, as its stator has two sets of stator windings with different pole numbers. The interaction and superposition of the two sets of rotating magnetic fields generated by the power winding and the control winding result in a more complex electromagnetic situation [1],[2]. If the motor wants to operate stably in such a complex magnetic field, the specific winding form of the rotor is particularly important.

Therefore, a two-dimensional model of a 1/3 pole brushless doubly fed motor was established, with a focus on electromagnetic analysis of asynchronous operation states. On this basis, different rotor winding forms were changed, and a comparative analysis was conducted on the entire process of click operation.

II. ANALYTICAL MODEL

As shown in Fig. 1, the rotor in (a) adopts a relatively complex winding form with unequal numbers of turns and unequal pitches, while the rotor in (b) adopts a winding form with unequal numbers of turns but equal pitches. On the stator side, the same 1/3 pole-pair power winding and control winding are used.

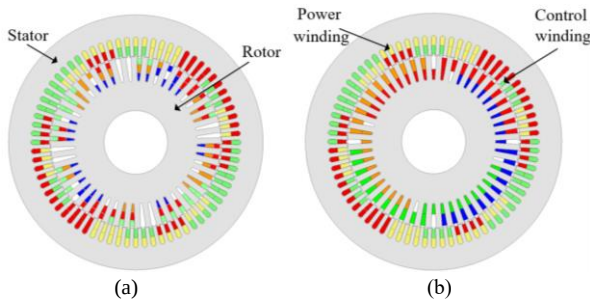


Fig. 1. Two-dimensional model of the brushless doubly-fed motor
(a) Rotor model with unequal turns and unequal pitches (b) Rotor model with unequal turns and equal pitches

The slip rate of the stator winding of a brushless doubly fed motor is defined by equation (1).

$$\begin{cases} s_p = \frac{\omega_p - p_p \Omega_r}{\omega_p} \\ s_c = \frac{\omega_c - p_c \Omega_r}{\omega_c} \end{cases} \quad (1)$$

The stator side of the brushless doubly fed motor has two sets of windings with different pole pairs. The doubly fed energy flow between them is indirectly achieved through the coupling of the rotor. As shown in Fig. 2, define the synchronous magnetic field and rotor speed reference direction.

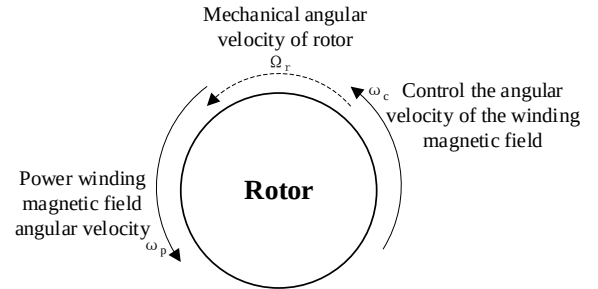


Fig. 2. Brushless doubly fed motor magnetic field rotation direction

The power winding of the brushless doubly-fed motor is always connected to the power grid. When the control winding is short-circuited by itself or in series with a resistor, the motor operates in an asynchronous state. When the angular velocity (ω_c) is zero, that is, when the control winding is connected to a direct current power source, the motor operates in a synchronous state and the rotational speed stabilizes at the natural synchronous speed. When the control winding is connected to an alternating current with positive or reverse phase sequence, the motor operates in a doubly-fed state.

Unlike ordinary motors, the synthetic magnetic field of brushless doubly fed motors can be expressed in the rotor coordinate system as equation (2).

$$\begin{aligned} b_g(\theta', t) &= b_{gp}(\theta', t) + b_{gc}(\theta', t) \\ b_{gp}(\theta', t) &= B_{gp} \cos[(\omega_p - p_p \Omega_r)t - p_p \theta' + \varphi_p'] \\ b_{gc}(\theta', t) &= B_{gc} \cos[(\omega_c - p_c \Omega_r)t - p_c \theta' + \varphi_c'] \end{aligned} \quad (2)$$

In order to reduce the magnetomotive force harmonics, the number of turns of the coils is distributed according to the following principle.

$$N' = \begin{cases} N_m \cos[(i-0.5)\alpha] & i = 1, 2, 3, \dots \quad q = 2i \\ N_m \cos[(i-1)\alpha] & i = 1, 2, 3, \dots \quad q = 2i + 1 \end{cases} \quad (3)$$

In the formula, α represents the slot pitch angle of adjacent coils, and N_m represents the maximum number of turns of coil.

III. SIMULATION AND ANALYSIS

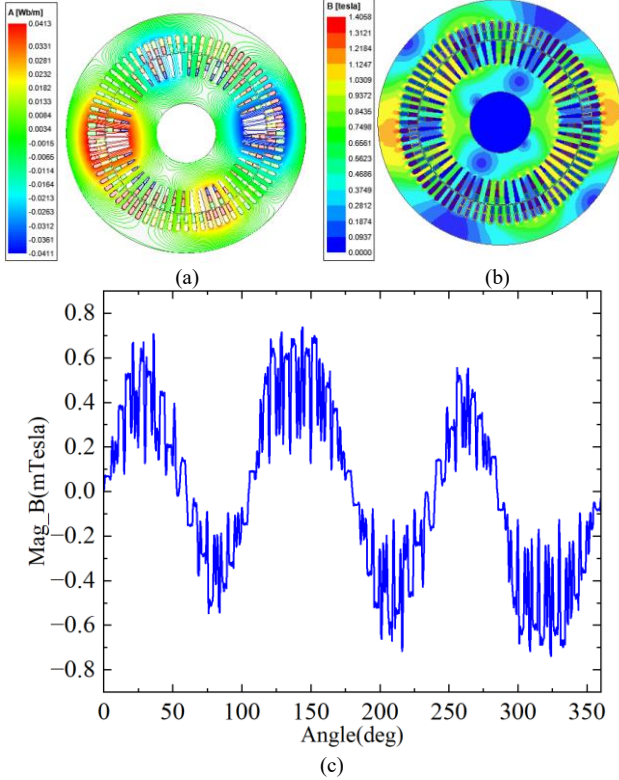


Fig. 3. Diagram of the asynchronous operating state (a) Magnetic flux density cloud diagram (b) Magnetic field line distribution diagram (c) Air-gap magnetic flux density distribution diagram

As shown in Fig.3, taking the unequal turn and unequal pitch rotor model as an example, when the power winding of the doubly fed motor is connected to the grid and the control winding is short circuited, it operates asynchronously. From (a), it can be seen that the magnetic flux density distribution and specific values of the motor at this moment. From (b), it can be seen that the magnetic field distribution inside the motor at this moment can be roughly divided into four phases. From (c), it can be seen that the air gap magnetic density can be roughly divided into six poles and multiple harmonics coexist.

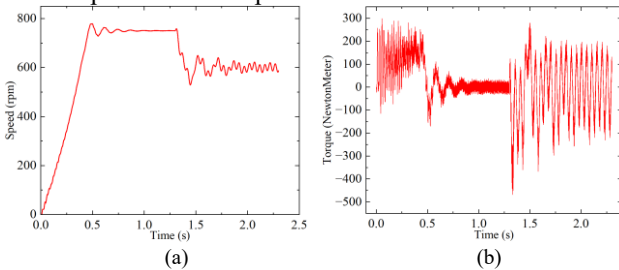


Fig. 4. Simulation waveform diagram of the rotor model with unequal turns and unequal pitches for the brushless doubly-fed motor (a) Rotational speed diagram (b) Torque diagram

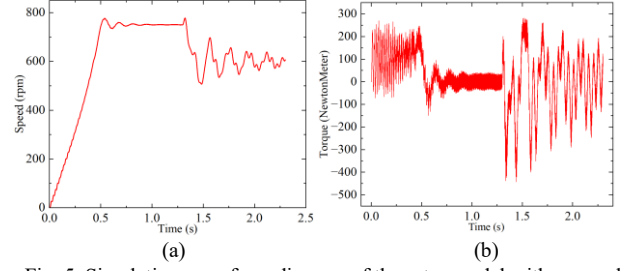


Fig. 5. Simulation waveform diagram of the rotor model with unequal turns and equal pitches (a) Rotational speed diagram (b) Torque diagram

The same excitation was applied to two models. The brushless doubly-fed motor was simulated to start asynchronously from zero speed and stabilize at the natural synchronous speed of 750 rpm. Then, at the 1.3 s moment after reaching the stable state, a 10 Hz excitation with reverse phase sequence was connected to the control winding, and the motor was transferred into the doubly-fed subsynchronous state, as shown in Fig. 4 and 5.

From the simulation results, in the asynchronous starting state, the time required for the two types of rotors to reach the steady state was basically the same. However, the torque fluctuation of the equal-pitch rotor model was relatively large after stabilization. In the doubly-fed subsynchronous state, the time required for the equal-pitch rotor model to stabilize was longer. This indicates that the unequal-pitch design can optimize the transient and steady-state performances of the brushless doubly-fed motor in the doubly-fed state.

IV. CONCLUSIONS

In this paper, the simulation of the brushless doubly-fed motor's asynchronous state was carried out to acquire the magnetic flux density, field lines and air-gap magnetic flux density. Through modifying rotor winding forms, two distinct rotor types were constructed. The entire process from asynchronous start-up to doubly-fed operation for both rotor models was meticulously simulated and comprehensively compared. The results clearly demonstrate that the rotor winding pitch exerts a significant influence. In the asynchronous operation, it directly affects torque fluctuation, while in the doubly-fed state, it notably impacts the stabilization time. This finding offers valuable guidance for optimizing rotor design to enhance the overall performance and operational efficiency of brushless doubly-fed motors.

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