Scholar Publishing Group
International Journal of Big Data Intelligent Technology
https://doi.org/10.38007/IJBDIT.2024.050105
ISSN 2790-0932 Vol. 5, Issue 1: 36-42

Review of Development of High Power and High Torque Density Motor

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Keywords: Home Appliance Motor; High Power; High Torque Density; Low Noise

Abstract: This paper analyzes the characteristics and design indicators of high power/torque density motors. Through the structural design of the inner rotor or outer rotor of the motor, combined magnetic tiles are developed, and the number of windings, slot numbers, and pole pairs numbers are optimized, and the number of the pole pairs is changed from integer pairs to fractional pairs. Improve power and torque density, reduce torque pulsation, and noise by optimizing the motor structure, selecting appropriate materials and manufacturing processes, the noise during motor operation is reduced and the user experience is improved.

1. Introduction

(1) Background

With the rapid development of our country's economy and the continuous improvement of people's living standards, the market demand for household appliances, as daily necessities, is increasing year by year[1]. As the core component of household appliances, the performance of motors directly affects the overall performance of household appliances[2]. In particular, high power/torque density motors have broad application prospects in the field of household appliances, such as air conditioners, refrigerators, washing machines, etc[3]. Therefore, studying the design, manufacturing and application of high power/torque density motors is of great significance to improving the overall competitiveness of my country's household appliance industry.

This paper focuses on the application of high power/torque density motors in the field of household appliances. It introduces the current research and development status at home and abroad from the aspects of basic theory, application analysis, design and simulation, manufacturing and testing, performance optimization and evaluation, etc., to develop high-performance, Low energy consumption, low noise motor provides reference.

(2) Situation Analysis

Foreign developed countries such as the United States, Germany, and Japan have conducted research in the field of motors earlier and have achieved a series of representative results. The United States has obvious advantages in motor design, especially in the design and manufacturing of high-power-density motors. It has developed motor products with high performance, high efficiency, and low noise. Germany has strong research strength in motor drive technology and has studied a variety of drive control strategies suitable for high torque density motors. Japan has rich experience in the field of motor applications, especially in the field of household appliances, and has conducted in-depth research on the performance of motors[4].

In recent years, many universities and research institutions have carried out relevant research on the basic theoretical research of high power/torque density motors in China. In terms of motor design, Chinese researchers have proposed a series of design methods, such as optimized design, low-noise design, etc., and have successfully applied them to actual product development[5]. In addition, in the field of motor manufacturing and testing, domestic companies already have certain manufacturing capabilities and can produce high-quality motor products that meet the needs of domestic and foreign markets.

2. Characteristics and design indicators of high power/torque density motors

2.1 Characteristics of high power/torque density low noise motors

High power/torque density motors, as a new type of motor, have many significant characteristics, giving them broad application prospects in various fields[6].

(1) Efficient

High power/torque density motors have high operating efficiency due to their advanced electromagnetic design, optimized cooling system and efficient power devices. Under the same output power, this motor has lower losses, thereby improving overall work efficiency.

(2) High power density

High power/torque density motors can output greater power with smaller size and weight. This feature is of great significance for reducing the size of the motor and the weight of the equipment, and is especially suitable for occasions with high space and weight requirements[7].

(3) High torque density

Torque density refers to the output torque of the motor per unit volume or mass. High torque density motors can output larger torque in a smaller volume or mass, thereby meeting the needs of high-load, high-torque applications. This makes high power/torque density motors have good application prospects in high torque applications such as automobiles, robots, aerospace, etc.

(4) Low noise and low vibration

High power/torque density motors take noise and vibration issues into full consideration during the design process. By optimizing the electromagnetic design, structural design and adopting advanced control strategies, the noise and vibration of the motor are effectively reduced and the user experience is improved.

(5) High reliability and stability

High power/torque density motors adopt high-quality components, advanced manufacturing processes, and undergo rigorous testing. They have high reliability and stability, allowing the motors to maintain good performance in various harsh environments and meet the requirements Applications requiring high reliability.

2.2 Design indicators of high power/torque density and low noise motor[8][4]

(1) Efficiency: the ratio of motor output mechanical power to input electrical power, usually expressed as a percentage.

(2) Power factor: the ratio of motor input active power to apparent power.

(3) Locked rotor current: The steady-state current effective value input from the power supply circuit when the motor is at rated voltage, rated frequency and the rotor is blocked.

(4) Locked rotor torque: the minimum measured value of the torque generated by the motor at rated voltage, rated frequency and when the rotor is blocked.

(5) Maximum torque: The maximum torque generated by the motor when the speed does not drop suddenly under the rated voltage, rated frequency and operating temperature.

(6) Noise: The maximum value of A-weighted sound power level dB (A) when the motor is running in a no-load steady state.

(7) Vibration: The effective value of vibration speed when the motor is running in a no-load steady state.

3. Characteristics and performance requirements of household appliance motors

3.1 Home appliance motors have the following characteristics[9]

(1) High efficiency. Improving motor efficiency helps reduce energy consumption and environmental pollution. High efficiency and energy saving are an important development direction for household appliance motors.

(2) Low noise. Reducing motor noise is key to improving the comfort of home appliances. Low-noise motor design requires optimization in terms of structure, materials, and control strategies.

(3) Miniaturization. As home appliances develop towards miniaturization and lightweight, motors also need to have compact structures and smaller volumes.

(4) High reliability. Home appliance motors need to have a long service life and stable operating performance to ensure the reliability of home appliances.

3.2 Performance requirements for household appliance motors

Taking the brushless DC motor of small household appliances as an example, the power is less 1kW, the rated speed is less 5000rpm, the rated power density is more or equal 0.8kW/kg; the motor operating noise is less or equal 45 decibels.

3.3 Application prospects

Compared with traditional motor products, the high performance, thinness and miniaturization of the machine improve performance and reduce product size[6]. If the motor product uses permanent magnet materials, especially high-performance rare earth permanent magnet materials, the efficiency of the motor can be greatly improved and the size of the motor can be reduced[7]. Brushless motors have been widely used in household appliances. For example, brushless DC motors are used to replace asynchronous motors in inverter air conditioners, and the efficiency is significantly improved[8]. The whole machine uses the motor rotor directly as the driving element, eliminating the need for an intermediate transmission mechanism, which not only simplifies the structure, but also improves system accuracy[9]. Permanent magnet brushless DC motors can also be made into outer rotor or inner rotor structures according to user requirements. Therefore, it has excellent generalizability and promising prospects[10].

4. Motor design

4.1 Motor design analysis

Based on specific application needs, through the structural design of the inner rotor or outer rotor of the motor, we develop combined magnetic tiles, optimize the pairing of windings, slot numbers, and pole pairs, and increase the number of pairs from integer pairs to fractional pairs, which can increase power and torque density and reduce torque. Pulsation, reducing vibration and noise, as shown in Figure 1:

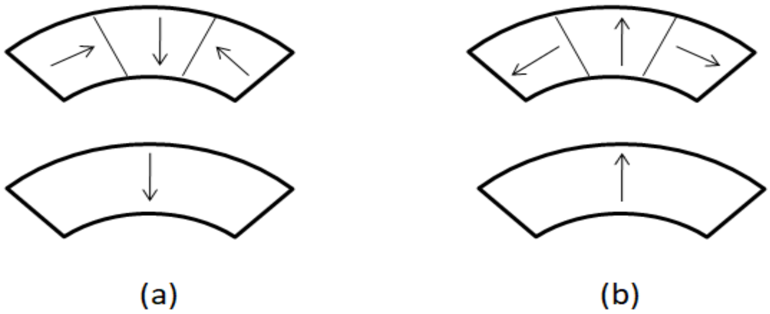
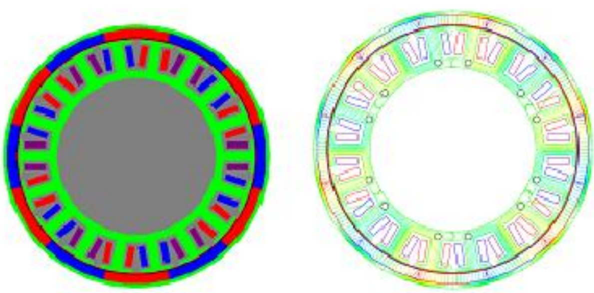


Figure 1. Multi-magnetic tile combination

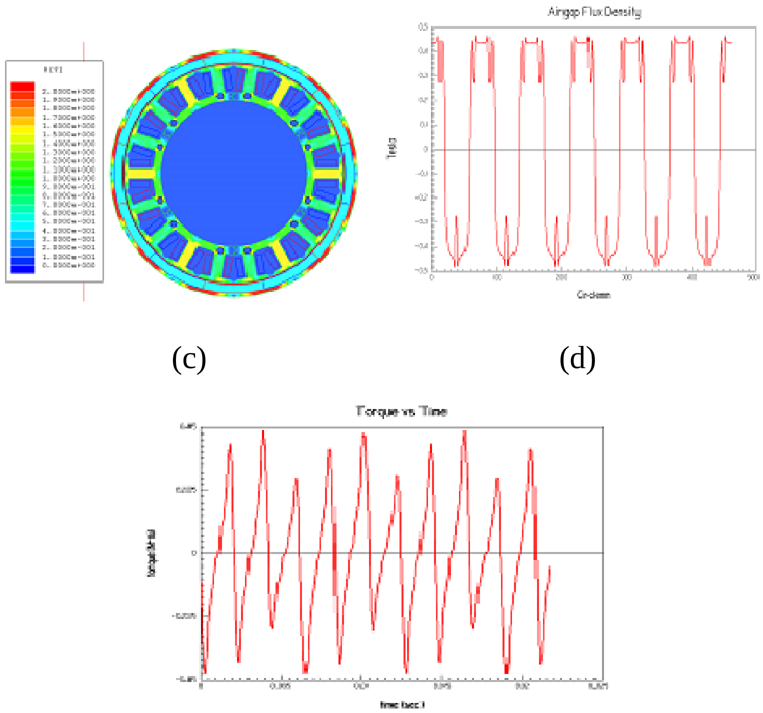
Based on 3D electromagnetic simulation analysis, the winding layout and winding manufacturing process are optimized. Based on the PWM variable frequency drive circuit, the control strategy and control algorithm are optimized to improve the speed control accuracy and torque output stability.

Based on the technical parameter requirements of the motor, 2D and 3D electromagnetic analysis are performed through electromagnetic simulation analysis software to determine whether the motor adopts an inner rotor or an outer rotor structure. The mechanical structure of the motor is optimized based on simulation analysis software to improve rigidity. Figure 2 shows the results of electromagnetic simulation analysis. In Figure 2, (a) is the motor model, (b) is the magnetic field distribution, (c) is the magnetic flux density distribution, (d) is the air gap magnetic flux density distribution, (e) is the magnetic trough torque.

Through electromagnetic and mechanical collaborative optimization, it meets the requirements of high power and high torque density, and reduces the impact of torque ripple and radial electromagnetic force on motor vibration and noise.



(a) (b)



(c) (d)

(e)

Figure 2. Electromagnetic simulation analysis

4.2 Low noise design

Taking a DC brushed motor as an example, in order to reduce the noise of motor operation, the structural design is improved in the following aspects:

(1) Use material reduction on the rotor core to reduce motor noise.

(2) Conventional arc brushes are changed into toothed brushes to reduce noise caused by friction.

(3) Add a damping rubber block to the metal shrapnel to reduce the noise caused by brush vibration.

(4) Find the best matching angle between the brush and the commutator, optimize the motor performance, and use the end effect of the magnet on the winding to improve performance.

(5) Study the impact of the fixing method of the magnets on the casing on the performance of the motor, and use glue fixation instead of using a slingshot to fix the magnets to improve the performance of the motor.

4.3 Application examples

Figure 3 shows the direct drive motor of a drum washing machine. Its main technical indicators are:

- Output power: 500W;
- Speed operating range: 50~1400rpm;
- Peak torque: 18.3Nm (duration 10s);
- Maximum efficiency: 83.0%;
- Motor peak torque density: 4.5 Nm/kg;
- Leakage current: ≤0.25mA;

- Durability test (under rated conditions, complete machine test or motor plus simulated load test): 6000cycle;
- Noise (700rpm): 45dB(A);
- Electrical strength (2100V, 1s): no flashover breakdown;
- Insulation resistance (DC500V): ≥5MΩ;
- Temperature rise: <105K;

Figure 3 Direct drive motor of drum washing machine

5. Conclusion

(1) High power/torque density motors have the advantages of small size, high efficiency, and fast response speed, which make them have broad application prospects in the field of household appliances.

(2) Through the structural design of the inner rotor or outer rotor of the motor, the development of combined magnetic tiles, optimizing the pairing of windings, slot numbers, and pole pairs, from integer pairs to fractional pairs, can increase power and torque density and reduce torque ripple. Reduce vibration and noise.

(3) When designing high power/torque density motors, low noise design requirements should be fully considered. By optimizing the motor structure and selecting appropriate materials and manufacturing processes, the noise during motor operation can be effectively reduced and the user experience improved.

Acknowledgements

This paper is supported by Projects of major scientific and technological research of Ningbo City (2020Z065, 2021Z059,2022Z090(2022Z050), 2023Z050(the second batch)), Major instrument special projects of the ministry of science and technology of China(2018YFF01013200), Projects of major scientific and technological research of Beilun District, Ningbo City(2021BLG002, 2022G009), Projects of engineering research center of Ningbo City (Yinzhou District Development and Reform Bureau [2022] 23), Projects of scientific and technological research of colleges student's of China(202313022036).

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