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STUDY OF STATOR SLOT CONFIGURATION AND COIL DIAMETER ON BLDC MOTOR EFFICIENCY AND STABILITY

The object of research is the axial flux BLDC (Brushless DC) motor, widely used in electric vehicles and industrial applications due to its compact design and high efficiency. One of the most problematic areas is optimizing the stator slot configuration and coil diameter to enhance efficiency and stability. Previous studies show that these parameters significantly affect magnetic field distribution, losses, and overall performance. However, a systematic investigation is still needed. Therefore, this study aims to identify optimal parameters to improve BLDC motor efficiency and stability.

In the course of the study, an experimental setup with a BLDC motor, controller, power supply, and measurement tool were used. The motor was tested with different stator slots (12 and 24) and coil diameters (0.2 mm, 0.5 mm, 0.7 mm). Measurements included power, current, speed, and temperature. Data analysis assessed the impact on efficiency and stability, supported by numerical simulations for validation and optimization.

Received results show that increasing stator slots from 12 to 24 improves magnetic field distribution and motor efficiency, with power output reaching 3060 W in the optimal configuration. This is due to the proposed stator slot variation, which reduces magnetic losses and enhances thermal efficiency. In particular, motors with 24 slots and a 0.5 mm coil diameter achieved the highest efficiency, while a 0.7 mm coil led to performance decline due to increased resistance. The findings highlight the need for an optimal balance between coil diameter and stator slot configuration for stable and efficient operation.

This ensures the development of high-performance BLDC motors with improved efficiency and stability. Compared to similar configurations, it offers higher power output, lower magnetic losses, and better thermal regulation. These findings support the advancement of reliable, energy-efficient BLDC motors for electric vehicles and industry, with future research focusing on advanced materials and manufacturing techniques for further optimization.

Keywords: *BLDC motor, stator slot configuration, coil diameter, operational stability, motor performance, rotational speed.*

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1. Introduction

In this modern era, the need for efficient and stable electric motors is increasing along with the development of electric vehicle technology and industrial devices. The axial flux type BLDC (Brushless DC) motor is a promising solution because of its compact design and high efficiency. However, one of the main challenges faced is how variations in stator slot configuration and coil diameter can affect the efficiency and stability of the motor. Optimal stator slot configuration can reduce magnetic losses and improve magnetic field distribution, while proper coil diameter can influence motor resistance and inductance.

Recent research has shown that variations in stator slot configuration can significantly influence the distribution of magnetic fields and magnetic losses, which in turn affects motor efficiency. Based on studies conducted by [1], variations in the stator slot configuration can influence the magnetic field distribution and reduce magnetic losses, which ultimately increases motor efficiency. Additionally, research by [2] shows that larger coil diameters can reduce resistance and increase inductance, which contributes to the operational stability of motors. According to [3], the use of new materials with better magnetic properties can also improve the performance of BLDC motors. Research by [4] emphasizes the importance of advanced manufacturing techniques in motor design optimization. The study by [5] shows that numerical analysis and computer simulation can help in predicting motor performance with high accuracy. Additionally, research by [6] found that variations in stator slot design can affect heat distribution and motor thermal efficiency. According to [7], the operational stability of the motor can be improved by optimizing the coil parameters. Research by [8] shows that the use of experimental techniques in validating simulation results is essential to ensure model accuracy. The study by [9] emphasizes the importance of laboratory testing in identifying factors that influence motor performance. Finally, research by [10] shows that the development of more efficient design models can meet the industry's need for more reliable and energy efficient electric motors. BLDC motors have been the subject of previous research that demonstrated a number of significant discoveries. These findings relate to the influence of variations in stator slot layout and changes in coil diameter on the functional stability and energy efficiency of the motor. The findings of [11] show that changing the stator slot configuration can impact the magnetic field distribution, thereby reducing magnetic losses and ultimately leading to a half increase in motor efficiency. It is shown by [12] that a larger coil diameter can reduce resistance and increase inductance, both of which contribute to the stability of motor operation two. In [13], it is emphasized that there is a need to utilize new materials that have superior magnetic characteristics to improve the performance of BLDC motors. According to [14], motor design optimization is significantly influenced by the utilization of advanced manufacturing techniques. According to [15], numerical analysis and computer simulation have the potential to help predict motor performance with a high degree of accuracy. In [16] it is found that differences in stator slot design can affect the heat dispersion and thermal efficiency of the motor a. By changing the coil characteristics, [17] showed that the operational stability of the motor can be improved. In terms of ensuring that the simulation model is accurate, [18] emphasizes the importance of experimental validation. Researchers of [19] emphasize the importance of laboratory testing in the process of determining the elements that influence motor performance. The findings of [20] show that the industrial demand for more reliable and energy efficient electric motors can be met by the creation of more efficient design models. Based on the findings of [21], the number of stator slots has an impact on the rotation speed and temperature of brushless direct current (BLDC) motors. A study conducted by [22] investigated the impact of changing the winding wire diameter on the overall performance of an induction motor. In [23], conducted research shows the impact of alternator spool fluctuations on voltage and current. Research findings [24] show that the rotation speed and temperature of BLDC motors are influenced by differences in the number of stator slots. The findings of research conducted by [25] show that the rotation speed and temperature of BLDC motors are influenced by differences in the number of stator slots.

The aim of this research is to identify optimal parameters that can improve BLDC motor performance, both in terms of energy efficiency and operational stability. By focusing on variations in stator slot configuration and coil diameter.

2. Materials and Methods

Fig. 1 shows an experimental BLDC motor setup, where this test involves several main components, namely the BLDC motor, controller, power supply, and supporting systems for measurement and analysis. The testing process begins with designing and assembling a test circuit that ensures all components are connected correctly. The BLDC motor is connected to the controller via a phase cable and a sensor, such as a Hall sensor, to detect the rotor position and provide a signal back to the controller. The controller is tasked with adjusting the switching pattern on the inverter according to the input signal. The controller specifications are 60 V voltage with a capacity of 500 watts. The power supply is used to provide the voltage and current required by the motor and controller. A power supply that functions as a converter of high voltage Alternating Current (AC) to low voltage Direct C++ current (DC) so that it does not exceed the maximum limit so that it can distribute electricity to the controller as needed.

Data generated during testing, such as power, phase current using an AVO meter while rotational speed, is measured using a tachometer. For measuring motor temperature using a thermogun. This data is analyzed to evaluate the performance of the BLDC motor, such as the efficiency and stability of the motor system. These test results can be used to validate motor designs and optimize control parameters for specific applications. Design of BLDC motor components as shown in Fig. 2.

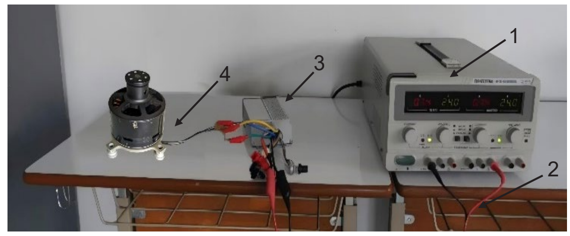

Fig. 1. Experimental setup: 1 – power supply; 2 – cable; 3 – electronic stability control; 4 – BLDC motor

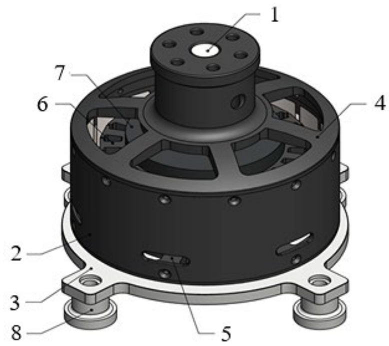

Fig. 2. BLDC motor components: 1 – shaft; 2 – cover; 3 – holder; 4 – upper cover; 5 – lower cover; 6 – roll place; 7 – roll place; 8 – bracket spacer

Table 1 shows the specifications of the BLDC motor which was tested by varying the number of slots, wire diameter windings.

Table 1

BLDC motor test specifications

Parameter	A1	A2	A3	B1	B2	B3
Stator diameter (mm)	84.25	84.25	84.25	84.25	84.25	84.25
Rotor diameter (mm)	108	108	108	108	108	108
Number of slots	12	12	12	24	24	24
Copper wire diameter (mm)	0.2	0.5	0.7	0.2	0.5	0.7
Number of coils per slot	80	45	25	80	45	25
Number of magnets	20	20	20	20	20	20
Magnet type	N52	N52	N52	N52	N52	N52
Coil relationships	Star	Star	Star	Star	Star	Star
Electrical voltage (V)	60	60	60	60	60	60

Table 1 presents the specifications of the BLDC motor tested under different configurations by varying the number of stator slots and copper wire diameters. The motor has a stator diameter of 84.25 mm and a rotor diameter of 108 mm, remaining constant across all configurations. Two sets of slot configurations were tested: 12-slot (A1, A2, A3) and 24-slot (B1, B2, B3). Within each configuration, the copper wire diameters were varied at 0.2 mm, 0.5 mm, and 0.7 mm, affecting the number of coils per slot, which ranged from 80 to 25. The motor used N52-grade permanent magnets and a star coil connection. The electrical voltage was consistently set at 60 V to ensure comparability of results.

3. Results and Discussion

3.1. Relationship between motor type and motor power

Fig. 3 shows that the motor output power shows the efficiency of the system in converting electrical energy into mechanical energy. From the power table, motor B1 produces the highest power (3060 Watts), while A3 produces the lowest power (2700 Watts).

This shows that the mechanical and electrical configuration, including the number of turns and copper wire diameter, plays an important role in motor efficiency. Type B generally has a higher average power than type A, which is likely influenced by the difference in the number of slots (24 slots for type B vs 12 slots for type A). Meanwhile, the number of turns per slot and the diameter of the copper wire affect the total resistance and current that can flow through the motor. Type A1 has more turns (80 turns per slot) with a small wire diameter (0.2 mm), providing higher impedance and smaller current. Types A2 and A3 have fewer turns and a larger wire diameter, which reduces resistance and allows greater current, but this can reduce motor power if not offset by proper current regulation. Meanwhile, in type B, a similar pattern is seen, but with more slots (24) which allow for more even distribution of the magnetic field, resulting in greater power than type A.

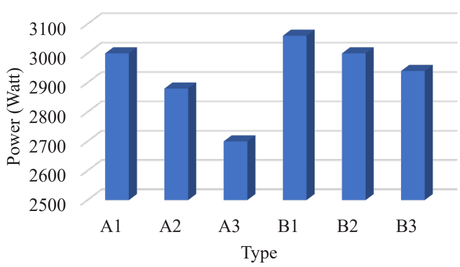

Fig. 3. Relationship between type and motor power

The use of N52 type Neodymium magnets with uniform dimensions in all types ensures a strong and stable magnetic field. The same electrical voltage (60 V) across all types indicates that power variations originate primarily from winding configuration and mechanical design, not from the power source. Uniform stator and rotor dimensions ensure mechanical compatibility across types. However, the larger number of slots in type B allows smoother and more efficient magnetic field regulation compared to type A, which can be seen from the difference in output power. The winding arrangement with star (Y) connections on all types provides advantages in terms of voltage distribution between phases. However, the efficiency of certain types, such as B1, can be better due to optimization of the number of slots and balanced windings. This configuration can be further optimized by adjusting parameters such as number of turns, wire diameter, or rotor design.

3.2. Relationship between motor type and electric current

Fig. 4 shows that the current flowing in a BLDC motor is influenced by the motor's electrical and mechanical design, including the number of windings, copper wire diameter, and the number of slots in the stator. In a motor with a fixed voltage (60 V), the current reflects the electrical power consumption which varies according to the motor configuration. The electric current flowing through the motor is an important parameter that reflects the power requirements and efficiency of the motor. Type B1 has the highest current (52 A), indicating greater power requirements due to the configuration of a larger number of slots (24 slots). Type A3 has the lowest current (45 A), which corresponds to its design which has the fewest number of turns (25 turns per slot) and a larger copper wire diameter (0.7 mm), reducing resistance. The greater current increase in type B compared to type A is due to more slots and a better magnetic field, allowing the motor to produce more power. In Type A (A1, A2, A3), the current decreases gradually from A1 (50 A) to A3 (45 A). This decrease correlates with a reduction in the number of turns per slot (80 on A1, 45 on A2, and 25 on A3) and an increase in copper wire diameter (0.2 mm on A1 to 0.7 mm on A3). A larger wire diameter reduces winding resistance, allowing greater current, but a smaller number of turns reduces total power consumption. Meanwhile, in type B (B1, B2, B3), a similar pattern is seen in type B, with B1 having the highest current (52 A) and B3 the lowest (49 A). With a larger number of slots (24 compared to 12 in type A), the current distribution in type B is more even. However, current variations are still influenced by the number of turns and diameter of the copper wire. The uniform dimensions of the stator and rotor in all types ensure that the mechanical influence on the current is almost the same. However, the larger number of slots in type B allows for a more efficient and stable magnetic field, which directly affects current consumption.

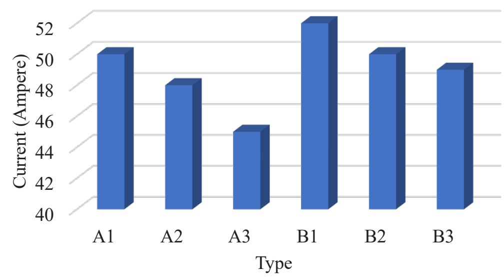

Fig. 4. The relationship between motor type and electric current

The use of Neodymium N52 magnets in all types provides high magnetic field strength, so that the motor can produce power with high efficiency. Differences in the number of turns and diameter of the copper wire affect how much current is needed to produce sufficient electromagnetic force. In motors with a fixed voltage, the current has a direct relationship with the electrical power consumed. The combination of current and power shows the efficiency of each type: Type A, with a smaller number of slots (12 slots), the current is lower than type B in certain configurations. This indicates lower efficiency because the magnetic field is less even. Type B, with a larger number of slots (24 slots), a larger current is required to produce higher power. It shows better efficiency due to better magnetic field distribution. The use of star (Y) connections on all types provides voltage stability between phases and optimal current regulation. However, efficiency can be increased by better adjusting the number of turns, wire diameter, and slot distribution.

3.3. Relationship between motor type and motor rotation

Fig. 5 shows that motor rotation speed is an important indicator that shows the performance and efficiency of a BLDC motor in converting electrical energy into mechanical movement. Type B1 has the highest rotation speed (6025 RPM), followed by type B2 (5870 RPM). Meanwhile, Type A3 has the lowest rotation speed (5423 RPM), which is in line with the fewest number of turns per slot (25 turns) and a larger copper wire diameter (0.7 mm). This speed difference is caused by mechanical and electrical configurations, such as the number of coils per slot, wire diameter, and number of slots. In addition, the number of coils per slot affects the motor rotation speed: Types A1 and B1 (80 coils per slot) have more coils, produces a stronger magnetic field. However, stronger magnetic fields increase inductance, which can limit rotation speed. Meanwhile, Types A3 and B3 (25 turns per slot) have a smaller number of turns, which reduces inductance but also weakens the magnetic field, resulting in lower rotation because the torque produced is smaller.

In addition, the diameter of the copper wire affects the winding resistance. In the type with a larger copper wire (0.7 mm in A3 and B3), the smaller resistance allows a larger current, but the resulting magnetic field is weaker due to the smaller number of turns. This explains the lower RPM compared to types with smaller copper wire (0.2 mm on A1 and B1).

Besides that, the number of slots has a big influence on the distribution of the magnetic field. Type B (24 slots) has a more uniform magnetic field distribution than type A (12 slots), resulting in higher efficiency and rotation speed. Type B1, with optimal winding and slot

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configuration, reaches the highest speed (6025 RPM). And Type A, with fewer slots, has a less even magnetic field distribution, resulting in lower RPM.

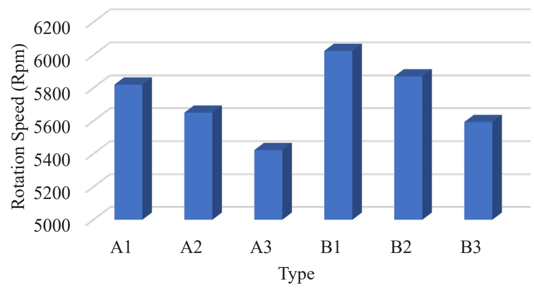

Fig. 5. The relationship between motor type and motor rotation speed

3.4. Relationship between motor type and motor temperature

Fig. 6 shows that motor temperature reflects the efficiency of electrical energy conversion to mechanical energy as well as the motor's thermal management. Type A has a lower operating temperature (average 40.56 °C) than type B (average 41.47 °C), while Type B3 has the highest operating temperature (41.6 °C), while Type A1 has the lowest temperature (40.5 °C). The higher operating temperature of type B indicates that this motor produces more heat, which is most likely due to the higher output power and greater current.

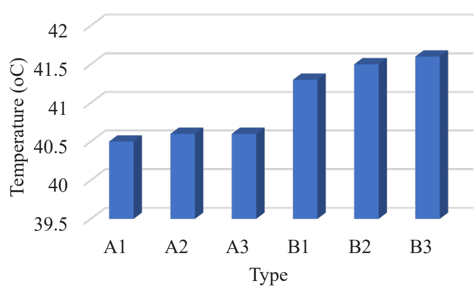

Fig. 6. The relationship between type and motor temperature

The temperature produced in a motor is closely related to the electric current (I) and resistance (R), based on Joule's law. In type B, a larger current (B1=52 A) causes greater power dissipation, so the motor tends to get hotter. Meanwhile, the larger copper wire diameter in types B2 and B3 (0.5 mm and 0.7 mm) reduces resistance, but heat still increases because the current is greater than type A. Type A, with fewer slots and lower current, produces less heat, resulting in lower operating temperatures.

The number of slots affects the magnetic field distribution and heat dissipation, Type A (12 slots) produces less heat due to lower current and a more focused magnetic field. Type B (24 slots) distributes the magnetic field more evenly but requires more current, resulting in more heat. The greater distribution of slots in type B increases the energy requirement to maintain a stable magnetic field across the slots, leading to an increase in temperature.

Meanwhile, the role of a larger copper wire diameter (for example, types A3 and B3, 0.7 mm) reduces resistance and prevents heat spikes due to resistance. However, the smaller number of windings in this type limits the magnetic field efficiency, which can affect heat dissipation indirectly. On the other hand, in types A1 and B1 (wire diameter 0.2 mm), the resistance is higher, so even though the current is smaller, the heat remains controlled.

3.5. Discussion

Fig. 3 shows that the uniform stator and rotor dimensions ensure compatibility between types. More slots in type b increase the efficiency of magnetic fields, which are like the output power. Star Connection (Y) Provides a Good Voltage Distribution, and Higher Efficiency in Type B1 Show Optimization of the Number of Slots and Better Balance of Turns. This configuration can still be increased by adjusting the winding, wire diameter, or rotor design.

Fig. 4 shows that the uniform stator and rotor dimensions maintain mechanical influence on currents remain consistent. Type B, with more slots, produces more stable and efficient magnetic fields, increasing current consumption. Magnet Neodymium N52 ensures a strong magnetic field and high-power efficiency. The number of windings and diameter of the wire affect the current needs for the electromagnetic force. In a fixed voltage motor, the current is directly proportional to the electrical power consumed. Type A (12 slots) has a lower current and lower efficiency due to an uneven magnetic field, while type B (24 slots) requires greater current for higher power, showing better efficiency. Star connection (Y) ensures stability and optimal current regulation, but efficiency can still be increased by optimizing winding, wire diameter, and slot distribution.

Fig. 5 shows that the diameter of the wire also plays a role in the winding resistance. Wire is larger (0.7 mm in A3 and B3) reduces resistance and allows the current to be greater, but the number of coils that fewer weaken the magnetic field, causing rpm to be lower than the type with smaller wire (0.2 mm at A1 and B1). In addition, the number of slots affects the distribution of magnetic fields. Type B (24 slots) has a more equitable magnetic field distribution than type A (12 slots), increases efficiency and rotation speed. Type B1, with optimal configuration and slot, reaching the highest speed (6025 rpm), while type A, with less slots, has an uneven magnetic field distribution, producing lower rpm.

Fig. 6 shows that the number of slots also affects the distribution of magnetic fields and heat release. Type A (12 slots) produces less heat because the current is lower and the magnetic field is more focused. Type B (24 slots) distribute more magnetic fields but requires more currents, so that the heat produced is greater. A broader slot distribution in type B increases energy needs to maintain the stability of the magnetic field, which contributes to the increase in temperature. In addition, larger wire diameters (for example, types of A3 and B3 with 0.7 mm) reduce resistance and prevent the surge of heat due to resistance. However, the smaller number of windings in this type limits the efficiency of the magnetic field, which can indirectly affect the release of heat. Conversely, in types A1 and B1 (wire diameter 0.2 mm), resistance is higher, but because the current is smaller, heat remains controlled.

The findings of this study can be applied to the development of electric vehicles, robotics, and BLDC propulsion systems. Understanding stator configuration, winding turns, and copper wire diameter helps optimize motor design for improved efficiency and power output. Additionally, temperature analysis supports the development of more effective cooling systems.

This study is limited to variations in stator slots and copper wire diameter, without considering factors such as core material and rotor shape. Testing was conducted under controlled laboratory conditions, requiring further validation in real-world operational environments.

Future studies could explore alternative materials, AI-based control optimization, and real-world industrial applications. Additionally, the development of adaptive sensor-based cooling systems could enhance the thermal stability of BLDC motors.

4. Conclusions

The research findings support the following conclusion:

1. Type B1 has the highest power (3060 Watts), while type A3 has the lowest power (2700 Watts). Type B with 24 slots shows higher efficiency than type A with 12 slots due to better magnetic field distribution.

2. Type B1 requires the highest current (52 A) because the more slot configuration supports a more even magnetic field. Type A3 has the lowest current (45 A) due to fewer turns and a larger wire diameter, which reduces resistance.

3. Type B1 reaches the highest speed (6025 RPM) thanks to optimal magnetic field distribution. Type A3 has the lowest speed (5423 RPM) because the number of turns is smaller and the wire diameter is larger.

4. Type B has a higher average temperature (41.47 °C) than type A (40.56 °C) due to greater power and current. The larger copper wire diameter helps reduce resistance, although heat dissipation remains higher in type B.

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Conflict of interest

The authors declare that they have no conflict of interest regarding this study, including financial, personal, authorship or other, which could be affect the study and its results presented in this article.

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Data availability

The manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the presented work.

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