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TESTING OF BRUSHLESS DC MOTORS ENGINEERED FOR LIGHTWEIGHT AERIAL PLATFORMS

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Abstract. Low-power motors and drives are becoming increasingly common, especially in large-scale products such as household electronics, toys, and laboratory equipment. Having a flexible in-house production line appears to be a significant priority for many European countries. This paper outlines a recommended procedure for developing such drives and presents a real-world development application: a 400W Brushless DC (BLDC) motor prototype, including preliminary and endurance tests. The prototype was tested as a free-running motor, a generator, and a full-power motor, with these tests confirming that the performance goals were met.

1. INTRODUCTION

Brushless DC (BLDC) motors represent a significant advancement in electrical motor technology, offering several advantages that enhance their application across various industries. Notably, these motors exhibit remarkable efficiency, high power density, and require minimal maintenance. As a result, BLDC motors are increasingly favoured in sectors such as industrial machinery, aerospace, and consumer electronics due to their reliability and superior performance [1,2].

One of the key features of BLDC motors is their brushless design. This design reduces wear and eliminates sparking, which are common issues in traditional motors. Consequently, BLDC motors operate more quietly and require less frequent maintenance, thereby improving overall operational efficiency [3]. With these compelling benefits, BLDC motors are well-positioned to drive future technological advancements. Their potential for innovation is truly inspiring!

The evolution of BLDC motors focuses on refining dynamic performance, advancing control systems, and optimising designs to perfectly suit various applications.[4]. Control methods for brushless direct current (BLDC) motors emphasise maximising performance and dependability across diverse operating conditions. These methods aim to improve the motors' efficiency, ensuring reliable performance despite variations in load, speed, and environmental conditions. By applying sophisticated control techniques, engineers can enhance the responsiveness and overall stability of BLDC motors, making them ideal for a wide range of applications. [5].

The optimization of Brushless DC (BLDC) motors often requires the implementation of multi-objective optimization techniques to strike an optimal balance between high power density, reduced weight, and minimized cogging torque. These characteristics are essential in enhancing the performance of propulsion systems and other demanding applications. [6,7]. These initiatives also embrace thermographic fault-detection techniques, which significantly

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improve reliability and safety in critical applications, such as aerospace. This is particularly important where high power ratings and compact designs are essential [2,8].

The control and characterisation of BLDC motors are significantly enhanced by employing innovative mathematical modelling techniques to effectively address their particular operation [9]. These advancements highlight the need to develop strong, efficient BLDC motors to meet the demands of contemporary technology.

2. BRUSHLESS DIRECT CURRENT MOTOR DESIGN

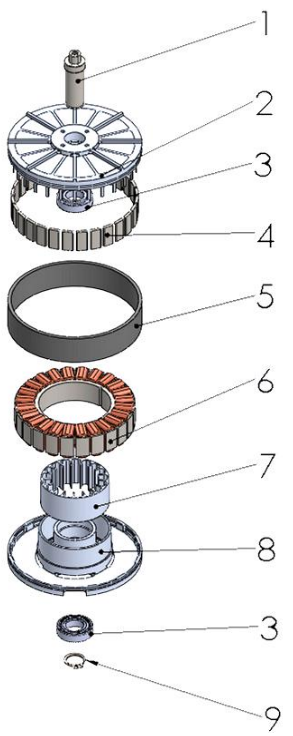
2.1 Initial design requirements

For the initial requirements, the main characteristics of the BLDC motor were imposed by the UAV developer, as follows:

- Motor size Ø85-Ø90 / 40-45 mm;
- Rated supply voltage 22.2-44.4 V_{DC};
- Peak current (180s) 85A_{DC};
- Motor weight 600…650g;
- Speed 3000…5800 rpm;
- Power 300…3845 W (using propeller).

2.2 General drawing

The propulsion unit under investigation is a Brushless Direct Current (BLDC) motor, designed specifically for lightweight aerial platforms. Key performance metrics for this application include efficiency, power-to-weight ratio, and thermal stability. The motor is presented in Fig. 1.



1-driving central shaft;
2-aluminium housing;
3-radial ceramic ball bearings,
4-NdFeB magnets,
5-steel enclosure,
6-stator of the motor,
7-radiator,
8-fixed stator casing,
9-retaining ring.

Fig. 1 – An exploded 3D view of the Brushless DC (BLDC) motor for lightweight aerial platforms.

The central driving shaft (1) is made from non-magnetic stainless steel, ensuring structural rigidity and effective torque transfer to the propeller without interfering with the magnetic field. The rotor assembly features an aluminium housing (2) that contains 28 high-performance NdFeB permanent magnets (4). These magnets are secured by an additional steel enclosure made of OL37 (5), which provides mechanical protection and partially closes the magnetic circuit. The stability of the rotor is maintained by radial ball bearings (3), which minimise friction and enable smooth rotation, while an axial retaining ring (9) prevents unwanted displacement of the shaft during operation.

The stator consists of a 0.2 mm-thick laminated FeSi core, which helps reduce eddy-current losses and enhance electromagnetic efficiency. Surrounding this core are copper windings with a diameter of 0.2 mm, which create the magnetic field necessary for rotor actuation. The laminated stack is enclosed in a fixed stator casing, which also serves as the structural interface for mounting the motor to the drone. To ensure stable operating conditions, an aluminium radiator is integrated to dissipate heat generated during high-load operations, protecting the copper windings and maintaining permanent magnet stability.

This configuration allows the motor to achieve high energy density, enhanced starting torque, and a reduced overall mass, making it highly suitable for drone propulsion. The careful selection of materials—stainless steel for the shaft, neodymium iron boron (NdFeB) for the permanent magnets, silicon steel (FeSi) laminations for the stator core, and aluminium alloys for structural and thermal components—reflects a design approach that emphasises both electromagnetic performance and mechanical durability. This balance ensures reliable long-term operation and highlights the suitability of this brushless DC (BLDC) configuration for next-generation aerial systems.

In a BLDC (Brushless Direct Current) motor, the stator is wound on the interior, while the rotor features permanent magnets on the exterior, creating an inverted configuration. Figure 2 depicts the wound stator, which includes a thermal radiator for dissipating heat from the windings on the left side of the image, along with the fully assembled BLDC motor.

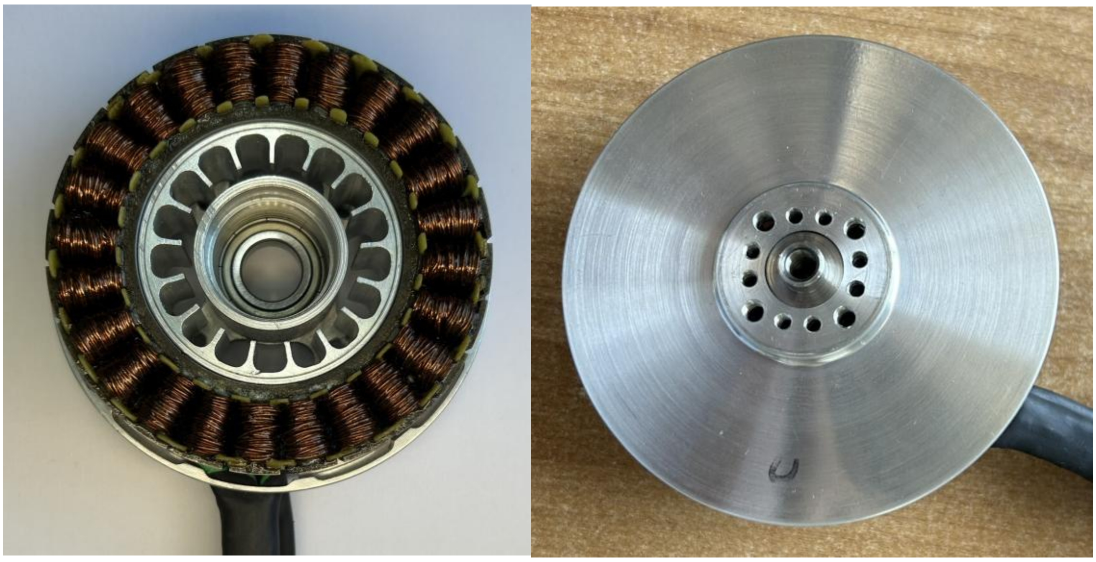


Fig. 2 – BLDC motor prototype for a light aerial vehicle.

The permanent magnets were attached to the housing using a two-component metal adhesive. The bearings were installed with a light press fit, and the stator core was secured to the shaft with adhesive. The wye-connected winding was impregnated for added mechanical strength while ensuring that all electrical terminals remained accessible from the outside.

The assembly is secured with a retaining ring to prevent disassembly. It includes threaded holes on both the stator and rotor sides, allowing the BLDC motor to be mounted within the testing system and on the aerial platform. To facilitate heat dissipation, the housing is designed with two rows of slots, along with additional slots on the terminal side. This design ensures continuous airflow through the winding region and across the radiator fins.

3. **TESTS OF THE PROTOTYPE**

3.1 Generator test

The tests were conducted with the motor prototype mounted vertically, allowing it to spin the propeller (blade) at variable speeds, as presented in Fig. 3.

Fig. 3 – Test stand for BLDC motors.

No-load tests:

The performed test used a DC adjustable-voltage generator providing an 18-52 Vdc supply. We started by measuring the no-load voltage in generator mode, followed by several tests with 1 Ω and 2 Ω resistive loads. We measured, for a supply voltage of 24 Vdc, the output voltage required during motor validation by spinning the motor on the test bench at progressively increasing reference voltages from 10% to 100% of the rated voltage, and the motor's speed, as shown in Fig. 3. The tests shown in Table 1 are without propeller.

Table 1

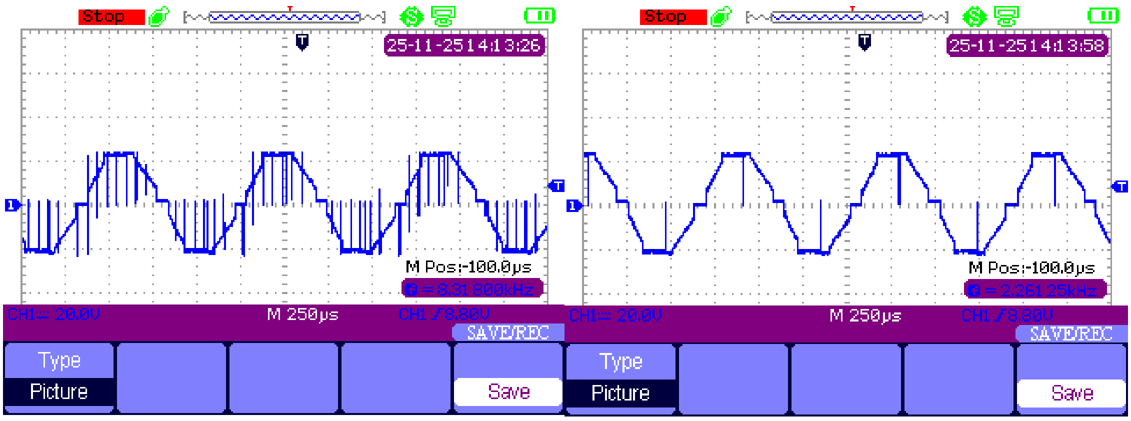
Supply current of the BLDC in various prescribed throttle

External ttrottle M [%]	Supply voltage U_{DC} [V]	Supply current I_{DC} [A]	Speed n [rpm]
10	24	0.2	280
15	24	0.33	553
20	24	0.49	843
25	24	0.61	1128
30	24	0.8	1377
35	24	0.98	1658
40	24	1.11	1928
45	24	1.3	2174
50	24	1.38	2419
55	24	1.49	2683

External ttrottle M [%]	Supply voltage U_{DC} [V]	Supply current I_{DC} [A]	Speed n [rpm]
60	24	1.64	2952
65	24	1.74	3213
70	24	1.83	3469
75	24	1.91	3723
80	24	2.03	3974
85	24	2.21	4214
90	24	2.36	4489
95	24	2.54	4726
100	24	2.63	4846

In this test, the supply current is linear, and the maximum speed is 4846 rpm.

There is a linear relationship between the prescribed throttle and speed for a given constant supply voltage. The back-EMF voltage of the motor during the tests in the last two rows is shown in Fig. 4: 90% of 24 Vdc and 100% of 24 Vdc.



(1) U_{DC}=24V, I_{DC}=2.54A, n=4726 rpm (2) U_{DC}=24V, I_{DC}=2.63A, n=4846 rpm

Fig. 4 – Back-EMF voltage for BLDC motor supplied with U_{DC} = 24 V_{DC}.

One can see that the back-EMF voltage shape is close to the theoretical prediction.

The next test was conducted using a higher supply voltage, U_{DC} = 48 V_{DC}. Due to mechanical limitations, the test without a propeller was stopped at 6000 rpm.

The measured values of speed and current consumption of the drive are presented in Table 2.

Table 2

Free-run characteristic at 48 Vdc supply

External ttrottle M [%]	Supply voltage U_{DC} [V]	Supply current I_{DC} [A]	Speed n [rpm]
10	48	0.15	625
15	48	0.37	1158
20	48	0.57	1701
25	48	0.82	2269
30	48	1.02	2853(1)

External ttrottle M [%]	Supply voltage U_{DC} [V]	Supply current I_{DC} [A]	Speed n [rpm]
35	48	1.23	3213
40	48	1.42	3744
45	48	1.67	4325
50	48	1.8	4820
55	48	2.02	5356
60	48	2.27	5920

KV Constant = Speed/Voltage – a typical parameter of drone engines, which indicates the voltage required to reach a certain speed when idling. According to the design data, the required KV constant is 5800 rpm / 48V_{DC} = 120 rpm/V. As a result of the tests, a KV constant of 5920rpm/48V_{DC} = 123 rpm/V is measured.

This 2.5% error is acceptable as a first iteration of the design

Generator mode tests

Tests use the BLDC as a generator with a resistive load connected at the stator's ends. The next test was conducted on a test bench using another BLDC motor with similar characteristics as a load, with its stator connected to a star-resistor load. We measured the energy absorbed by the motor from the DC side at each of the converter's 10 throttle command increments. Initially, there is a 2 Ω load resistor, followed by a 1 Ω resistor. The referenced motor tests are presented in the last three columns of Table 3. The DC voltage is set to 20V_{DC}.

Table 3

Generator tests

Throttle	2Ω		1Ω		Throttle	Referenced motor - No Load	
[%]	Speed [rpm]	I_{DC} [A]	Speed [rpm]	I_{DC} [A]	[%]	Speed [rpm]	I_{DC} [A]
10	356	0.62	317	0.69	40%	2669	7.83
20	806	1.49	720	1.86	42%	2764	8.63
30	1247	2.62	1127	3.56	44%	2871	9.64
40	1637	3.9	1504	5.5	46%	2972	10.66
50	2023	5.36	1886	7.97	48%	3112	11.9
60	2404	6.98	2254	10.75	50%	3220	13.06
70	2773	8.76	2627	13.82	52%	3359	14.7
80	3167	10.9	3000	17.28	54%	3487	16.34
90	3531	13.26	3343	20.76	56%	3635	18.36
100	3694	14.2	3476	21.85	58%	3743	19.99

In the no-load condition, measuring the consumed energy estimates mechanical and ventilation losses associated with both the motor and the load generator. When a 2 Ω load is applied to the generator, the drive's power consumption increases to 284 W. In contrast, using a 1 Ω load results in a higher consumption of 437 W, as shown in Fig 5.

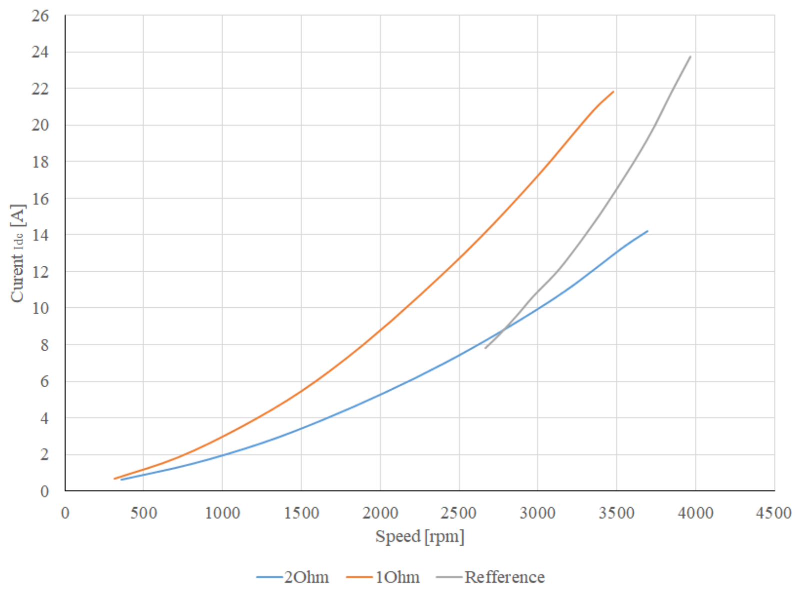


Fig. 5 – BLDC motor characteristics at variable load (half-load blue, full-load orange and reff. red).

From Fig. 5, we observe that the motor's load characteristic is linear. The test was performed at the inverter's maximum supply voltage (20 V_{DC}), thus limiting the performance.

4. DISCUSSION AND CONCLUSION

Our BLDC motor was designed to meet the requirements imposed, within the limits of possible measurements. The waveforms of the Back-EMF voltage are those specific to the brushless direct current motor (BLDC).

Following the no-load testing, the motor's KV parameter had an error of 2.5%, satisfactory for a first iteration of the design.

In the absence of a propeller drive, the operation under Load was simulated by coupling the shaft of the designed motor to another motor, operating in generator mode with two resistive load values. Comparing the load operation of the designed motor with that of a commercial engine, within the limits of measurements, the engine operates within similar parameters.

These experiments confirm the correctness of the design methods and can lead to the large-scale local implementation of manufacturing lines for drone motors that meet current requirements, thereby reducing dependence on third parties.

CONFIRMATION

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BIBLIOGRAFY

1. K.A. Abro, A. Atangana, J.F. Gómez-Aguilar, *Chaos control and characterization of brushless DC motor via integral and differential fractal-fractional techniques*, International Journal of Modelling and Simulation, **43**, *4*, pp. 416–425, June 2022.
2. A. Glowacz, *Thermographic fault diagnosis of ventilation in BLDC motors*, Sensors, **21**, *21,* p. 7245, Oct. 2021.
3. T. Nag, A.K. Ganguli, D. Chatterjee, A. Chatterjee, S.B. Santra, *Fuzzy logic-based loss minimisation scheme for brushless DC motor drive system*, IET Power Electronics, **9**, *8*, pp. 1581–1589, June 2016.

4. G. Di Rito, A. Suti, A. Ricci, R. Galatolo, G. Mattei, *Experimental characterisation of Li-Po battery packs and BLDC machines for hybrid propulsion systems of lightweight UAVs*, IEEE 9th International Workshop on Metrology for AeroSpace (MetroAeroSpace), , pp. 49–53, Pisa, Italy, 2022.
5. D.L. Gabriel, J. Meyer, F. du Plessis, *Brushless DC motor characterisation and selection for a fixed wing UAV,* IEEE Africon '11, Victoria Falls, Zambia,pp.1–6, 2011
6. P. Bogusz, M. Korkosz, J. Prokop, *A study of design process of BLDC motor for aircraft hybrid drive,*IEEE International Symposium on Industrial Electronics, pp. 508–513 Gdansk, Poland, 2011.
7. L. Popescu, O. Craiu, *Energy Consumption Analysis for an EV Powertrain Using Three Bldc Identical Motors*, RRST-EE, **68**, *2,* pp. 152–157, Jul. 2023.
8. N. Faundes, V. Wunsch, S. Hohnstein, B. Glass, M. Vetter, *Research paper on the topic of different UAV drive train qualification and parameter sets*, IEEE/AIAA 32nd Digital Avionics Systems Conference (DASC), pp. 6E3–1-6E3–15, East Syracuse, NY, USA, 2013.
9. D. van Niekerk, M. Case, D.V. Nicolae, *Brushless direct current motor efficiency characterization*, Intl Aegean Conference on Electrical Machines & Power Electronics (ACEMP), Intl Conference on Optimization of Electrical & Electronic Equipment (OPTIM) & Intl Symposium on Advanced Electromechanical Motion Systems (ELECTROMOTION), Turkey, 2015.
10. X. Huang, A. Goodman, C. Gerada, Y. Fang, Q. Lu, *Design of a Five-Phase Brushless DC Motor for a Safety Critical Aerospace Application*, IEEE Transactions on Industrial Electronics, **59,** *9*, pp. 3532–3541, Sept. 2012,
11. E. Denis*, Assesing the world's wind resources*, IEEE Power Engineering Revue, **22**, *9*, pp.4–9, 2002.