Fast Sizing Tool and Optimization Technique for Concentrated Wound Slotless Outer Rotor Motor for eVTOL Application

Nisarg Dave, David Gerada, Gaurang Vakil, He Zhang, Bowen Shi, Fengyu Zhang, Jing Li, Chris Gerada

***Abstract* -- This paper aims to present the feasibility and advantages of slotless motors for electric aircraft applications. Currently, eVTOL (electric vertical takeoff and landing) aircraft are equipped with a slotted motor with concentrated windings and an outer rotor with strong magnets. Slotless machines with Halbach array can offer significant advantages over traditional slotted machines. Instead of using the round conductor, this paper is focused on the slotless coils made up of stranded copper strips, which leads to a low inductance machine. Furthermore, employing a drive made up of wide bandgap semiconductors enables slotless technology. The paper presents analytical modelling of the slotless machine and compares different groupings of the concentrated winding for the same number of poles. This analytical model is coupled with the optimization tool to find the most power-dense design, and these designs are validated with the commercially available FEA software to demonstrate the accuracy of the proposed method.**

***Index Terms*— airgap winding, concentrated winding, eVTOL, fast sizing tool, Halbach magnets, optimization, power density, Slotless machine.**

I. Introduction

SINCE the beginning of commercial aviation, air passenger traffic has increased significantly [1]. However, this growth has brought challenges in greenhouse gas emissions and sustainability. Current civil air transport accounts for 2-2.5% of the man-made CO2 emission, and 90% of which is generated by commercial aircraft operations [2].

Electric propulsion offers significant advantages and sustainability at a reduced cost. For example, energy sourced from the electricity grid costs only 30% of equivalent energy obtained from aviation fuel. In addition, electric propulsion simplifies the power transmission than mechanical drivetrains using multi-rotor systems and variable speed drives. Moreover, simplified rotorcraft assembly, fewer moving parts, reduced maintenance hours, and reduced part count make electric propulsion more sustainable and reliable [3].

Increasing population and congestion within the cities present significant transportation challenges in the future. Currently, many businesses are investing in a novel solution for eVTOL aircraft [4]. This technology represents a viable option in the coming years with the improvements in battery technology [5][6]. Different companies have envisioned many different configurations [3].

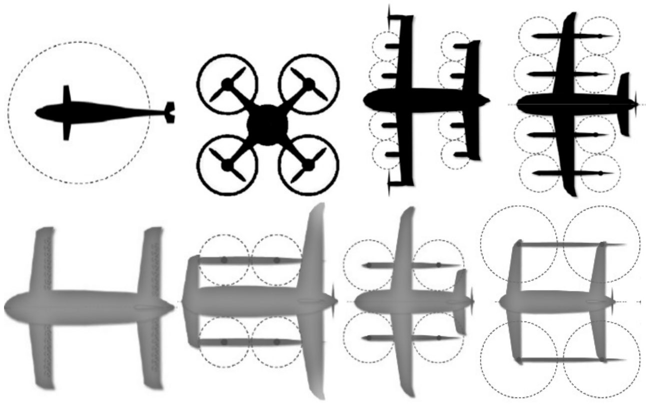

Fig 1 Configurations of eVTOL [3]

The electric aircraft motor should be of high torque – high power rather than higher speed. Also, as the torque is directly related to the mass of the motor, the main objective of designing the electric aircraft motor is to target higher power density (kW/kg). Surface-mounted PM (permanent magnet) motor presents desirable electric aircraft propulsion motor properties. Hence, most electric aircraft motors are PMSM motors in most literature and the industry. The eVTOL vehicle will primarily be airborne, and lifting mass would be a critical parameter; an air-cooled system is better suited for eVTOL aircraft than liquid cooling. However, the benefit of liquid cooling is insufficient to offset the system's performance due to the additional weight it offers and its complex structure.

Generally, there are two configurations for the surface-mounted PM motors, i.e., inner rotor and outer rotor. Inner rotor motors are widely used motors in industry, with stationary housing and rotating rotor with the shaft at the centre of the motor. These motors are suitable for high-speed operation and where coupling with a mechanical gearbox is required. On the other hand, outer rotor motors have a stationary core with the stator and rotating housing coupled with the rotor. Due to the increased radius of the PMs and more rotating mass with a higher moment of inertia, the outer rotor motor offers slightly higher torque than its inner rotor counterpart [7]. Moreover, in eVTOL aircraft, the propeller is fixed on the housing of the outer rotor motor. Therefore, with air cooling and efficient housing design, the outer rotor motor

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can benefit from improved cooling performance than the inner rotor motor for the eVTOL applications.

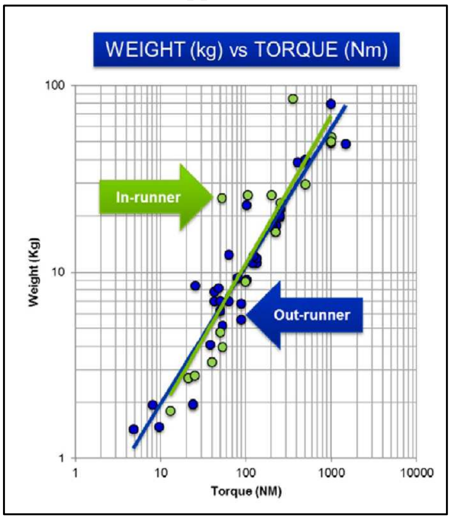

Fig 2 Comparison of the inner rotor and outer rotor motors [7]

II. SLOTLESS MOTOR

The slotless motor offers simplicity and good performance over the slotted machine [8]. Slotless structure eliminates the need for punched lamination and replaces it with a simple ring laminated core. Also, a slotless motor can save 23% iron volume without sacrificing performance compared to a slotted structure [8]. The slotless motor thus reduces the iron loss to a great extent. The slotless coils can be fixed with stator ring core with thermal resins, or pseudo thermoplastic teeth can also be used, as shown in [9].

In a conventional slotted machine, the teeth tips are prone to saturation, and this flux concentration on the tooth tip generates harmonics in the airgap flux density distribution. However, due to the absence of teeth on the slotless structure, these harmonics can be eliminated, which provides sinusoidal airgap flux density distribution and consequently, reduced/eliminated torque ripple and cogging torque, lesser unbalanced magnetic pull, better NVH (noise vibration and harmonics) characteristics, reduced magnet losses at high speed, improved overall efficiency and sinusoidal back EMF (electromotive force) waveform.

To amend the design of the slotted machine, the die of the punching tool for the lamination needs to change, and laminations need to be punched, which is a very time-consuming task. With the slotless machine incorporating copper strips, the amendment in the design is straightforward and effortless. The machine can size and build significantly less time than the slotted counterpart. Moreover, using copper strips with a high coil fill factor (or slot fill factor) instead of round conductors offers better heat transfer capability and improved cooling. Rectangular conductors have a better fill factor than the round conductor and more surface area for the heat to dissipate.

A. *Rotor magnets*

Generally, a higher pole count reduces iron and magnet volume and dimensions, leading to the motor's higher power density. However, the PWM and drive frequency limit the pole count number. Moreover, it results in lower magnetizing inductance and higher copper mass. Current eVTOL aircraft motors have a high pole count of 42 poles. In this paper 28-pole motor has been explored.

The default choice is parallel or radial magnets in the slotted surface-mounted PM machine, while a significant back iron is required to complete the flux path. On the other hand, as with the Halbach arrangements, there is no need for back iron as it completes the flux path within the magnets. The housing thus can be made up of any non-magnetic, high strength and lightweight material.

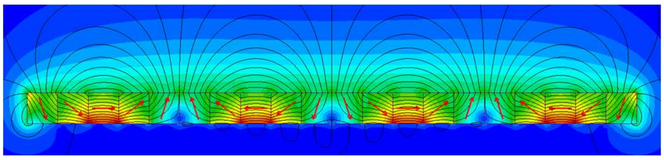

Fig 3 Five-stage Halbach array with direction vectors

Moreover, a sizeable effective airgap has resulted in the slotless structure, and a larger magnet thickness is required with uniform or radial magnets in the rotor than the Halbach magnets. The airgap flux density profile is also more sinusoidal using the Halbach array with no presence of the teeth; the Halbach magnets make an ideal candidate for the slotless motor application.

The analytical field expression described in [10] is used to calculate the magnetic field in the slotless airgap. The equations (1) and (2) give the radial and tangential flux density equation by Halbach magnetized PM rotor.

$$B_{mr}(r,\theta,t) = \sum_{n=1,3,5\ldots}^{\infty} B_{rn}(r)\cos(np\theta - n\omega t) \quad (1)$$

$$B_{mt}(r,\theta,t) = \sum_{n=1,3,5\ldots}^{\infty} B_{tn}(r)\sin(np\theta - n\omega t) \quad (2)$$

where B_{mr} and B_{mt} are radial and tangential flux densities due to the Halbach array, respectively, and they are the function of the airgap radius, angle along the stator periphery and time or rotation. n is harmonic order, t is time, p is pole pairs, and ω is the angular frequency.

B. *Coil configuration*

The slotless coils are designed with copper strips for improved thermal performance and ease of assembly. The coils are wound in concentrated winding to reduce the axial length of the machine, reduce the copper loss, achieve a higher fill factor and for higher efficiency. The slotless machine with distribution is discussed in [11]. Also, [12][13] has demonstrated different topologies of slotless machines for electric aircraft propulsion.

For concentrated windings, there are several coil grouping patterns. In this study, two different coil grouping has been taken into consideration. Therefore, the coil pole combinations of 21Coils-28Poles and 24Coils-28Poles are presented in this paper. The grouping patterns of these two combinations are shown in Fig 4.

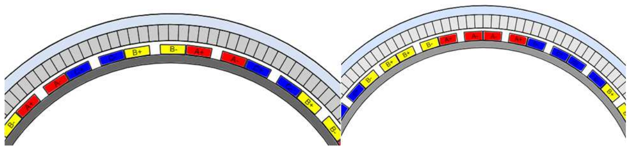

Fig 4 Section of (a) 21Coils-28Poles (b) 24Coils-28Poles slotless machine showcasing the difference in the winding pattern

While keeping the outer rotor diameter constant, these two machines have been optimized and designed to deliver the peak power of 1.2kW at 6000rpm. Therefore, the machine's rated speed is 4000rpm with a rated torque of 0.8Nm, while the peak speed is 6000rpm with a peak torque of 2Nm. This power node is typical for medium size eVTOL drones; hence this power node is chosen.

III. FAST SIZING TOOL AND OPTIMIZATION

Due to the Halbach array, the airgap flux density varies sinusoidally in the slotless PM machine. The airgap flux density multiplied by the airgap radius gives the force constant, a prerequisite to calculating the back EMF and the electromagnetic torque. The force constant can be defined as,

$$F_n = \frac{1}{R_1 - R_s}\int_{R_1}^{R_s} rB_{mr}(r)dr \quad (3)$$

Where R_1 is the radius of the stator bore and Rs is the radius of the stator coil's inner surface. B_{mr} is calculated from equation (1). Moreover, r is the radius of the air gap.

A. *Winding factor calculation*

Compared to the slotted machine, the winding factor calculation in the slotless machine is different due to the big equivalent airgap. The winding factor calculation of such a machine is explained in [14].

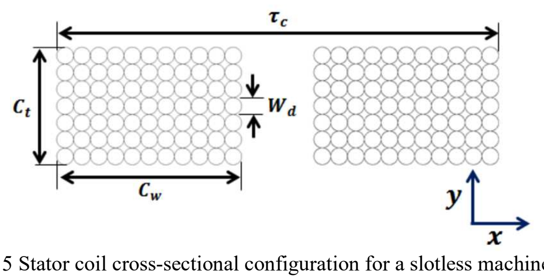

Fig 5 Stator coil cross-sectional configuration for a slotless machine with copper strips where Nx = 11 and Ny =7 [14]

The winding factor equation can be written as the product of kcpn, kcdn and kdn [14].

$$k_{wn} = k_{cpn}k_{cdn}k_{dn} \quad (4)$$

B. *Back EMF and Torque formulation*

The back emf can be represented by the derivative of flux linkage in the coil regarding time. The equation of the back emf can be written as follow.

$$e_\emptyset(t) = \frac{d\Psi_\emptyset(t)}{dt} \quad (5)$$

Where, $e_\emptyset(t)$ is induced emf in a phase. $\Psi_\emptyset(t)$ is flux linkage of a phase.

The equation for the flux linkage in each phase can be written as,

$$\Psi_a = \sum_{n=1,3,5\ldots}^{\infty} \frac{2LN_s}{3anp} k_{wn}F_n \cos(n\omega t) \quad (1)$$

$$\Psi_b = \sum_{n=1,3,5\ldots}^{\infty} \frac{2LN_s}{3anp} k_{wn}F_n \cos\left(n\omega t - \frac{2\pi}{3}\right) \quad (7)$$

$$\Psi_c = \sum_{n=1,3,5\ldots}^{\infty} \frac{2LN_s}{3anp} k_{wn}F_n \cos\left(n\omega t - \frac{4\pi}{3}\right) \quad (8)$$

ω is the angular frequency, t is time in seconds, L is stack length, N_s is the number of turns per phase, a is the number of parallel paths, n is harmonic order, and p is the number of pole pairs.

The instantaneous torque can be measured as,

$$T = i_a\frac{d\Psi_a}{d\theta} + i_b\frac{d\Psi_b}{d\theta} + i_c\frac{d\Psi_c}{d\theta} \quad (9)$$

And average torque can be written as,

$$T_{avg} = \frac{3p}{2}\Psi_a i_q \quad (10)$$

where, i_q is the q-component current. And Ψ_a, Ψ_b, Ψ_c are as mentioned in equations (6), (7) and (8).

C. *Optimization*

A genetic algorithm-based optimization tool is used to select the optimal design for the machine shown in Figure 4. The single objective of maximizing the power density has been set up with the constraints of current density limits, back EMF and output power or torque. For this exercise, the DC link voltage is 48V, and the back EMF limit is carefully chosen not to exceed the battery voltage. The initial population size of 250 and 100 number of generations were selected for this optimization using the MOGA-II engine.

Other input parameters are the power node of the machine, material-specific parameters, fixed outer diameter, coil pole combination and coil fill factor. The input variables are coil span, coil thickness, PM thickness and machine length. The values of all input parameters and variables are shown in Figure 6. Designs were assigned to the design space from the given range of the variables.

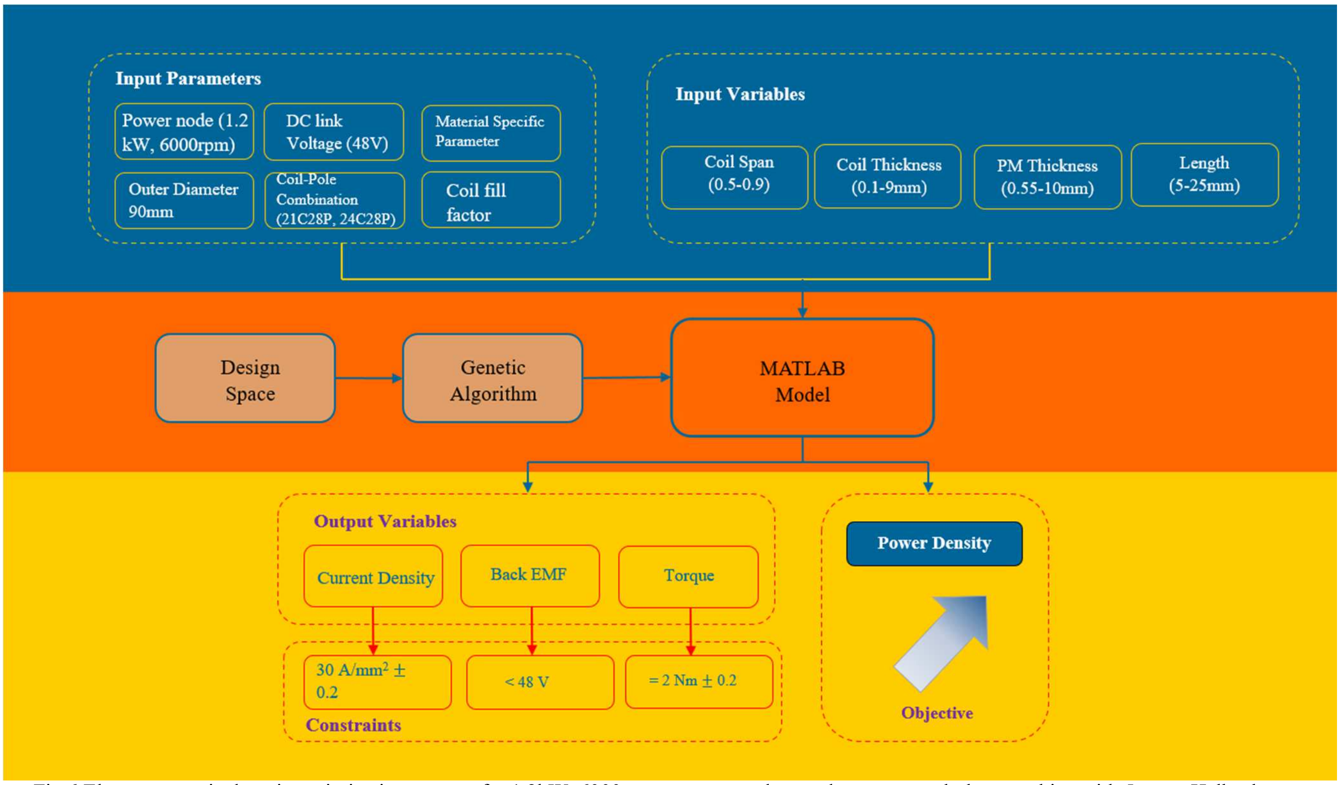

Fig 6 Electromagnetic domain optimization process for 1.2kW, 6000rpm concentrated wound outer rotor slotless machine with 5-stage Halbach array

The analytical model calculates all the performance parameters and the machine mass. For the power density calculation, only the active weight of the motor is considered, i.e., copper, magnets, and stator back iron weights. With power density unit of kW/kg.

The stator back iron thickness and the mass of the components are calculated as per (11), and for concentrated winding, the end winding volume is calculated as per the following equation.

$$Vol_{EW} = 2\pi R_{av} A_c k_{fill} N_s \tag{11}$$

Where R_{av} is the radius, as shown in Figure 5, Ac is the cross-sectional area of one coil side, and k_{fill} is the coil fill factor.

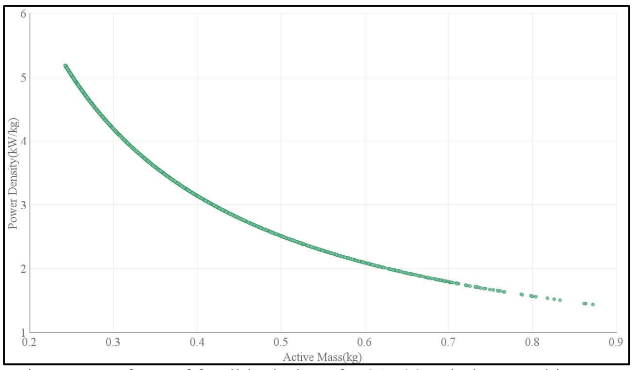

Fig 7 Pareto front of feasible designs for 21C28P slotless machine optimization

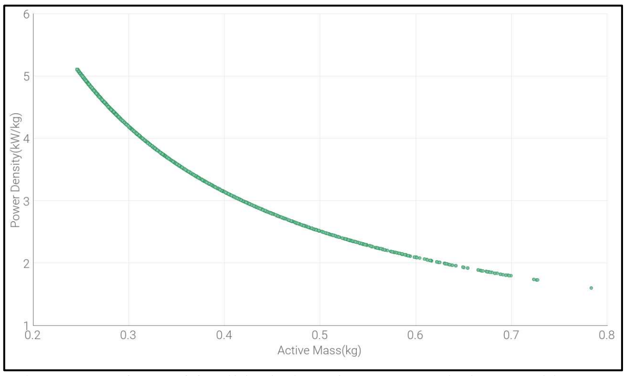

Fig 8 Pareto front of feasible designs for 24C28P slotless machine optimization

The results show that with a 21-coil machine, the achievable power density is 5.2 kW/kg, while with a 24-coils machine achievable power density is 5.1 kW/kg for 1.2kW; 6000rpm outer rotor machine with 28 poles and coil groupings as shown in Figure 4. The outer diameter is fixed to 90mm to ensure the structural stability of the rotating outer rotor. For all the designs, this value is constant. Moreover, all the designs generate the same power, i.e., 1.2kW at 6000 rpm. The slotted design of the 24-slot 28-pole machine has a higher slotted winding factor than the 21-slot 28-pole machine, and the former slotted machine would have more power-dense than the latter slotted machine. It is interesting to observe that the exact calculation of the winding factor is not applicable for the slotless machine, which is reflected in FEA results in the following section.

IV. FEA VALIDATION

The optimal design from the coil pole combination was transferred to FEA software to validate its performance parameters.

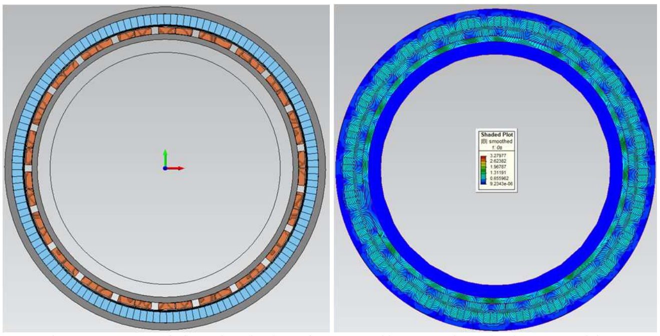

Fig 9 FEA model and solution for 21Coils-28Poles slotless machine

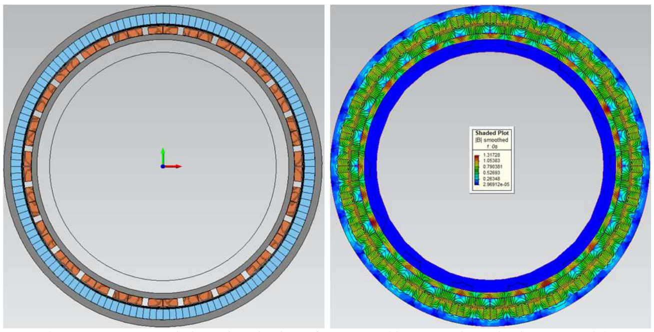

Fig 10 FEA model and solution for 24Coils-28Poles slotless machine

The back EMF and torque comparison of FEA and analytical model for 21-coils and 24-coils and the 28-poles machine are presented in the table below.

TABLE 1. VALIDATION FOR FEA AND ANALYTICALLY CALCULATED BACK EMF AND TORQUE

	Average Torque (Nm)	**Back EMF (V) (L-L:: peak)**	**% Difference**	
			Torqu	BEMF
21-Coils 28-Pole	2.01 (Analytical)	19.75 (Analytical)	1.5%	1.3%
	2.04 (FEA)	20.00 (FEA)		
24-Coils 28-Pole	2.00 (Analytical)	19.81 (Analytical)	1.5%	1.4%
	2.03 (FEA)	20.09 (FEA)		

The design details for 21 coils and 24 slotless machines with 28 poles are as shown in Table 2.

TABLE 2. DESIGN PARAMETERS FOR OPTIMAL DESIGNS

	21-Coils 28-Poles	**24-Coils 28-Poles**	Units
Average Torque	2.04	2.03	Nm
Power	1.28	1.28	kW
Speed	6000	6000	rpm
Current Density	30.00	30.00	A/mm2
Copper fill factor	0.70	0.70	-
Current (peak)	71.59	73.41	A
Turns	2.00	2.00	-
Peak Phase Back-EMF	11.50	11.60	V
Outer-most Diameter	90.00	90.00	mm
Stator bore diameter	79.00	79.00	mm
Coil thickness	2.05	2.33	mm
PM thickness	3.00	3.00	mm
Length	18.50	18.00	mm
Total active weight	0.24	0.25	kg
Active Power Density	5.30	5.20	kW/kg

V. CONCLUSION

The study shows that slotless machines can deliver smooth torque with increased efficiency and sinusoidal back EMF due to the absence of teeth harmonics. The power density of the slotless machine is also comparable to that of slotted machines. This paper demonstrates that the slotless machine is a promising candidate for the eVTOL application, with a performance similar to the slotted counterpart. The slotless structure offers low inductance, but the slotless machine can be a viable option for electric aircraft applications by exploiting the recent advancements in wide bandgap semiconductor technology. Furthermore, the structure is significantly more straightforward for modifications or scaling than a slotted structure. Therefore, the industry can significantly benefit from slotless machines due to their simplicity and ease of manufacturing and assembly.

VI. REFERENCES

[1] W. Cao, B. C. Mecrow, G. J. Atkinson, J. W. Bennett and D. J. Atkinson, "Overview of Electric Motor Technologies Used for More Electric Aircraft (MEA)," in IEEE Transactions on Industrial Electronics, vol. 59, no. 9, pp. 3523-3531, Sept. 2012, DOI: 10.1109/TIE.2011.2165453.

[2] J. Benzaquen, J. He and B. Mirafzal, "Toward more electric powertrains in aircraft: Technical challenges and advancements," in CES Transactions on Electrical Machines and Systems, vol. 5, no. 3, pp. 177-193, Sept. 2021, DOI: 10.30941/CESTEMS.2021.00022.

[3] Duffy, M. J., Wakayama, S. R., Hupp, R., Lacy, R., and Stauffer, M., "A Study in Reducing the Cost of Vertical Flight with Electric Propulsion," Conference Paper, 17th AIAA Aviation Technology, Integration, and Operations Conference, Denver, CO, 2017.

[4] eVTOL Aircraft Market to Expand at 30.30%; https://www.globenewswire.com/en/news-release/2021/02/25/2182758/0/en/eVTOL-Aircraft-Market-to-Expand-at-30-30-CAGR-to-Attain-Valuation-of-USD-4-063-3-Million-by-2030-Projects-Market-Research-Future-MRFR.html

[5] AMTE Power launches 'Power Up' project to develop ultra-high-power battery cells; https://www.greencarcongress.com/2021/10/20211014-amte.html

[6] MAHLE Powertrain and Allotrope Energy unveil breakthrough battery technology; https://www.mahle-powertrain.com/en/news-and-press/press-releases/mahle-powertrain-and-allotrope-energy-unveil-breakthrough-battery-technology-85632

[7] M. Duffy, A. Sevier, R. Hupp, E. Perdomo and S. Wakayama, "Propulsion Scaling Methods in the Era of Electric Flight," 2018 AIAA/IEEE Electric Aircraft Technologies Symposium (EATS), 2018, pp. 1-23.

[8] M. S. Islam, I. Husain and R. Mikail, "Slotless lightweight motor for drone applications," 2017 IEEE Energy Conversion Congress and Exposition (ECCE), 2017, pp. 5041-5048, DOI: 10.1109/ECCE.2017.8096851.

[9] M. S. Islam, R. Mikail and I. Husain, "Slotless Lightweight Motor for Aerial Applications," in IEEE Transactions on Industry Applications, vol. 55, no. 6, pp. 5789-5799, Nov.-Dec. 2019, DOI: 10.1109/TIA.2019.2935055.

[10] Z. P. Xia, Z. Q. Zhu and D. Howe, "Analytical magnetic field analysis of Halbach magnetized permanent-magnet machines," in IEEE Transactions

on Magnetics, vol. 40, no. 4, pp. 1864-1872, July 2004, DOI: 10.1109/TMAG.2004.828933.
[11] N. Dave, G. Vakil, Z. Xu, C. Gerada, H. Zhang and D. Gerada, "Comparison of slotted and slotless PM machines for high kW/kg aerospace applications," 2020 23rd International Conference on Electrical Machines and Systems (ICEMS), 2020, pp. 609-613, DOI: 10.23919/ICEMS50442.2020.9291221.
[12] Z. Song, C. Liu and H. Zhao, "Comparative Analysis of Slotless and Coreless Permanent Magnet Synchronous Machines for Electric Aircraft Propulsion," 2019 22nd International Conference on Electrical Machines and Systems (ICEMS), 2019, pp. 1-6, DOI: 10.1109/ICEMS.2019.8921494.
[13] D. Lawhorn, P. Han, D. Lewis, Y. Chulaee and D. M. Ionel, "On the Design of Coreless Permanent Magnet Machines for Electric Aircraft Propulsion," 2021 IEEE Transportation Electrification Conference & Expo (ITEC), 2021, pp. 278-283, DOI: 10.1109/ITEC51675.2021.9490162.
[14] S. G. Min and B. Sarlioglu, "Advantages and Characteristic Analysis of Slotless Rotary PM Machines in Comparison With Conventional Laminated Design Using Statistical Technique," in IEEE Transactions on Transportation Electrification, vol. 4, no. 2, pp. 517-524, June 2018, DOI: 10.1109/TTE.2018.2810230.

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