

Design and Analysis of Raxial Flux Motor: A Review

Vishal D. Pund^{1*}, Dipesh B. Pardeshi²

Abstract

This review paper offers a comparative study of radial-flux motors and axial-flux motors, providing a detailed analysis of the design and performance of raxial flux motors. The manufacturer of an axial flux motor is "Koenigsegg," a Swedish company that specializes in producing high-performance cars, primarily sports cars. The four-seater Koenigsegg Gemera was designed to be powered by a raxial flux motor. Quark, the name of the motor, reexamines the four principles of packing, cooling, material, and magnetism. Because Gemera needs a lot of acceleration in its low-speed range, a raxial flux motor was necessary. The topologies of axial-flux motor and radial-flux motor were combined to create the term raxial-flux motor. The very good torque to power to weight ratio in the factory was created by combining both radial-flux and axial-flux motors, which are more power-dense and less torque-dense, respectively. Axial flux motors are more torque-dense and less power-dense.

Keywords: Raxial flux motor, axial flux motor (AFM), radial flux motor (RAR), Nd-Fe-B permanent magnets, double rotor

INTRODUCTION

The raxial flux motor was engineered to power the all-new Koenigsegg Gemera which is a four-seater car. The motor was named Quark which relooks at the four fundamentals of magnetism, material, cooling, and packaging. Gemera requires severe acceleration in its low-speed range, which is why a raxial flux motor was required. The 300 m steel used to build this motor is primarily used in the motorsport and aeronautical industries. Opting for direct cooling was the selected choice, because of its own smaller size and higher cooling efficiency. This raxial flux motor weighs just 30kg and can produce a torque of 600 nm with a power delivery of 250 kw for a peak time of 20 sec. After 20 sec, the figures drop to 98.55 kw and 249.47 nm. This motor provides a good balance between torque and power by combining axial and radial flux construction.

Study of Axial Flux Motor

The axial-flux motor (AFM) isn't a novel technological invention. This type of apparatus is recognized as the first electrical generator in history. An axial-flux machine, or primitive disc motor, was created in 1831 by Michael Faraday. The rotor and stator core structures as well as the flux

direction are the two main ways that axial flux machines differ from conventional machines. An axial direction of magnetic flux is produced by the AFM, in contrast to conventional radial flux machines [1].

AFMs are employed in situations demanding elevated torque density and superior efficiency within a compact axial space [2]. Because of a substantial air gap in the rotor disk, this machine had a problem with a very huge peak in the magnetization current, which made it impractical to use at the time [3]. The air gap problem has been solved thanks to developments in superconducting

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and permanent magnet materials, which can be replaced with materials that conduct well, such as Neodymium (NdFeB) magnets. These magnets derived from the Nd-2Fe-14B compound discovered by General Motors in 1982 and Sumitomo special metals in 1984, are known for their high conductivity [3]. Concise AFPM machine explosion view reveals the internal structure as shown in Figure 1(a) and the actual machine model is shown in Figure 1(b).

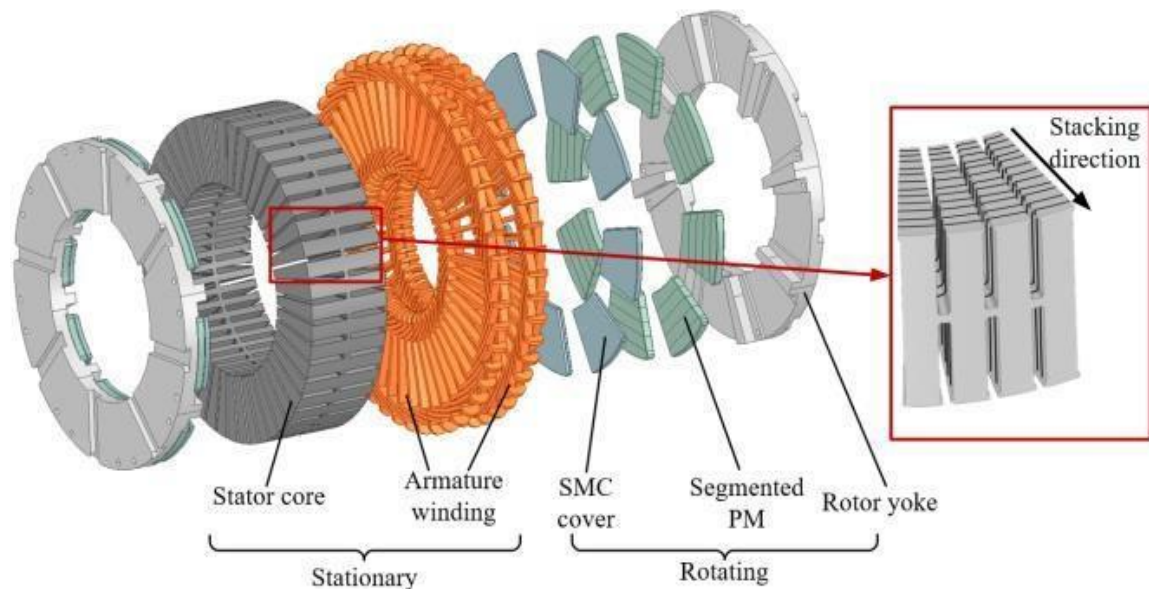


Figure 1(a). Design layout for the axial-flux permanent magnet machine (AFPM).

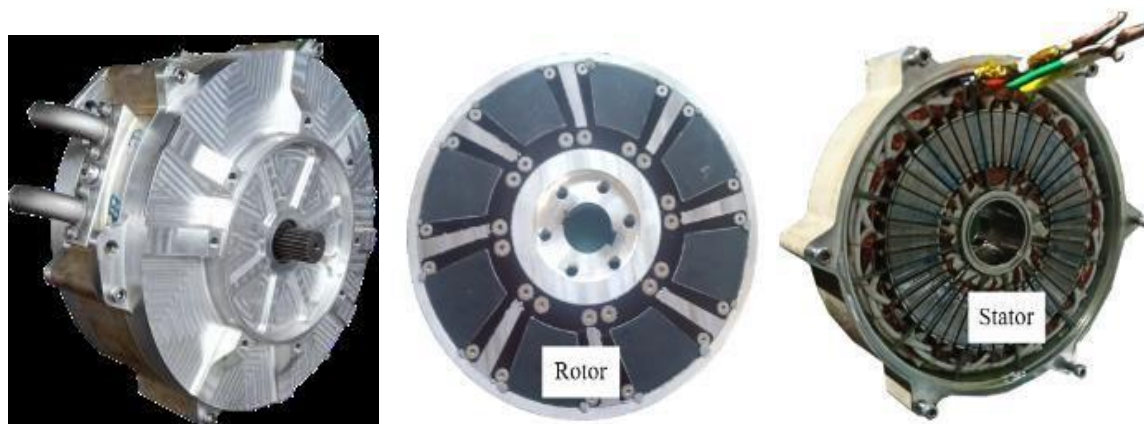


Figure 1(b). Concise AFPM machine explosion view reveals internal structure. Actual machine model.

Axial flux motors come in two main topologies: single rotor/dual stator and dual rotor/single stator, also known as torusstyle machines. The flux loop begins at the first magnet in a dual-rotor axial flux topology, travels axially through a stator tooth, and then immediately reaches the second magnet [3].

This indicates that in radial flux machines the flux path is notably longer, enabling the motor to have a higher power density and efficiency while being smaller for the same amount of power [1].

For several reasons, axial flux motor manufacturing has also proven difficult at times. Dual-rotor machines with a yokeless topology in which the stator's iron teeth are retained but the iron yoke is removed solve some of the issues without requiring the diameter and magnets of the machine to be scaled down [11]. However, removing the yoke presents new difficulties, such as figuring out how to

reposition and adjust individual teeth without the mechanical yoke connection. It is more difficult to remove the heat as well [4].

But because the shaft ring connects the discs directly to one another, the forces cancel each other out. Thus, the only purpose of the internal bearing is to maintain the stator's position in the middle, between the two rotor discs, and it does not bear these forces [5].

Even while dual-stator single-rotor machines don't have the same difficulties as torus machines, the stator design is far more intricate and challenging to automate. Because it isn't like any conventional radial flux machine, the equipment and production methods were just invented recently [5, 24].

Study of Radial Flux Motor

The typical radial flux structure has an internal cylindrical rotor and an external cylindrical stator. Because of its widespread industrial application, this radial flux motor is regarded as a reference solution [6]. The copper windings in this motor are wound around slots. The rotational axis is not perpendicular to the flux created. A rotor composed of permanent magnets housed inside a stator makes up a conventional radial flux motor [10]. A stator has a support called a yoke that has electromagnetic coil "teeth" attached to it. The teeth are magnetic poles that alternate. The torque of the motor is produced resulting from the interplay of the rotor's magnetic poles and the wound stator teeth's alternating magnetic flux [7,10].

These days, radial flux topology is used by most permanent magnet motors. In this instance, the magnetic field loop originates as a permanent magnet situated on the rotor, travels radially down the stator, and then goes through the first tooth. After that, it travels via a second tooth and reaches the rotor's second magnet [6]. In contrast, the flux in radial motors goes through the very first tooth after which it returns to the magnets in the following tooth through the stator. It must also travel in two dimensions [7]. The radial flux motor with a permanent magnet rotor is shown in Figure 2.

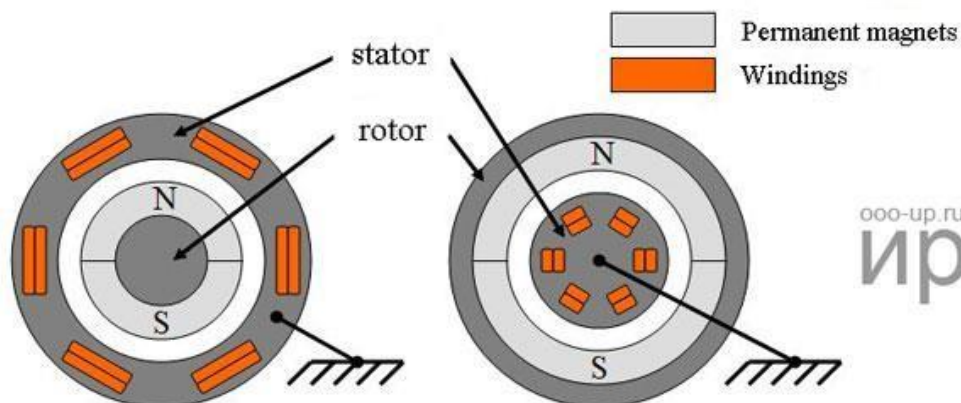


Figure 2. Radial flux motor with permanent magnet rotor [12].

Comparison Procedure

It is common practice to compare various electric motors using the "sizing math equations," which establish a relationship between the motor's electromagnetic force and its working motor lengths and motor reference diameter. The sizing equation that is found most for Radial-Flux motors (RFMs) has the following equation form:

$$Te = \epsilon r. Dr^2. L, \quad (1)$$

where L (m) represents the effective axial length of the stator core and D_r (m) is an air-gap diameter. Both the electric loading and the air-gap density of flux have an impact on the coefficient $\epsilon_u(N.m/m^3)$ (air-gap current linear density). Based on Equation (1), compares radial and axial flux motors in this research. Both the electrical and magnetic load must be determined by the designer using expertise, as Equation (1) neglects the consideration of the real fluxes and current density that exist in varied motor components [6]. A problem remains unaffected by alternative sizing formulas, as, for instance,

$$T_e = \epsilon_e \cdot D_e^3 \cdot L, \tag{2}$$

where $D_e(m)$ is the external motor dimension and the value of the facto $\epsilon(N \times m/m \times 4)$ is dependent upon the conductor current density, flux density in the stator tooth, and stator yoke. As an alternative, a comparative method used in this work is based on basic thermal principles [6]. Compression between radial flux and AFM is shown in Figure 3.

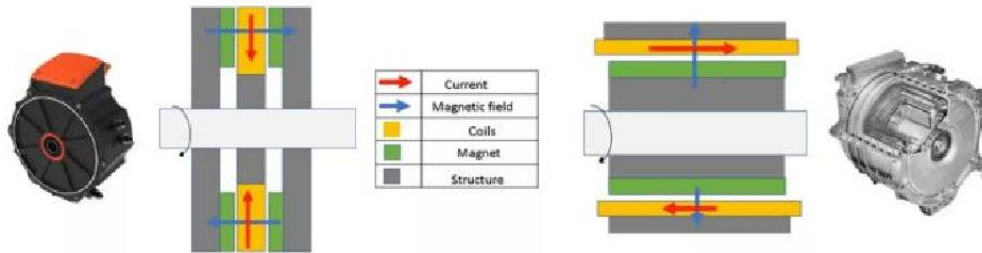


Figure 3. Compression between radial flux and AFM.

A RFM is more convenient when a longer shaft is required. At first, as the number of poles increases, so does the torque capability [9]. This is due to the need for minimal space for the end winding connection as well as the height of the rotor and stator yoke. Because iron losses grow with the number of poles, torque capacity tends to decrease [6, 25].

An axial flux motor may produce a lot of torque if the length of the axial is extremely short. For an extensive number of poles, this torque density value produced a range that varied based on the motor pole number [6]. Compression of current and magnetic flux in radial-flux and AFM is shown in Figure 4.



Figure 4. Compression of current and magnetic flux in radial-flux and AFM [13].

Axial-flux electric motors, particularly those with “single stator – double rotor” topologies, are more electromagnetically efficient than conventional radial flux electrical motors [7]. A perfectly straight coils of wires fed by a current that is DC can be used to create a relatively uniform magnetic field, comparable to that of a bar magnet, which helps to illustrate the effects of magnetic field orientation. The magnetic field generated by feeding an identical coil with a sinusoidal electricity source (AC) will be orientated according to the sign of the current [2].

A sequence of the north and the south magnetic poles is produced along the machine’s air gap by the set of AC windings in permanent-magnetic (PM) motors, both axial and radial. The torque is produced through the interaction of these poles with the permanent poles that are magnetic on the rotor surface [11, 16]. Electrical machines are classified as either axial- or radial-flux machines depending on the ways of flux in the air gap. When it comes to a radial-flux machine, the conductors are axial and the air-gap flux is radial, while in an axial flux device, the opposite is true [7].

Raxial Flux Motor (Quark)

Quark uses a design of radial and axial flux balance that is rich in torque and power. To construct a torque vectored unit for the terrier, Koenigsegg paired a Quark e-motor with its newly manufactured 6-phase inverters David pulse planetary gearbox set. Instead of following the usual, the Quark reconsiders the four foundations of magnetism, martial, cooling, and packaging. As a result, the Quark elementary particle feels all four fundamental forces: electromagnetic, gravitation, strong interaction, and weak interaction.

The Quark’s remarkable efficiency, when paired with a matrix for torque, power, RPM, and weight, leading in class makes it unique. That suggests that a step-down gearbox is not required when using the device in a marine, aircraft, or vertical take-off and landing application since the motor's rpm remains constant throughout [17].

1. *The Dimension of the Quark:* Quark electric motor is having a height of 303 mm, width of 334 mm, and length of 112 mm. Quark weighs just 28.5 kg if we consider each complimentary component, it goes around 30 kg, as it gives a volume of 8 L.

The Quark uses the propulsion of system voltage of 850 V, a peak power of 250 kw, peak torque of 600 nm, and a power density of 8.3 kw/kg. After 20 sec, this Figure 5 falls due to power and high operating voltage.



Figure 5. The raxial flux motor (Quark).

2. **The Electric Vehicle Terrier Drive Unit:** The Quark electric motor featuring the previously announced David-inverter allowed Koenigsegg to generate The Terrier, an EV industry torque vectoring drive unit. An electric motor unit is powered by a David Inverter and two Quark e-motors. David's 6-phase reduces weight, space, and componentry by lending three phases each of the Quark, so the Terrier only needs one inverter instead of two. Moreover, David might carefully slide between two Quarks to create a square-packed container because of the flat packing of the Quark. In conclusion, only small, very highly effective planetary gear arrangements with low ratios are required for each output because of the enormous power and torque that the Quarks produce at low speeds. The Terrier can securely attach directly to the monocoque or chassis using elastomeric bolts because of its small packing [18, 22].

The dimensions of the Terrier unit are $340 \times 475 \times 425$ mm (H×W×L). The breadth rises to 620 mm with driveshaft tulips. The unit has a 40-l volume and weighs 85 kg. Peak power is 2×250 kW, peak motor torque is 2×550 N·m, peak power density is 6 kW/kg, and the nominal voltage of the system is 850 V. The Terrier EV drive unit is shown in Figure 6.

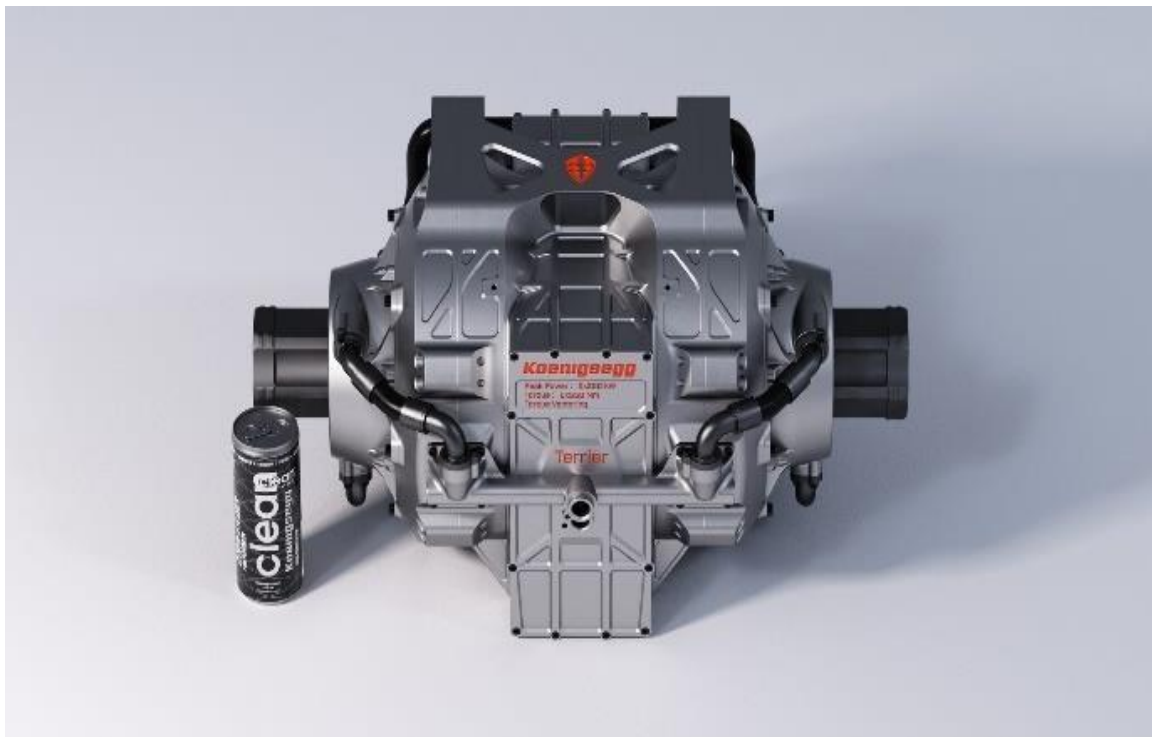


Fig: 6. The Terrier EV drive unit.

David Inverter

Koenigsegg unveiled the David SiC six-phase inverter (as shown in Figure 7) at the beginning of Dec-2021. The in-house development of the David inverter was specifically crafted for Jamaican needs and potential future demands. With a weight of just 15 kg and the capability of 10 l, this compact-sized inverter can produce up to 750 kW of power and 1300 AC ARMS at DC 850 V across six phases. Placed in the Gemera – a new benchmark – are 12 phases (6/motor) with a 1.5 MW power in dual mode (30 kg weight with a capability of 20 l) [23].

David is powered by software and Koenigsegg's own flexible algorithms, which are updated frequently beyond the Koenigsegg cloud via OTA. David is competent in operating one motor up to 750 kW or two motors independently. Safe connections can be made without opening the case or requiring additional tools thanks to the fast connections and fully sealed housing. David is also

offered in versions that are instantly busbar integrated with Koenigsegg electric motors, providing an alternative to cable connections for stand-alone devices. David's volume should be reduced to about nine liters as a result.



Figure 7. David inverter.

CONCLUSIONS

The AFM and RFM were both compared in detail in this paper. For both motors, finite element analysis using sizing equations was finished. The current flow parameters, voltages, and magnetic fields were compared. The effect of magnetic field introductions on an almost uniform magnetic field akin to a bar magnet can be produced by feeding a straight coil of wiring with a DC.

The radial flux motor can be the game changer in the upcoming era, some impacts like the short peak period can affect industrial uses if it gets better in a long-time high-power delivery will be one of the best motors in the future.

Future research for the examined additional optimization for the axial flux motor may be necessary, such as modifying the slot configurations to increase the machine's efficiency. The time of the day at which a motor produces its maximum power will be investigated and attempted to be incorporated into further simulations using various tests and software.

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