Get your motor runnin'

By John Benson

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1. Introduction

Yes, I know, this is the second line I've used in a paper title from the ancestor heavy metal song, but you will need to give me a pass. I'm an old rocker, and the subject of this song is motor cycles, and I rode these for much of my adult life. Also this post is about motors (albeit electric and not Harleys').

Specifically, this post is about axial-flux motor with a PCB stator. This design has been used in a number of machine designs, and will probably be critical in all types of electric vehicles (EVs) going forward, especially smaller light-weight EVs.

2. Infinitum Electric

First of all, I did quite a bit of research both on this (and similar) designs and on this company. First of all this company has been around since 2014. Their headquarters is in Round Rock, TX (just north of Austin). They have around 30 Employees. They appear to we moderately well-funded, as they gone through five rounds of venture-financing: two Series A, a $12.5 million Series B round in 2019, $40 million Series C funding in 2021, and $80 million in Series D funding in 2022. The Series C round included an investment by Caterpillar Venture Capital Inc. The series D round included an investment by Applied Ventures, LLC, the venture capital arm of Applied Materials, Inc.[1]

Infinitum first shipped product in 2020, *The company's IEs205 10 horsepower motor will be used by Comefri to power more efficient, space-saving commercial plenum fans used in commercial and industrial buildings to deliver more sustainable heating and cooling airflow and help fight climate change.*

Infinitum appears to be the only company developing an axial-flux motor with a PCB stator, although I did find a similar design from a company in the EU.

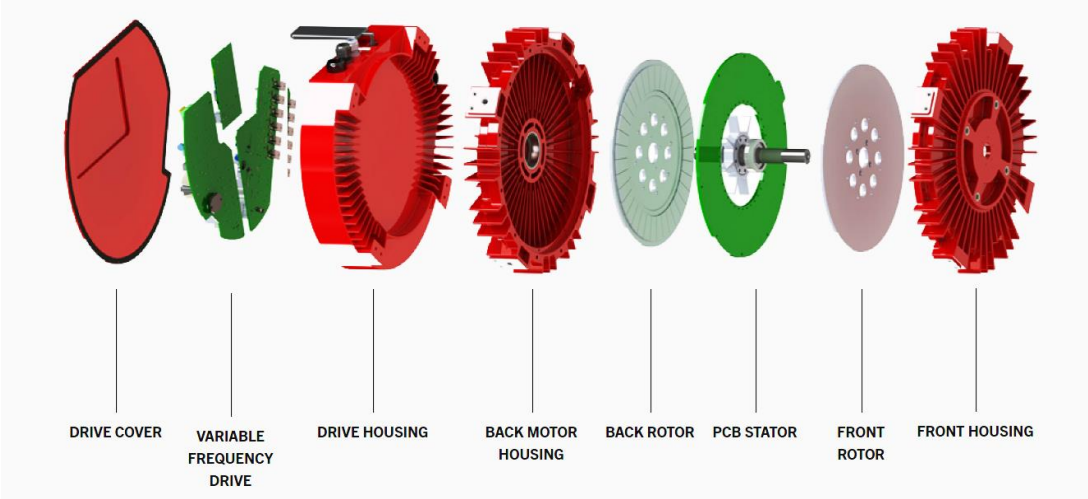
2.1. Basic Design

The figure to the right is a fully assembled motor.

With a forward-thinking design philosophy, we've reduced the size and weight of a motor from the equivalent of a 20-pound medicine ball down to a frisbee, unlocking design potential for you to make any machine lighter, quieter, and more efficient.

The figure at the top of the next page is an exploded-view of this design.

[1] Infinitum Electric News, https://www.infinitumelectric.com/press/



The most basic parts of (any) electric motor are stator and rotor. It is the electromagnetic interaction between these that produces a motors torque, rotation and thus power.

The stator, traditionally made of iron, tends to be heavy. Stator iron accounts for about two-thirds of the weight of a conventional motor. To lighten the stator, some people proposed making it out of a printed circuit board.[2]

Although the idea of replacing a hunk of iron with a lightweight, ultrathin, easy-to-make, long-lasting PCB was attractive from the outset, it didn't gain widespread adoption in its earliest applications inside lawn equipment and wind turbines a little over a decade ago. Now, though, the PCB stator is getting a new lease on life. Expect it to save weight and thus energy in just about everything that uses electricity to impart motive force.

This saving of energy is critically important: Software may be eating the world, but electricity is increasingly what makes the world go round. Electric motors consume a little over half of the world's electricity today. Some 800 million motors are now sold annually worldwide, according to the market research group Imarc, a number that has been increasing by 10 percent each year. Electric motors are making serious inroads into cars, trains, and aircraft, as well as industrial equipment and heating, ventilating, and air-conditioning systems. Transportation, construction, and HVAC together account for about 60 percent of all U.S. greenhouse gas emissions; more efficient electric motors will help cut emissions in these sectors.

Despite the benefits of the PCB stator, people were slow to embrace the design because of a few misconceptions.

First, there was the mistaken belief that PCBs were good only for delicate applications. But in 2011, CORE Outdoor Power developed a leaf blower and a weed trimmer, both of which used a PCB stator and yet were rugged as well as quiet.

Second, there was a sense that PCB stators could be used only for low-power machines. But in 2012 Boulder Wind Power put a PCB stator in a 12-meter-diameter direct-drive generator for a wind turbine that output 3 megawatts of power and just over

[2] Paulo Guedes-Pinto, Infinitum Electric via IEEE Spectrum, "This Axial-Flux Motor With a PCB Stator Is Ripe For an Electrified World," 20 March, 2022, https://spectrum.ieee.org/axial-flux

1.5 million foot-pounds of torque. It was one of the smoothest-running high-power generators ever built.

Author's comment: The basic design of just about any motor can also be used for a generator, alternator or some combination, as they frequently are in most EVs.

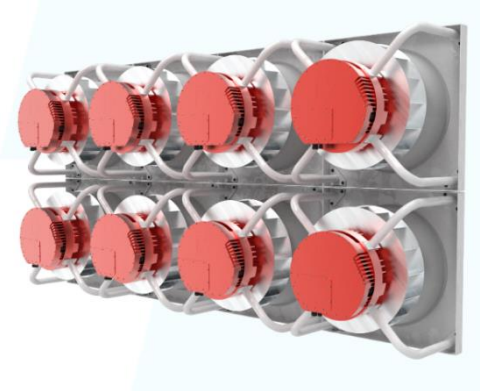
Neither company endured. Boulder Wind Power ran out of funding before it could secure commercial contracts. CORE Outdoor Power couldn't compete in a crowded market where there were cheaper options. Still, their pioneering achievements demonstrated the feasibility of PCB stators.

Fast-forward to today. My company, Infinitum Electric, of Austin, Texas, has developed a PCB stator motor that fits a wide variety of purposes. Our motor generates as much power as a traditional alternating-current induction motor but has half the weight and size, makes a fraction of the noise, and emits at least 25 percent less carbon. It is now finding applications in HVAC, manufacturing, heavy industry, and electric vehicles…

2.2. Applications

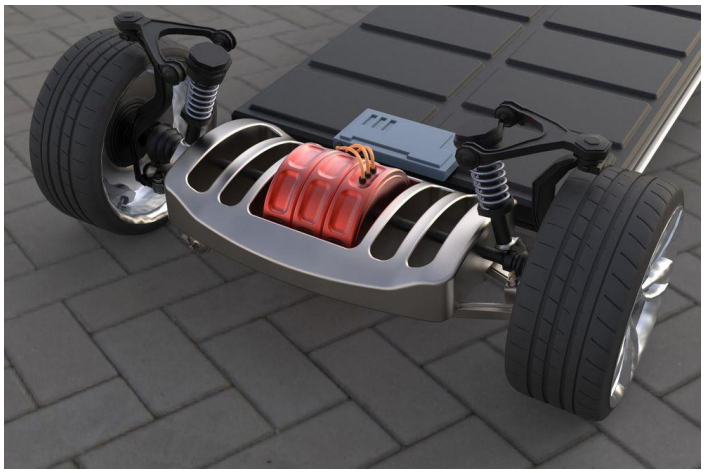
The following words and most images are taken from the Infinitum Electric Web site linked above (reference 1, the site's Applications tab).

Fans: *Infinitum Electric has reimagined the electric motor, making it possible to move large amounts of air more efficiently and sustainably than ever before. Our innovative motor design replaces the iron-core stator found in traditional motors with a PCB stator that increases durability and reliability in a form factor that is significantly smaller and lighter. Applications such as fan arrays built using our motors are easier to ship, install, and service. Additionally, our motor's integrated variable frequency drive (VFD) allows you to optimize operational control and reduce energy costs by more than 50%.*



Pumps: *From commercial HVAC systems to wastewater and water treatment facilities, many industrial and commercial pump applications require powerful and durable pumps to efficiently move fluids. Imagine if every one of those pumps was powered by a motor designed to increase efficiency and improve system reliability, delivered in a form factor that is significantly smaller and lighter than a traditional motor. Sound impossible? It's not. Infinitum Electric has you covered. Our motors also offer additional flexibility for pump applications through the integrated variable frequency drive (VFD) and our optional Internet-of-Things (IoT) capabilities, making it straightforward for facility managers to program and monitor pump performance while optimizing for wire-to-water efficiency.*

We're pushing the boundaries of motor technology for mobility applications with an innovative liquid-cooled, smarter air-core motor design. At half the weight and size of a traditional motor, Infinitum Electric motors deliver premium performance for a wide variety of applications that drive, fly, and sail.



Note that the Image to the right came from the above referenced IEEE Spectrum (reference 2).

Infinitum Electric is revolutionizing alternator design with the same ground-breaking air-core, PCB stator technology that powers our motors. As a result, our alternators remove many of the complexities present in conventional alternators such as copper windings and traditional exciters. Our next-generation alternator, IEalt, is significantly smaller and lighter than other alternators on the market, opening up the possibilities for OEMs to significantly reduce the package size of their power generation solutions from 10 kW to 150 kW.

Author's Comment: It is good that Infinitum is spread out over multiple applications and markets. This will allow them to go where the best income is to grow their business to a critical mass.

2.3. Design Details

The Infinitum Electric motor is what's known as an axial-flux motor, a design in which the stator's electromagnetic wiring stands parallel to a disk-shaped rotor containing permanent magnets. When alternating current flows through, it makes the rotor spin. The motor also has an air core—that is, there is no iron to mediate the magnetic flux and nothing in between the motor's magnetic parts but thin air. Put all these things together and the result is an air-core axial-flux permanent-magnet motor.[2]

In the past, attempts to build such a motor faced serious practical obstacles. A complex manufacturing process was needed to build the stator, the copper windings were bulky, and the coil support structure was intricate. As a result, the air gap was so wide that only a substantial magnet mass could create the necessary magnetic flux.

At Infinitum Electric, we did away with those copper windings and instead use photo-lithographic techniques to etch thin copper traces interleaved with epoxy-glass laminate, which insulates each coil from neighboring coils. Eliminating the iron core and minimizing copper together save 50 to 65 percent of the weight and 50 to 67 percent of the volume of the motor, when compared to an equivalent conventional iron-core motor. And conveniently, the copper and the laminate expand and contract similarly as the temperature rises and falls, avoiding stress that might otherwise slowly pull the components apart.

The absence of a stator core allows us to put two identical rotors facing each other on either side of the stator, with each rotor carrying powerful permanent magnets. This arrangement creates a constant magnetic flux. As in other axial-flux motors, that flux is parallel to the axis of rotation, rather than radial. Because the magnetic air gap is narrow, we need only a small magnet, which is why we can wring a lot of power from a given mass and volume.

What's more, PCBs are manufactured by an automated process, which means they're much more uniform and reliable than hand-wound machines. We made them even more reliable by simplifying their topology, which has to do with the motor's phases.

An electrical phase is an alternating voltage that forms a sinusoidal wave that is shifted in time relative to the voltage in another phase. The various phases are synchronized so that the sum of the currents is always zero. When a multiphase voltage system is applied to a motor that has a separate winding for each phase, the circulation of several currents generates a magnetic field that rotates in space. The interaction of this rotating field and the field produced by rotor magnets is what turns the rotor.

Previous PCB stators mixed the copper traces from different phases in the same layer, which created the potential for short circuits. We instead have each layer carry only one electrical phase, and we minimize the number of connections between layers. That arrangement provides a continuous path for the electric current and reduces the risk of electrical failures.

Another advantage of the new layout is the freedom it gives designers to connect coils either in series or in parallel. Connecting the coils in series is appropriate for three-phase industrial applications and next-generation electric vehicles. Connecting in parallel is better for low-voltage applications, such as in an auxiliary EV motor.

Like other permanent-magnet motors, our axial-flux motor requires a variable frequency drive to smoothly start and accelerate the motor to the desired speed. The VFD also controls the speed and torque as required by the application.

However, the air-core design gives the motor exceptionally low impedance (typically just 5 to 7 percent as much as in a conventional iron-core motor), because air cannot contain as much magnetic energy as iron can. There is thus very little magnetic energy available to smooth out the variations in the voltage supplied to the motor by the VFD. To remedy this deficiency, we added another element: an integrated variable frequency drive that is fine-tuned to operate with a low-impedance motor. Our VFD uses high-efficiency silicon carbide MOSFETs, which reduce losses and contribute to overall system efficiency.

Note that the VFD is part of the basic motor design, see the above exploded-view.

The VFD also monitors performance, and the results can be reported via the cloud, if the user wishes. The motor's software can also be updated in this fashion. Such remote monitoring offers a variety of ways to conserve energy, manage performance, and predict when maintenance may be needed.

The thinness of the PCB furnishes a high surface-to-volume ratio, which makes for more efficient cooling, thus allowing us to push two to three times as much current for a given amount of copper. The cooling can be done by blowing air over fins on the outside of the motor and across the electronic compartments…

Note that liquid-cooling is used for very high-power designs (like for EVs traction motors).