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Marine electric propulsion

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ELECTRIC PROPULSION INSIGHTS

AC & DC MOTORS

Boat owners considering a conversion to electric propulsion today have several manufacturers to choose from. Each of these manufacturers has developed their products based on their own experiences, background and insights. As a result, choosing a given manufacturer involves choosing their design approach as well. This is healthy for the market in that the manufacturers are competing on approach as well as price. It's also generally good for boat owners, who have a diverse menu of options to choose from. However, as each manufacturer seeks to highlight the benefits of their approach through their advertising, web sites and social media, boat owners may find the resulting flood of information confusing and thereby draw incorrect conclusions as to what system would work best for them and why.

One way in which electric propulsion system designs vary from one manufacturer to another is the type of motor to use – AC (alternating current) or DC (direct current). Which one is better? This is a debate as old as electric power itself. At the birth of the electric power industry, for example, Edison & Westinghouse clashed over whether power grids should be AC or DC in the late 1800's. With Tesla on his side, Westinghouse prevailed and AC won. For marine electric propulsion, however, the question is less clear-cut. Instead, like many questions put to engineers, we say "It depends…" At CeM, after years of research, lab testing, sea trials and feedback from customers, we have concluded that at power levels of 12 kW and below, the DC motors used in our Thoosa products offer many more advantages than disadvantages when compared with AC motors. Specifically, DC motors offer very high torque capability given their weight and size, but this advantage brings with it the downside of having brushes which must be replaced from time to time. AC motors, on the other hand, avoid brushes, but they rely on transmission of electromagnetic force through an air gap, and this requires larger magnets with greater surface area on both sides of the gap. Also, AC motors require more sophisticated controllers that are capable of "inverting" DC into AC at varying frequencies.

Considering these factors merely opens the door to the subject. The next level of inquiry involves the different types of motors within the broad categories of "AC" & "DC". For example, both can use either permanent magnets or wires wound around ferrous cores which become magnetized when currents pass through them. AC motors are made in "synchronous" and "induction" arrangements, while DC motors may or may not be "separately excited". Sifting through each of these distinctions in an abstract manner often yields little in the way of insight. Instead, at CeM, we have found that evaluating motor types and system designs through the lens of features desirable for boat owners and operators offers a clearer way to understand how different system designs align with boaters' needs and concerns. In the following paragraphs, we evaluate various aspects of system performance and explore how they relate to the type of motor selected.

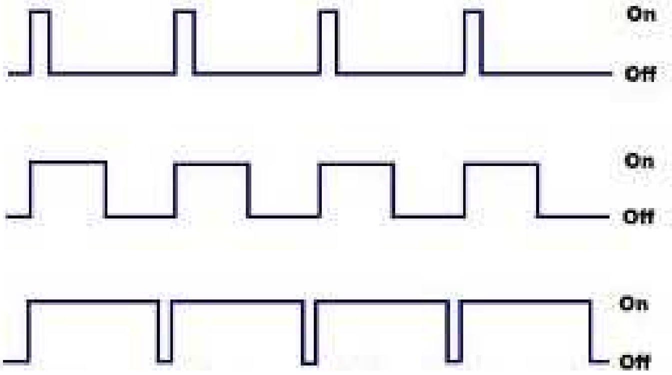
DIRECT DRIVE vs. REDUCTION: One electric propulsion system manufacturer has chosen a direct-drive design, in which the motor shaft is directly connected to the propeller shaft. Their literature includes claims that this design is inherently superior to those in which the motor's output is reduced by means of a gearbox or belt/pulley arrangement. While it's true that gearboxes and belt/pulley mechanisms introduce a small power loss from friction as well as additional moving parts, they more than make up for these by greatly improving the ability of the system to be properly matched to the boat's propeller and allowing for the use of high-efficiency, rugged motors that are made in large quantities for a wide variety of demanding applications. The vast majority of both AC and DC motors manufactured today at power levels suitable for boat propulsion – regardless of what they are used for – are designed to spin at 1,800 – 3,600 RPM or more. However, propellers for displacement hull vessels such as sailboats, launches, trawlers, etc. rarely spin faster than 1,500 RPM. This is due to the physics of the interaction between water and propeller blades. Spun too fast, a propeller reaches a point at which its ability to grab and move water actually decreases. At still higher RPM's, it "cavitates" – forming small vacuum pockets at the edges of the blades that cause pitting of metallic surfaces – and produces little or no thrust. Designing an electric propulsion system for direct drive, therefore, restricts the designer to heavy, slow-rotating motor designs. This restriction has a series of cascading negative effects:

- The motor, and the system framing, become larger and heavier compared with gearbox or pulley/belt designs
- The slower-spinning motor moves less air over its heavier windings, thereby requiring still more size and weight in the form of heat-conducting metal to maintain sufficient cooling
- The customer is less likely to be able to keep the existing propeller
- The installation becomes more difficult due to the increased size and weight

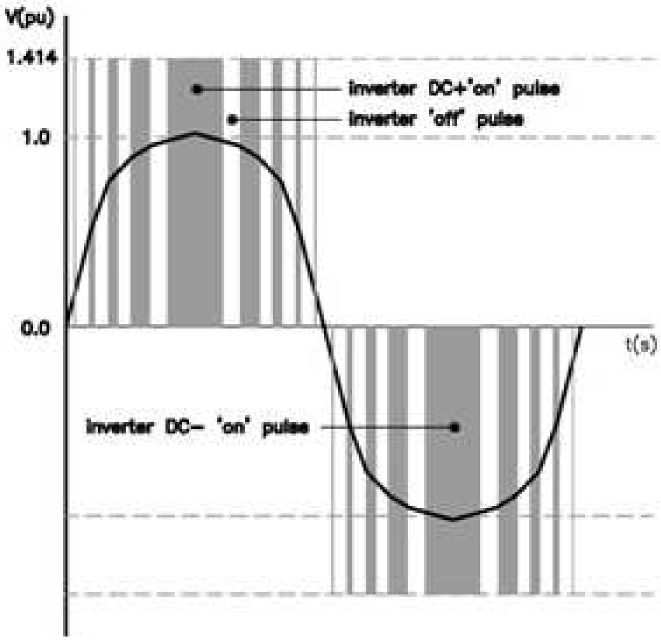
Meanwhile, properly engineered gearboxes and belt/pulley assemblies reduce both power losses and added wear and maintenance issues to insignificant levels. Thoosa systems, specifically, use industrial-grade high-torque thrust bearings, drive pulleys and belts with teeth – like automotive timing belts – that transmit torque efficiently, are easy to tension, are inexpensive, and last 3,000 – 5,000 hours of operating time. The drive pulleys are available in a wide range of sizes. While the standard reduction options are 2:1, 3:1 and 4:1, intermediate reductions are readily available. This allows Thoosa systems to spin a wide variety of propellers at RPM's at which they reach their peak efficiencies.

EFFICIENCY: By cherry-picking data for various types of AC and DC motors, an electric propulsion manufacturer can claim that an AC motor is more efficient than a DC motor, or vice-versa. Doing so can leave the reader with the impression that ALL DC motors are less efficient than ALL AC motors, for example. This is similar to suggesting that all white wines are superior to all red wines. In reality, there are great wines, good wines, so-so wines, and bad wines – both white and red. Similarly, there are cheap, inefficient AC and DC motors, and there are high-quality AC and DC motors that offer high efficiencies. At 5.5 kW and above, Thoosa systems use permanent magnet LMC motors developed by the British inventor Cedric Lynch. These motors feature Neodymium-alloy magnets in a "pancake" design that packs extremely high torque levels into a small enclosure. Their peak efficiency is 93%, which they reach and hold in a wide range of load and RPM levels. Meanwhile, selecting a high-efficiency motor is an important step toward delivering a highly efficient electric propulsion system – but it is by no means the only step. The high-efficiency motor has to match the prop at *its* most efficient point. The high-torque drive pulleys and belts described above – with the correct reduction selected – do exactly that. A direct-drive system, on the other hand, might use an equally efficient motor, but is much harder to match to customers' propellers. As a result, Thoosa systems typically outperform their competitors when compared in terms of total delivered efficiency.

Meanwhile, systems based on DC motors do enjoy an efficiency edge on the order of a few percentage points over those based on AC motors. This arises from the nature of the task the motor controller has to perform in either case. For permanent-magnet DC motors like the LMC, the motor controller simply has to "baloney slice" the incoming DC current into periods in which it is on and periods in which it is off. The motor magnets, which resist sudden changes in current flowing through them, smooth out the pulses such that the motor actually "sees" a steady voltage that varies with the width of the pulses. This technology, known as Pulse Width Modulation (PWM), requires fewer components and less complication than AC motor controllers. AC motor controllers, on the other hand, must create an AC waveform of varying frequencies from in the incoming DC current. This requires twice as many switching devices – one set each for the positive and the negative portions of the AC waveform – and more circuitry that precisely controls the timing of the switching components.



Pulse Width Modulation – to increase DC motor speed, increase the "ON" period and decrease the "OFF" period



DC-to-AC Inversion – to increase motor speed, increase AC waveform frequency by shortening switching intervals

MAINTENANCE: Maintenance is an inescapable fact of life for boat owners and operators. Switching to electric can reduce the frequency, difficulty and cost of propulsion system maintenance regardless of the type of motor used. Still, some electric systems may need more frequent maintenance than others, and this becomes a factor to consider as part of the overall system selection process. An electric propulsion manufacturer offering one type of system may be tempted to paint competitors' systems as undesirable due to increased maintenance requirements, but these claims seldom hold up under scrutiny. Thoosa system owners, for example, can expect at least 3,000 hours of operation before needing to carry out any maintenance. At that interval, they may need a new motor brush set and a new belt. The brush set costs less than $400.- and requires about 15 minutes to install. The belt costs less than $50.- and involves about 20 minutes to replace. Neither job requires special tools or skills. This is a small price to pay in exchange for a system that's lighter and more compact than those offered by competitors and easier to properly match to the propeller it's driving. Meanwhile, a day sailor might motor 3 hours total from and back to the dock. If she sails 30 times per year, that's less than 100 hours of motoring time – she will likely sell the boat or hand it down to her son or daughter before reaching 3,000 hours. A "snowbird" cruising couple from the New York metro area who make the trip to Florida each year and back can plan on an average of 75 days of motoring 10 hours/day per year, for 750 hours/year total. Their maintenance interval will therefore be once every four years. In summary, the additional maintenance required with a Thoosa system does not constitute a significant factor in deciding whether to use an AC or DC system.

MOVING PARTS: A deeper look at exactly what is and is not moving within a boat's propulsion system reveals that electric propulsion systems based on AC motors enjoy no inherent advantage over those based on DC motors. For inboard systems, converting to electric propulsion – regardless of type – does not get rid of shaft seals and cutless bearings. Fortunately, due to materials engineering advances, these have improved in recent years such that they last longer, perform better and need less maintenance than older versions. Meanwhile, the phrase "moving parts", for many of us, brings back memories of old cars, lawn mowers, bicycles, sewing machines, etc. that needed constant lubrication to avoid seizing up mechanically. Today, however, due again to materials engineering advances, moving parts of all kinds can last for years with either infrequent oil or lube changes or none at all. Manufacturers of rotating bearings, for instance, now make them from special alloys in which microscopic droplets of oil are absorbed into the granular structure of the metal itself. Therefore, as its surface wears, its lubrication is replenished by the "stored" oil. As a result, bearings made from these alloys are rated for lifetimes in the tens of thousands of hours. The motors and thrust bearings supplied with Thoosa and Triton systems use bearing technologies like these so that for all practical purposes, their moving parts will outlast the boat they are pushing without imposing any additional maintenance requirements.

MOTOR CONTROL INTEGRATION: Over the past three decades, technology advances in the fields of semiconductor materials and power system electronics have yielded extraordinary gains in the performance, efficiency and reliability of motor controls. This is true for both AC and DC motors. As a result, elevators and escalators, heating, cooling and ventilation systems, washers and dryers, golf carts, conveyors and robotics in factories and distribution centers, drone aircraft…all operate at high efficiency and under precise control to a degree unimaginable in the 1970's using both AC and DC motors. Indeed, the resurgence of interest in marine electric propulsion for small craft might not have occurred without these advances. Integrating motors and controls – again, for both AC and DC motors – has never been easier, as large, competitive and constantly innovating industries now exist in both motor and controls manufacturing. Today's motor controllers, for both AC and DC motors, include built-in microprocessors for which experts – like those who have designed and built Thoosa electric propulsion systems for over 15 years – develop customized settings and programming. The result is a fully-integrated motor/control package. What matters, with respect to system integration, is not the type of motor – it's the expertise and experience of the team who carries out the integration effort. In this regard, the Thoosa/Triton Team is second to none.

PLUG & PLAY: This overused phrase can best be restated as “ease of installation and activation”. This, again, is an issue that’s completely unrelated to the choice of AC or DC motors. AC- and DC-motor-based electric propulsion systems can be cobbled together cheaply, packed and sent to customers on a “good luck, have fun” basis, or, like our Thoosa & Triton systems, they can be thoroughly engineered for quick and straightforward installation with keyed connectors for controls and well-labeled battery and motor cables. Customers can even specify the control, battery and motor cable lengths when they order. Other factors that improve or detract from a system’s ease of installation and activation include:

- Weight – particularly when installing the system in a boat on the hard, less weight can greatly reduce the cost and difficulty of simply getting the components onto the boat.
- Modularity – another way to reduce the amount of weight that has to be handled at any given time is to “divide and conquer” by delivering the system in modular components. Our Thoosa & Triton systems take full advantage of modularity benefits by placing at the point of connection to the propeller shaft only those components which functionally need to be there. The controller, meanwhile, comes in its own purpose-designed enclosure which can be mounted wherever it best fits on board.
- Integration - “plug & play” does little to improve the ease of installation of a system that is hundreds of pounds heavier and significantly larger than Thoosa or Triton systems of comparable power ratings.

WATER RESISTANCE, IP RATINGS & ENCLOSURES: All providers marine propulsion systems, including those based on internal combustion engines, must harden their equipment so that it can withstand dampness and water in the engine compartment. Adopting a design strategy based on housing vulnerable system components in sealed enclosures with high IP ratings is one way – but not the only way – to meet this requirement. In other words, while a high IP rating does indeed constitute a high level of protection against water intrusion, the question needs to be asked – what is so fragile inside such that the enclosure needs to be built to this high rating? Thoosa & Triton systems are both supplied with motors that tolerate the environment inside a boat’s engine compartment well. The LMC motors supplied with the Thoosa systems from 6 to 12 kW, for example, also drive dirt bikes, scooters, industrial robotics in factories with hot, dirty environments and other demanding applications. They have been known to survive complete immersion with a simple fresh water rinse and forced air drying. The motors supplied with our Triton AC systems, made by Leroy-Somer, spin large pumps in damp environments such as water treatment and chemical plants. Again, there is nothing inherent about a DC motor that renders it less tolerant of the marine environment than an AC motor. At the same time, using a motor – DC or AC – that needs a full enclosure adds yet more weight and takes up more space. It also introduces a significant disadvantage – reduced ease of inspection. The open-frame design of Thoosa and Triton systems, in contrast, renders them easy to inspect while underway. In the rare event of a loose connection, slipping belt or excessive vibration, the condition can be viewed, assessed and solved quickly without having to loosen a series of bolts and lift off a large, heavy cover plate.

In summary, boat owners and operators considering a conversion to electric propulsion should carefully consider their options and explore how various system design approaches align with the manner in which they use their boats. Which type of motor – AC or DC – a given system uses merits consideration, but only within the larger context of the overall design concepts upon which the system is based. Neither AC nor DC motors are inherently superior to the other. Instead, a prospective electric propulsion customer should seek to understand *exactly* what type of AC or DC motor a given manufacturer has chosen for their system and *why*. At CeM, we have chosen the LMC motor as the basis for the Thoosa system for the following reasons:

- By using Neodymium-alloy magnets in a permanent-magnet DC motor configuration with long-life brushes, LMC motors allow Thoosa systems to pack very high power levels in a small footprint with low weight. As a result, in classic older vessels with small engine compartments, Thoosa systems may be the only products on the market that will fit at the desired power level.
- LMC motors are inherently simple and rugged. They can therefore tolerate the rigors of the marine environment for many years without the additional weight, lack of easy inspection and extra space requirements associated with enclosures required to house more vulnerable motor designs.
- LMC motors are proven performers in very demanding applications.
- LMC motors need infrequent, inexpensive, easy and quickly-completed maintenance.
- DC motor control is simpler and slightly more efficient than AC motor control.

We invite you to contact us with any further questions about Thoosa and Triton systems, electric propulsion design or how to select the system that's best for your boat.

Clean eMarine Americas, LLC
David M. DiQuinzio, PE
CTO

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