

# The Electric Wheel

## *Horsepower and Motors, or Apples and Oranges*

by **DAVID E. TETHER**

The first thoughts I had about electric drive systems were based on previous limitations and preconceived notions. They included a fascination for Electric Launches and those World War II stories about the diesel electric submarines. The launches are just beautiful as they slide through the water. ELCO and Duffy have carried those traditions on with new emphasis on efficiency and battery technologies that make them go farther with more power. The diesel electric submarines were amazing too, coming up to the surface to charge batteries and then submerging again. While submerged they were quiet and fast. I also discovered that there were diesel electric Tugs that performed in the very same manner as the fossil fuel tugs. The diesel electric tugs were much cheaper to maintain and had better fuel economy along with having unlimited electricity and quiet running. Understanding what all this meant has now brought me a new view of electric boating which can be made available to everyone.

I first became involved with electric boats when the automakers would not use our Solomon Technologies, Inc. inventions for electric cars. We had built a 10 hp and a 5 hp motor which were tested under the general supervision of the NASA Mid-Atlantic Technology Applications Center (MTAC). They proved to be extremely powerful and efficient. Our Electric Wheel, combined with state-of-the-art NeoDymiumIronBoron brushless DC motors, turned out to be a real winner. After the NASA 2005 Symposium, Mr. Dan Goldin (NASA Administrator) said that our Electric Wheel had application to everything that moved. I still wondered why the automakers weren't interested, but decided to look for other applications that were equally important for the environment and energy conservation. Because I was an avid sailor I thought that replacing that "demon below" would be a wonderful place to start with our new high-tech drive system.

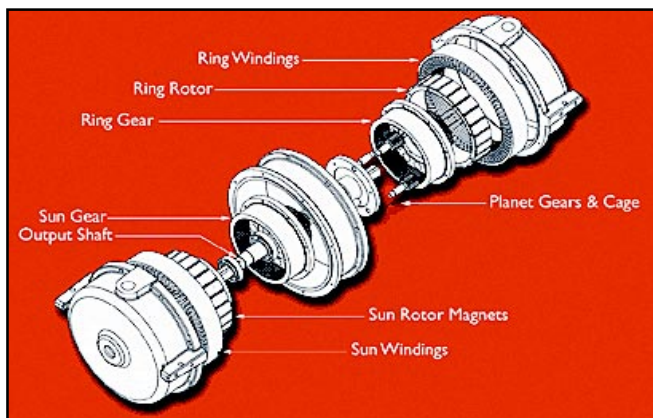
We found an antique 32-foot sailboat that weighed in at 19,000 lbs and floated pretty good. Well, it floated most of the time with the help of two 1,000 g/hr Rule bilge pumps. The important fact is that it was heavy and had a 22 hp diesel motor that was ailing. Well, the real important fact was that

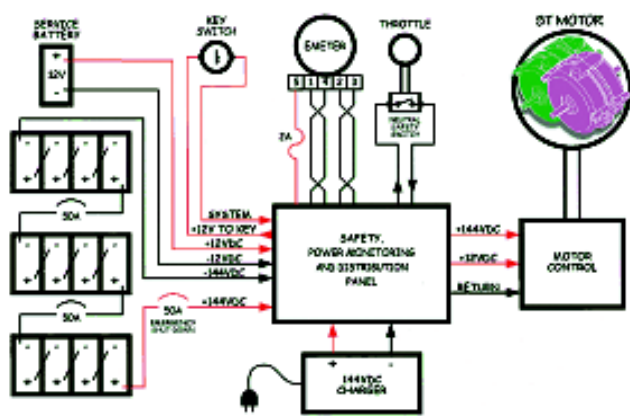
it was cheap, only \$600. The performance with the diesel was predictable. It did 5 knots, which was hull speed, and would stop if you started the stopping process early. If you tried to stop too quickly it would stall the motor. If you tried to accelerate too fast it would puff out smoke and sometimes stall too. The 5-knot hull speed is expected on this boat because it is 28 feet at the water line and has a 10-foot beam. It would accelerate to this speed in about 4 or 5 boat lengths, depending on whether the wind was with us or against us.

The diesel motor was taken out and the bilge scrubbed and cleaned as much as possible. Then, I installed 12 group 27 Interstate Megatron batteries with 6 on each side under the seats, centered in the middle of the boat. These batteries were installed in series to achieve 120 volts of direct current. The motor I installed by myself. I would never attempt to install a diesel by myself because it is too heavy and difficult to align the shaft couplings, but the electric motor could be handled easily. It fit nicely onto the same motor mounts as the diesel. The electronic controls for the motor were screwed to the bulkhead right beside the motor and the E-Meter set into the dash panel where the RPM gauge had been. Sounds easy and it was. Again, I am not a mechanic and would never have tried this with a diesel engine. Once the prop shaft was coupled and bolted up, I connected the rheostat (like the balance control on a stereo) and mounted it in the cockpit where the Morse control had been. I also left the shaft, stuffing box, and the 18" three-blade prop there as original equipment. I did all this work while the boat was in the water.

The first time we took the boat out we had limited expectations. The prototype Electric Wheel was 10 hp and we thought that it would go about 3 or 4 knots, which would be acceptable. We also expected that it would perform well around the dock, but wouldn't have full hull speed. When we first accelerated the boat we were shocked. The boat accelerated to hull speed in an instant! Later we found that we could do all of the 5-knots and get there in two boat lengths! We then hit reverse and found that it could also stop the boat instantly with no stalling - in 20 feet! How was this possible? At the time we could not explain it. After about 2 hours of motoring around and double checking the current and voltage, we brought the boat back to the dock still in amazement of what we had just experienced. I went home and told my wife but said nothing to my partners because they would just think I was crazy. I wasn't though, and I immediately went to the white board to try and figure out how this was possible. I also called Dr. Kevin Smith at the NASA MTAC and explained to him what we had found. He, too, found it incredible and we talked for several hours about the inefficiencies of fossil fuel motors. Bingo! It was at this time that we realized we were talking about apples and oranges when it came to horsepower in motors.

The appropriateness of the motor RPM and the ability of the motor to develop torque at lower RPM has everything to do with how the motor performs in a given application.





While a different motor may have more horsepower, if it does not have the necessary low-end torque it will not perform as well as the lower horsepower motor that has more torque and does not have to develop Velocity to make the torque. Velocity was a new word for me - velocity is torque and speed together already moving in motion and doing work. A diesel engine has to "idle" so it already has some velocity in the engine to begin developing additional velocity to move the prop and boat. Our motor doesn't need velocity to develop torque, therefore it does not have to idle and can jump the prop into action with much less horsepower.

Since then we have found the parasitic losses of the fossil fuel engine to be enormous. We have also found that a high torque motor in a boating application has many benefits over a lower torque motor. This is why, when comparing diesel engines to gasoline engines, the higher torque diesel engine will push a larger, more efficient propeller with less horsepower. The Solomon Technologies, Inc. motor which has even higher torque will push even bigger low RPM props. The operative word is torque. That is what propellers want and Horsepower = RPM x Torque. With this in mind we see that two motors can have the same horsepower, but one is 3,000 RPM and 10 ft./lbs. of torque and the other is 1,000 RPM and 30 ft./lbs. of torque. This is what is meant by the "appropriateness" of the motor output. Given that displacement hull boat propellers from 15" and up want to be turned at approximately 1,100 RPM (or less for the larger ones) the motor should be designed to operate at 1,100 RPM for optimum efficiency and torque characteristics. The diesel engine is designed for 3,200 RPM and therefore needs a transmission to convert the engine output to less RPM and higher torque. Usually this is accomplished with gear ratios of 1.6 to 2.5:1. And, usually, the diesel engines are oversized approximately 20%, so the motor has good low RPM control. Also, usually, the props are smaller as you find that most diesels less

than 20 hp are pushing propellers that are only 12"-15". On the other hand, the Solomon Technologies' SOLO 37 will drive up to an 18-inch prop which will transfer more of the horsepower to actual movement of the vessel. A lot of energy is lost when using a small prop that turns fast. Even more energy would be lost if you were using a gasoline engine that was designed to operate at 5,400 RPM, unless a larger gear ratio is used, such as 4 or 5:1.

Now back to the "parasitic" losses. These are the things tied to the motor to make it work right in the application. For the electric motor there are none, zip... zero. Motor mounts are all you need and they are minimized because there is no rattling and shaking. They are installed for quieting purposes. Did you know that all the rattling and shaking is lost energy, too? The other parasitic losses for a fossil fuel engine are the alternator, water pump, raw water pump, belts, oil pump, transmission, transmission oil pump and anything else tied to the engine. In fossil fuel engines, like money, it takes horse-



Battery placement in a 46' J.J. Fioleau-designed cat



## Electric Wheel

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*Electric Wheel configuration on same catamaran*

properly adjusted pulley and belt (under load), will eat as much as 3 hp, and without the properly adjusted belt can eat 4 or 5. If you started out with a 24 hp motor you are now down to 20 and all you have done is charge the batteries and power the gauges and solenoids. The raw water pump with its accompanying belt can eat 5 horsepowers. Now we have 15 hp left, but we have gauges, we are cool and water is splattering out of the back of the boat with a whole lot of rattling and shaking going on. You are now beginning to see what we found. When you add up all these things you quickly find that what actually makes it to the prop on the typical 27- to 33-foot sailboat is about 6-10 hp. And believe me, it is closer to 6 than 10 because the transmission and its pump will eat 10 to 20 percent of what is left.

We must now consider propeller sizing. This is an important puzzle and anyone who has helped size a propeller knows all too well that it is a nightmare of trade-offs with the overall consideration being efficiency. Did you know that no matter how you make the power in the boat, that 20% to 50% of the energy will be lost by trying to transfer it to the water? This is the kinetics of prop dynamics and has no implications on an individual propeller manufacturer, it is just the way it is. If the prop is not sized right for the hull it can lose 50% of the power. As you would expect, it is typically about 30% to 40% in order to preserve fuel economy in the engine and push the boat with some authority. So, let's see, 6-10 hp made it to the propeller and now 30% is removed, leaving 4-7 hp worth of actual forward motion being achieved. Now we know why in boats the fossil fuel motor, through its whole cycle of use, is about 20% efficient. If you idle a lot this number is lower and if you use the engine to keep your house batteries charged it is even lower.

Let's look at the diesel generator. It is balanced and blue-printed to run at a specific RPM with a balanced load and to make electricity. The alternator only makes enough energy to charge the battery over a long period, so it can be as much as 70% smaller. The water pump does not have to cool the engine at idle and at a full 24 hp, so it is 50% smaller. There is no transmission and the engine always runs at the perfect speed with optimum efficiency in energy conversion. Because it has a quantifiable constant temperature, it can be put into a cocoon with virtually no sound and no heat getting into the outside environment. On our boats we consider heat and sound as harmful to the environment too! The overall affect is that you can convert the fossil fuel at three times the efficiency with one fifth of the maintenance, heat and noise. You then convert the electricity to power at the prop with a properly sized prop, losing only 20% of the energy and a motor running at 94% efficiency and, voilà, you have tripled your economy. You have also made the maintenance easier, it is almost dead silent and virtually no heat in the engine room. The muffler is smaller, you can't hear the exhaust, the pollution is less and you have electricity. Oh...yeah, that's right... you have electricity. Lots of electricity for microwaves, TVs, VCRs, electric water heaters, air conditioning, radios and whatever your heart desires. One of my idiosyncrasies is keeping the boat lighted at night. I used to have to count watts for the masthead light and the head light... now I keep on the spreader lights too, and other night lights on the boat in case I awaken to an emergency.

Now, for the real clincher. When you are sailing along, the motor turns into a generator and charges the boat and powers other things on the boat by acting as a hydroelectric plant. Flow of water across the propeller is turned into electricity just because the motor has magnets on it. The whole system is self regenerating. Hence, our bumper sticker which says "It's a great day to Regenerate."

For the multihull user there are even some additional compelling reasons to use a diesel electric. The first of these is balance. The motor only weighs 78 lbs and the generator can be located with the batteries amidships right in front of the mast. This gives the boat perfect balance and centralizes the electronics. The second is space. A diesel engine is difficult to hide in a narrow hull on a catamaran or tri-hull. An electric engine that is only 13" in diameter and 13" long with no transmission, belts and "stuff" can be hidden under the deck with ease. This reduces, and in some cases eliminates, the space, noise, heat, exhausting and water piping problems that we are currently dealing with. And, did I mention that we have virtually unlimited electricity? When my wife figured that one out I was in big trouble. The good news is, now that I have embraced her needs, I am more comfortable too.