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MARINE GROUP

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The Design and Testing of a Floating Hydroelectric Dynamo

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WILL A NEW ENGINEERING DESIGN ALLOW US TO HARVEST MEGAWATTS OF REGENERATIVE ENERGY FROM SAILS?

This is a new look at marine vessel energy regeneration. Regeneration for a hybrid automobile is basically the energy recaptured by the act of slowing it down by braking or coasting down a slope. For the EnergyTech Marine 83 HD-X vessel the principle is essentially the same except you don't use brakes or coast down mountainsides. Instead, you rub off some of the velocity of your vessel achieved from wind in the sails by converting it to stored electricity. You can actually travel farther and faster by first converting the wind energy in your sails to electricity to be used later for motor propulsion, rather than wasting most of it by trying to sail with it.

The new EnergyTech Power Core™ Hybrid-ion Energy System turns a vessel into a giant hydroelectric generator. The sails are used to contribute to a hybrid transportation system, which can provide performance identical to that of a motor yacht, instead of just waiting for the wind to blow you around on the water. A hybrid electric car uses vast amounts of regenerative energy and performs and feels just like a fossil fuel powered car. Why shouldn't a yacht be the same? This paper explains the principles of how this energy can be harvested so that you can quit wasting energy in your sails and start using it more efficiently for regeneration in an amazingly new and different hybrid system. A subsequent paper describes the practical uses of it. See *The Operational Advantages of Using Regeneration Energy* on the **energytechmarine.com** home page.

EnergyTech Marine Group believed it was possible to build an 83' yacht that was capable of regenerating a million watts of free electricity in a single day by functioning as a floating dynamo. This paper outlines the theory and design of the 83 HD-X and its Power Core Hybrid-ion Electric Energy system only as it pertains to free energy regeneration. Earlier papers on the **energytechmarine.com** web site (*Pulse Buffering Power Core*, *The Next Giant Leap Beyond Diesel-Electric*) describe The Power Core's hybrid applications as they pertain to fossil fuel and shore-power conversion and efficiencies.

The heart of the design goal revolved around the question of whether one could invent a system capable of skimming off and harvesting *only* the excess power being absorbed by the sailing rig once it is propelling the vessel beyond its target velocity *without affecting the power that got it up to that initial velocity*. In other words, if the wind was driving the vessel at (any speed) for instance 12 knots, and one was willing to trade off two of those knots in exchange for being able to convert that specific power to stored electrical energy which could be used later when the wind was not blowing as briskly, what would the gain be? The goal was to come up with a way to do it without depleting any of the power being used to achieve the first ten knots. This paper describes how this goal was met.

THE PREMISE

In the simplest terms, a propelled boat is a device designed for transporting things through the water by converting energy into thrust — whether it is the energy of calories burned by the work of muscle power rowing a canoe or by converting the energy stored in combustible fuel into work by producing thrust by the process of burning the fuel in an internal combustion engine.

We use energy to move a force through a distance. On a boat, we use most of it to increase velocity. Ironically, on a sailboat when the wind is outputting its greatest power, we get the least velocity per horsepower. That is because when wind is at its strongest it goes mostly to waste. The goal of capturing this waste was the motive for setting out to design a mechanism to skim off and store this peak wind energy when it occurs, to use it later when the wind is lighter. By using it later in the form of electricity, we can produce drastically more speed and distance from the same power than we could if we tried to use it for propulsion when the wind was blowing strongly. The trick was to devise a mechanism that could accomplish this without affecting or disturbing any of the power required to get the vessel up to its base chosen speed.

There are many sources of energy that can be successfully converted into thrust to propel a vessel. We as a generation have pretty much come to think of propulsion for a marine vessel as only being the result of burning combustible fuel. We clearly are going to be forced to change this myopic concept of propulsion. It's not politics and it's not ecology that will ultimately change this dynamic. It is supply.

At EnergyTech Marine Group we are currently testing the 83 HD-X, which utilizes a diverse number of readily available energy sources. The 83 HD-X is available as a hybrid yacht with sails or as a "non sailboat" in the form of a fast trawler. Here, we will be addressing the hybrid sail version. It is not the options that are so unique. It is the new ways they are employed that are so different. We are not talking a small benefit. We are talking about a major benefit of a proportion that you may have never considered.

This is not a paper about saving Earth from global warming or debating the net efficiency of bio diesel. It is simply an analysis of current readily available energy sources based on convenience and cost benefits. The long list of other benefits is real and self evident but is simply a collateral result of newly engineered efficiencies.

A HYBRID WITH SAILS CAN BENEFIT MOST FROM THIS TECHNOLOGY

First of all we will address the basic design of the 83 HD-X. A displacement hull vessel is different than a planing hull vessel. A sailboat, like a trawler, a rowboat, or a supertanker, is a displacement hull vessel. Because of this difference, they offer a large opportunity to exploit a sizable hidden cache of free energy if you deploy The Power Core's new hydroelectric turbine design.

Let's look at why this is. Displacement hull vessels move *through* the water rather than skimming over it like skipping a stone on a pond or speeding around in a ski boat. They sit in the hole they make in the water. To travel through the water, they must move all of the water in front of them out of the way and let it fill in the hole they leave behind them as they move forward.

As a displacement vessel goes faster it experiences an exponential increase in wave making resistance resulting in ever increasingly exaggerated drag. It is not just that it experiences more drag as its speed increases. It is that the drag increases exponentially. Think of sailing in candy-taffy, which has the consistency of water when you are going slowly, and the consistency of silly putty when you are going very fast. The faster you go the thicker it gets until almost no practical amount of power will take you any faster.

A displacement hull is limited to a speed which is equal to the velocity point at which all of the thrust of the vessel is absorbed by the drag resistance. To go faster it must increase thrust or reduce drag. However, there comes a point at which adding more thrust results in almost no increase in speed. This is the practical maximum velocity for the vessel. This hypothetical wall is referred to as the *hull speed* of a displacement vessel. You are done when thrust = drag.

The overly simplified version is that displacement hull vessels make a wave as they move the water out of the way. The faster they go, the more the wave builds up in front of the bow. The buildup is exponential and therefore disproportional. There comes a point at which it requires more power than is practical to climb up that hill of water.

For the purpose of this paper, one of the most interesting points is that the wavelength of a vessel's wake is proportional to its waterline length. The result is that the longer the vessel is, the more slowly the rate the wave drag increases. This means longer vessels can go faster.

Don't worry. We know there are a lot more kinds of drag that affect this outcome and we have just skipped over about ten pages of the complete explanation. As we said, this is a very simplified explanation of displacement hull speeds, because this is not about theoretical hull speed. We simply wish to establish the fact that as a displacement hull vessel approaches its maximum hull speed, it requires much more power to increase speed by the next additional knot than is required to achieve the preceding knot.

As you will see, this power requirement difference can be extremely large. It can be more than most vessel operators ever think about. It is within the zone of these huge power requirement differences that the new EnergyTech regeneration system is designed to harvest very large amounts of free energy. It was designed to capture only the energy that is going almost entirely to waste. We know this sounds improbable, but stay with us to see how it works.

This regeneration system accomplishes a great deal more than the traditional system of just dragging an un-feathered prop in the water while sailing.

HOW DO WE KNOW THE AMOUNT OF POWER ABSORBED BY SAILS?

The 83 HD-X has mechanisms or machinery (motors and sails) on-board that turn energy into thrust. That's what propelled vessels do. The Power Core Hybrid-ion Energy System has twin diesels that are used to combust diesel fuel and convert it into charged ions (just think of it as electricity) stored in its super capacitors and its proprietary lithium-ion batteries. It also has twin hydroelectric reaction turbines capable of converting the water-flow beneath the vessel into a similar charge while sailing. When needed, the stored ions are converted to electricity, which produces work by turning the hundreds of horsepower of electric motors. The electric motors spin the impellers in the twin UltraJet® jet drives, which produce the thrust to propel the vessel.

This is what is known as a *series hybrid*. Even without sailing, it uses much less diesel fuel than if you were to simply couple the internal combustion engines to the drive shafts for direct-drive propulsion. See the "Pulse Buffering Power Core" article at the **energytechmarine.com** home page.

Let's look at the amount of power required to create enough thrust to propel the vessel at a range of speeds. The same amount of forward thrust is required to propel the vessel at a particular speed regardless of the energy source. In a moment we will compare the different energy sources of diesel fuel and wind. It is easiest to first measure the power delivered to the water through the jet drives. This measurement can be quite exact, because the power absorption of the impellers is as close as you can probably come to a constant dynamometer measurement. In fact, dynamometers use impellers to measure power absorption for all sorts of applications including motor vehicles.

It is almost impossible to mathematically calculate the horsepower produced by the sails of a vessel. We are not going to get into that discussion because the variables are almost infinite. We are also not going to join the heated debate about which moves a sailboat through the water, lift, or thrust, because for the purpose of this paper it doesn't matter. We clearly know that the kinetic energy captured from wind moves the vessel when it is sailing because when the wind doesn't blow, the vessel doesn't move at all. Save your e-mails on that subject because this paper is not about that. For simplicity we are just going to refer to this force as thrust.

Even though we cannot practically calculate the wind horsepower with raw numbers, we can do a good job of empirically measuring it. We need to deduce the amount of horsepower absorbed from the sails in order to project the potential energy regeneration capabilities. For regeneration we are only concerned with the power absorbed resulting in the net forward thrust delivered by the mechanical mechanisms of the sails.

We can measure it quite simply. Starting at the beginning, we have tested and therefore we know that 12 kW (16 HP) of power is absorbed by the impellers in the act of accelerating the water sufficiently to produce enough thrust to move our vessel through the water at five knots. We first tested this with direct-coupled diesel engines. This isn't the amount of power produced by the running diesel at the shaft or the power produced by the batteries. The 12 kW is the amount of net measured power absorbed by the process of accelerating the water to generate the thrust to move the vessel at five knots. Simply put, it takes 12 kW (16 HP) of power to propel the vessel with electric motors or diesel engines at five knots on a flat sea. The power absorption of an impeller in a jet drive and a prop are almost identical at the same rpm.

Therefore, if the vessel is moving at five knots we can deduce that 12 kW (16 HP) of power is being converted to forward thrust. This is true if it is driven by either the jet drives or by the sails. When under sail there would be more power delivered to the water that is not resulting in forward thrust, but we can ignore that for the purpose of the measurements in this paper. Lateral forces from the sails on the hull and keel absorb power too, and not all of it results in forward motion. We are only examining the amount of power expended that results in forward thrust because that is the only power from which we can harvest regeneration energy.

So where are we? We are at the point at which we simplify the statement of our original design. We are going to quit always referring to *forward* thrust for the sake of simplicity even though that's what we always mean. We will occasionally just call it thrust. So our concise premise is that it takes the same amount of thrust to propel our test vessel at a given speed regardless of the energy source, i.e. diesel or electricity or wind. If it takes 12 kW (16 HP) absorbed by the impeller and transferred to the hull to generate the thrust to move at five knots with jet drives, we can conclude that it takes 12 kW (16 HP) to be absorbed by the sailing rig and transmitted to the forward motion of the hull to travel at five knots from absorbed wind power.

The jet drives generate thrust, which is transferred to the hull of the vessel by the bolts on their mounting plates. The sails capture wind energy and generate power, which is transferred to the hull of the vessel through their attachments to the mast and rigging resulting in thrust. Identical amounts of forward thrust will result in identical velocities. Identical forward velocities are the result of identical amounts of forward thrust. We can deduce the amount of power being absorbed by the sailing rig and being converted to thrust by observing the velocity through the water produced by it and comparing that to the amount of exact measurable power being absorbed by the impellers to produce enough thrust to achieve the identical velocity while motoring without sails.

SO WHERE'S THE AMAZING AMOUNT OF HAVESTABLE ENERGY?

Now let's get to the interesting part. What we are saying is that if we are absorbing, for instance, 300 HP from the motors at the impellers to plow through the water at *X* knots, it would take the same amount of horsepower delivered from the sails to achieve the same *X* knots with the motors off. Somewhere in the process, 300 HP from the sails was being converted into forward thrust or it wouldn't have reached the *X* knots. For this paper we are not concerned about the efficiency of getting from the energy source to the thrust. We are only interested in a viable way to measure the amount of power provided from the sails to produce the work to generate that thrust.

As we have said, when our vessel motors at five knots, we know it is using 12 kW (16 HP) of power to produce the required thrust. That is at the rate of 2.4 kW per knot through the water. We know from empirical measurement that when the vessel is motoring at ten knots it is using 128 kW (171.7 HP) to produce the required thrust. That velocity requires us to use power at the rate of 12.8 kW per knot. That is five times the power per knot required to achieve five knots.

Now let's examine the additional amount of power required to add another knot of speed to cruise at eleven knots instead of ten. Instead of 128 kW (171.7 HP) to go ten knots, it requires 222 kW (298 HP) to go eleven knots. It requires expending an extra 94 kW (126 HP) per knot to achieve the one extra knot once you are already traveling at ten knots. That is 7.3 times the average amount of power per knot required to sustain ten knots. The exact required amount of power must be expended in order to overcome the additional drag created by moving the hull through the water at the extra knot of velocity. Remember the analogy of what would happen if the taffy got thicker as you tried to go faster. In reality, the water doesn't get thicker, but the wave you must climb becomes exponentially higher as you approach your theoretical hull speed, producing a similar effect in the form of wave drag.

Now let's see how much extra power is required to go still another knot faster once you are already cruising at 11 knots. To go the additional one knot to reach a velocity of 12 knots requires a total of 452 kW (606 HP). That is an extra 230 kW (308 HP) to travel yet one knot faster than 11 knots. That is 18.4 times as much power required per knot than the average power per knot required to go ten knots. As you can see, it requires an ever-increasing amount of power to go a little bit faster as you begin to approach the hull speed of displacement hull vessels.

To cruise at 12 knots instead of ten knots requires an extra 324 kW (435 HP). The top sustainable design cruise-speed of the 83 HD-X with the standard Power Core is 13 knots. As you can see, it requires a ridiculous amount of power to motor at that speed and you would never rationally elect to burn the amount of diesel or electricity required to sustain it on a cruise. It is there in case you need to dodge a tanker or power up an oncoming wave in *The Perfect Storm*.

These are actual empirical test measurements on the 83 HD-X. Most displacement hull vessels will perform worse because of the more advanced hull design of the EnergyTech Marine vessel. Regardless whether a displacement hull goes a little faster or a little slower, they all ultimately reach the point at which it is impractical to commit enough additional power to go any faster than its so-called hull speed.

WHAT ABOUT USING FREE ENERGY?

Unlike mere mortals, Mother Nature does not have to worry about the cost of any excessive energy she produces. She seems content to leave vast quantities of it just lying around on the surface of the earth, free for the taking. This leaves us with a situation in which we might find ourselves sailing at a velocity that would be preposterous to maintain if we were purchasing the energy required to generate that amount of thrust from motoring.

In our above example, would any money-loving individual apply an extra 126 horsepower, while motoring, to go eleven knots instead of ten? Would they likewise apply 606 HP to go 12 knots instead of 172 HP to travel at ten knots?

The reality is that you can often find yourself cruising along at 11 or 12 knots in brisk winds, under sail-only, without giving it much of a second thought. We don't think about it because the energy absorbed by the rig to provide the power to produce the required amount of thrust is free. Mother Nature could care less about throttling you back to ten knots in order to save energy.

Imagine how microscopic the amount of energy is that you are absorbing from the wind that is blowing at the same velocity over tens of thousands of square miles of ocean at the same time. How much of the energy from that weather system did your sails snag?

SO WHAT DOES THIS MEAN?

So far every reader who has sailed probably intuitively knows all of this even if they have never bothered to think of it in these measured terms. Again, the goal of the EnergyTech regeneration technology was to create a system that could skim off only the power that was being used to drive the vessel that extra knot, or two, or three, after it has reached the acceptable cruise speed, without affecting the speeds below the desired target cruise speed.

In other words, the design goal was to harvest *only* from the pool of energy that was going almost entirely to waste anyway once the vessel began to exceed the operator's targeted desired cruise-speed.

The design team decided that once the vessel reached a point at which it was consuming in excess of a hundred or even hundreds and hundreds of extra horsepower to gain insignificant velocity increases, that power was, for all practical purposes, going to waste. Further, the design goal was to let the operator choose and dial-in the acceptable cruise speed below which there would be no effect (including the option to select zero speed sacrifice if desired).

For simplicity, let's first look at the amount of power available to be harvested from the velocity difference between ten knots and 12 knots. As we already pointed out, we know that the additional drag encountered by our test vessel by increasing from ten knots to 12 knots absorbs an extra 324 kW (435 HP) of power in the process of overcoming it. We know that specific amount of power is being consumed to produce the thrust to achieve only the *extra* speed beyond ten knots.

This means that we know that if we are sailing along at 12 knots and we deployed some sort of drag-brake until we slowed the vessel to ten knots that it will have absorbed 324 kW (435 HP) of power into that drag. That is the measured amount of power required to overcome the drag that causes a two knot reduction in cruise speed. We know this because we can measure, when motoring, that if we reduce the throttles and deliver 324 kW (435 HP) less power we only go ten knots instead of 12. Once your speed is reduced to ten knots, you no longer need the extra 324 kW (435 HP) to maintain that speed. But if you still have the extra power being delivered to the water anyway via the sails, it is available to be used for something else.

This is precisely the pool of spare power being converted by the Power Core regeneration system. The 83 HD-X has twin nacelles with encapsulated hydroelectric reaction turbines. Variably adjustable ram inlets can be deployed from each nacelle. The inlets can be opened and closed in such a way as to create a range of drag from zero when closed, to large amounts of drag, capturing dynamic pressures containing hundreds of horsepower of kinetic energy in the flow of the water diverted through the turbine blades.

The wider the scoops open, up to the frontal square surface area of the blades, the more kinetic energy in the form of flowing water is diverted through the enclosed turbine. There is no mathematical difference between a stream of water flowing past a still turbine or a turbine attached to a boat hull moving with a force through still water.

The mathematics for the conversion of the kinetic energy of flowing water apply equally in this case. The power that can be converted to a usable mechanical form is the energy/second intercepted by a device with a particular frontal area *A* flowing at *V* velocity in water with *D* density. Power is equal to density (about 1,000 kg/cubic meter), times area (sq. meters), times velocity (meters/sec.) cubed.

For the EnergyTech Power Core, the critical number is that the potential electrical energy that can be regenerated is cube driven by the velocity of the water through the encased turbine. The Power Core system uses the vast above-described amount of wasted sail horsepower to overcome the dynamic pressure from the drag, which is increased as the scoops widen which increases the frontal area, which in turn increases the kinetic energy being diverted through the turbines. The system converts the kinetic energy in the flowing water into torque, which is used to generate electricity.

Even at a mere 33% efficiency, the difference in the kinetic energy between ten knots and 12 knots would leave us with more than net 100 kWh of regeneration energy, after 66% losses, for every hour of operation. Ten hours of sailing could produce a million watt hours of electricity.

Simply letting your standard propulsion propellers spin from the water flow while sailing cannot accomplish the same level of regeneration. Props are not encapsulated to avoid tip losses (reaction turbines must completely constrain the water pressure during energy transfer). They are not of the proper size to capture all of the available energy. They are not of the proper type, nor are they pitched properly to capture sufficient energy. This is why a specialized separate reaction turbine is needed to capture energy at these levels.

HOW MUCH ENERGY IS POSSIBLE?

The Power Core on the 83 HD-X offers the option of fixed-in-place regeneration alternators capable of generating at a sustained 400 kW even though the vessel could never capture at that level. That huge amount of regeneration would cause enough drag to slow the vessel to almost a complete stop and you would not be able to capture anything. Even though the generating capability is there, that energy level cannot be successfully converted. We point it out only to display how little is being asked of the equipments capabilities.

So this system allows us to skim off the excess power, which goes mostly to waste on a sailing displacement hull vessel, without touching the energy required to reach your elective cruising speed, say ten knots.

For the real-world application of how to increase average speed and distance covered using this technology, read about energy-smoothing™ in the PDF document, Regeneration: the operational advantages on the **energytechmarine.com** home page.

The following tables display an idea of the net amount of energy available for conversion, after losses, at different sailing speeds. The stated net converted kilowatt-hours of energy are the potential based on a projection of one-third efficiency for the hydroelectric reaction turbines. The table displays the approximate offset in sailing speed, which would be traded for the net stored energy per hour of operation. Using this stored energy later for electric propulsion results in a net gain in speed and distance.

Net electric energy stored per hour vs. speed offset as a result of converting one third of the water-flow's kinetic energy. Sailing speed reduction (speed shaving) is adjustable by the operator. This provides a partial menu of energy/hour and speed choices:

Speed-shaving™ results in stored electrical energy

2-knot speed reduction at 33% efficiency

5 knots instead of 7	7 kWh
6 knots instead of 8	9.7 kWh
7 knots instead of 9	12.3 kWh
8 knots instead of 10	26.3 kWh
9 knots instead of 11	50.6 kWh
10 knots instead of 12	107.9 kWh

1-knot speed reduction at 33% efficiency

5 knots instead of 6	2.7 kWh
6 knots instead of 7	4.3 kWh
7 knots instead of 8	5.3 kWh
8 knots instead of 9	7 kWh
9 knots instead of 10	19.3 kWh
10 knots instead of 11	31.3 kWh
11 knots instead of 12	76.6 kWh

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