Hybrid Propulsion

What is it, and when does it make sense for ships?

Environmental Protection IN THE AIR

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Hybrid vehicles are becoming increasingly common on the roadways. We see hybrid cars, buses, and even SUVs … but when will we see hybrid ships? By our experience, the answer is "soon." There is a rising tide of interest in marine hybrid drives and an increasing number of hybrid propulsion ship projects in existence.

What Do We Mean by "Hybrid?"
A "hybrid" drive means there is more than one power source that can turn the shaft, via an electrical interconnection. There might be a combination of batteries and diesel generators, all of which can feed their power into an electric propulsion motor. Additional power sources can include solar panels or even windmills. While the contributions from these sources may seem small, every drop of propulsion power collected from the sun and wind means one less drop of fuel purchased.

What Are the Advantages?
Fuel efficiency. In an ideal hybrid drive system, the system automatically determines the most efficient source of power for a given load demand. In the case of a large passenger vessel, the demands of the "hotel" load and "propulsion" load can be coupled together electrically and powered by a combination of power sources including generators, batteries, and alternative power sources. This permits operators to "tune" each operation into an extremely fuel-efficient mode that likely would have been impossible with traditional mechanically geared propulsion systems.

In hybrid operation, the engine in the system (e.g. a diesel generator) runs at a constant load. When this load suits the vessel's propulsion needs, this power is sent to the propellers (as electricity sent to a motor) and consumed in propulsion. But during those times when this power is not needed—during low-speed maneuvers, for example—the engine still produces the power, but it is "banked" in an accumulator array (usually batteries). Then, when required, the accumulator array is drawn upon and its power is added to the still-continuous output of the engine. Thus, the engine runs at a steady load even while the motor is throttled up and down. This steady load is optimal for best fuel consumption.

The stainless steel cases on the right-hand side house large battery banks on this hybrid vessel. All photos courtesy of RiverQuest, Pittsburgh, Pa.

Easy to upgrade. A hybrid drive is inherently modular. Consider a typical hybrid, having one or more diesel generators, a battery bank, and a propulsion motor. In a case like this, you can change out a major component of the system without disturbing the rest. This may be as sim-

Mythbuster

Traditional marine vessel propulsion plants require engines that are sized for the maximum output and speed that may be required. While there is an attempt to optimize fuel consumption across a wide range of power and RPM, even modern diesel designs with electronic injection systems have a reduced efficiency while operating at loads that vary from its design point. This necessarily involves compromises. Optimizing a hybrid drive for a single power point permits a tight optimization and the best fuel economy the engine is capable of.

Note that in this example the engine is sized for "average" power, and does not have the horsepower reserve required for peak power. Peak power is accomplished by drawing on the accumulator or battery system. This means that the diesel engine that is coupled to the generator is smaller than would be specified in a normal marine propulsion direct drive system.

But this reduction in engine size is not the key to reduced fuel consumption. The smaller engine will indeed have a smaller fuel consumption rate, but the total gallons per day needed may not be reduced, because a smaller engine must run longer hours. The "work"—the energy required to move the ship across X miles at Y knots—is the same for the smaller engine and its larger sister. If there is a reduction in fuel consumption it will not be because the engine is smaller, but rather because it operates at a more efficient point on its performance curves.

ple as removing one generator set and replacing it with another. Or let's imagine that NiMH batteries become affordable, an example of changing battery technology. In this case, you can change the battery bank without touching the motor or generator. For that matter, when other, more effective forms of energy storage are commercialized, the batteries can be replaced by them.

The engine room on a hybrid drive vessel showing the propulsion generator. The cabinet on the right holds propulsion control electronics.

A related advantage is that the individual components are generally smaller and lighter than their traditional counterparts. Thus, the manipulation of any one component is likely to be physically easier.

Additionally, modularity means that the components of the system need not come from a single vendor. One preference, for example, is to use a common power standard such as 120V AC, or 240V three-phase power. Using such a common standard is equivalent to using USB devices on your computer—everything is plug-and-play. The motor doesn't need to know what type of generator you have, the generator doesn't care what RPM the motor works at, etc.

Arrangeability. This modular or "component architecture" nature of a hybrid drive also brings some potentially important design flexibility: It is possible to put the components nearly anywhere on the boat. Thus, the generators can be placed in the bow or the stern, freeing the midships portion for mission-related functions.

Operational flexibility. In a hybrid drive there is no need for all the generators to be the same size. We might imagine a twin screw boat with two 400 hp electric propulsion motors and a 60kW ship service electric load, and equipped with one 400kW generator, one 200kW unit, and one 50kW unit.

With all generators online, full power can be delivered to the props (600kW is about equal to 800 hp). Running only the bigger generator attains an economical cruise at about 80 percent of max speed, while still providing the full ship service electrical capacity. Note that the propulsion power can still be evenly distributed to the two props, even though only one diesel is running. With just the 200kW generator running, the boat goes into a "quiet mode" at about 50 percent speed, say, for tourism. In fact, if there are batteries aboard, too, then both generators can be shut down for a super-quiet "stealth" mode, ideal for activities like whale-watching.

During all of these modes, both props are turning. It's a much more flexible mode than shutting down one conventional engine and limping along on one shaft only. Further, all of these generators could be based on the same engine while having different cylinder configurations, creating parts commonality galore. This system architecture gives the operator the opportunity to decide which power source to have online depend-

ing upon the immediate needs of the ship, instead of having a 400 hp engine putting out 100 hp for cruising.

What Are the Disadvantages of a Hybrid?
There Ain't No Such Thing as a Free Lunch. It's true that a hybrid drive can lower fuel consumption, be more flexible and arrangeable, and have other advantages over a conventional mechanical drive. Unfortunately, but unsurprisingly, those advantages also come at a cost. In some cases, this cost is financial, but some of the "costs" are measured in other units, such as complexity or weight.

In a conventional drive, the driveline is fairly simple: propeller, shaft, clutch, gearbox, engine. In a hybrid drive there are more pieces: propeller, shaft, motor (maybe no gearbox), cables, switchgear, batteries, generator. Further, let's look at the weight of some of these pieces. Imagine a 500-horsepower installation. The generator includes a diesel engine that may be slightly less than 500 hp—let's say 400 hp. The actual size will depend on the duty cycle questions mentioned above. Now we add the electrical part of that generator, which is a pretty big piece of copper that might weigh half as much as the diesel. Then we add a 500-hp electric motor, which is another very big piece of copper. The switchgear at this power level includes some pretty large cabinets of electronics, and finally we add batteries, which are made of lead. The result of all this is that, for equal total power, the hybrid drive system will be heavier than a mechanical drive system.

Of course, each of those "weighty" components must be purchased. Further, there is substantial cost involved in the installation, with wiring and other components necessary. The complexity of the system may also limit your choice of shipbuilders; not all boatyards are up to the challenge of installing a hybrid drive. So the cost of the hybrid drive is again likely to be higher than the cost of a mechanical drive.

Be Advised: Batteries Are Consumables. Of course batteries do not last forever. Battery choices include lead-acid, advanced glass mat, gel, nickel metal hydride, and lithium ion. For most operators, the lead-acid or advanced glass mat battery is still a very competitive battery candidate for a hybrid ship, but a lead-acid battery can only survive approximately 1,000 charge/discharge cycles. Eventually it reaches a point where it no longer holds a useful amount of energy. We have all experienced this with car batteries at times (usually whenever the weather is least pleasant).

Plugged In

In some applications, people speak of "plug hybrid" vehicles. These are vehicles wherein the power accumulator can be charged by plugging the vehicle into the electrical grid.

This may be thought of as a way of getting a "free tank of gas" by storing a full charge of energy without using the ship's engine. Of course, this is not free, but it is probably less expensive than producing the energy onboard.

It is also possible, depending on the route, that the morning charge could be large enough to permit a substantial reduction in the size of the onboard engine, with attendant weight and cost savings. At present, however, this technology is only suitable for very small vessels on very short runs.

As a result, while a hybrid drive may reduce fuel consumption, and this can benefit your bottom line, it will also lead to increased battery consumption. You should make the appropriate financial provisions for this in your operating budgets.

When Does a Hybrid Make Sense?
So what's the bottom line? Is the hybrid a good idea? Are all ships going to be hybrids in the next decade, or none of them? Well, as always, the answer is "it depends."

Hybrid drives are not suitable for all applications. A hybrid drive is a specialized means of optimizing a propulsion system, and, like any propulsion optimization effort, it depends upon the specifics of the vessel, the operation, the regional availability of resources (fuels), and myriad other concerns. An individual cost/benefit analysis is a must.

The best place for a hybrid drive is in an application with a varied duty cycle, such as a vehicle that has many different levels of power demand during its day. Consider the following examples:

- A commuter ferry like those in Puget Sound or San Francisco Bay. In these cases the ferry runs are between 30 and 60 minutes long, and turnaround times are fairly short. There is not a lot of stop-and-go content to the service, as they operate only between two ports.

This type of operation is probably not suited to hybrid drive. We studied hybrid drive for the San Francisco Water Transit Authority and found that, for their nominal 45-minute runs, a hybrid drive would actually result in increased emissions, compared to a clean diesel installation. This is because the weight increases associated with hybrid drive resulted in reduced passenger

I have a hybrid electric drive on my recreational vessel. A few years ago, I "repowered" from one generator to another in one day by doing nothing more than lifting the old one off and placing the new one on and plugging it in. Had I performed a similar upgrade with a diesel it would have meant hours of fiddling with motor mounts, alignments, and other matters.

One of the more humorous results of using hybrid electric drive: I don't know where the fuel docks are in my area. When a transient boater asks me where to find fuel, I have to shrug and say something like, "I don't know. I don't use it, myself."

—Chris McKesson

capacity on the ferry, so that the fuel burned was moving fewer people, and the increases in fuel efficiency were not sufficient to compensate for this.

- A water taxi. This might be, in some ways, the opposite of the commuter case. Here, we envision a small-capacity boat making short hops between many closely spaced locales, with passengers hopping on and off frequently. Such services exist in New York, Fort Lauderdale, and Victoria, B.C., among other places.

The water taxi may, depending on the route, spend as much time idling at the dock as it does underway. In fact, the National Park Service's Arizona Memorial taxis in Pearl Harbor spend more time at idle than underway. These services are ideal for hybrid drive. A quite small generator can be used, which might have a power output as little as one-fourth of the propulsion motor power. As explained above, this little generator runs at full output the whole time, and the power is stored in batteries for use when the taxi "sprints" to its next destination.

Twin Seimens propulsion motors joined together in a combining gearbox. The propeller shaft emerges to the right.

- Escort tugs. These tugs use an extreme, newly emerging application of hybrid drive. In this application, there is a lot of horsepower that is rarely used. The tug spends much of its time merely being "available" to a ship, and then providing a significant push for a short time as part of harbor maneuvers. In such a case, it makes little sense to have a 5,000 hp engine running at idle just to lean on it for five minutes out of the hour. Instead, the hybrid tugs use a substantial battery bank and two small generators that feed the battery bank.

Another situation where a hybrid makes sense is where there is a substantial amount of shore power available. This could apply to a vessel that makes only one or two harbor cruises a day, or a vessel whose turnaround time is so long that it makes sense to plug in and charge up at each dock call.

In the most extreme case, this vessel could have no onboard engines, and be entirely battery-powered. Alternatively, we might want some onboard generating capacity, but this would be used primarily for ship service purposes or to power an electric galley, and the ability to cross-connect to feed the power into the propulsion plant would be only a backup or "casualty" mode, with the boat running on batteries 99 percent of the time.

Hopefully, we have painted the picture that a hybrid drive can have substantial attractions, but that it is also a complex system that needs to be well tailored to the particular application of the vessel.

Given the number of variables and areas for optimization presented by the hybrid concept, it is very important to approach it as an integrated, comprehensively engineered solution. It is too easy to collect a few good parts, but assemble them in a non-optimized or non-marinized system, and end up with a disappointment.

Of course, this is true of any of a ship's engineering systems, but the complexities and opportunities of hybrid drive make it all the more important in this case.

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