The Foss Low Emissions Hybrid Tug: From Innovation to Implementation

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ABSTRACT

This paper presents the world's first hybrid tug, a 5,080 horsepower harbor tug built by Foss Maritime Company at its shipyard in Rainier, Oregon. The tug, named *Carolyn Dorothy,* is owned and operated by Foss Maritime Company. This paper discusses the impetus behind the innovation, the evolution of the idea into a workable concept, and its implementation and construction. The hybrid system and its application in harbor assist work will be presented, illustrating how the hybrid system achieves significant reduction in emissions and fuel consumption while maintaining the high performance standards of her sister Dolphin-class tugs.

1. MOTIVATION

Foss Maritime Company has a stated, written and continually reinforced set of core values centering on the safety of our people and stewardship of the environment. Our business model at Foss incorporates the principles of sustainability through the triple bottom line of people, planet and profit.

Some of the key tenants of our environmental policy are a commitment to operate our business based on responsible management through continuous improvement in our environmental performance and efficiency in our use of natural resources, both renewable and non-renewable.

Foss has a long tradition of technological innovation and creative problem solving. It is therefore only natural that we would apply these attributes to environmental solutions in our industry. We feel environmental issues constitute one of the biggest challenges to our industry and will continue to do so for the foreseeable future. Foss is committed to participating in the development of sound policies and solutions to environmental problems within our industry. The development of this ground breaking tugboat was not driven by regulatory requirements or governmental mandates. It is rather the culmination of a concept that began at Foss and succeeded because our commitment to the environment is rooted deeply in our culture.

2. CONCEPT

Hybrid technology seemed an elegant solution to reduce air emissions through increased efficiency and lower fuel consumption. In a hybrid design, fuel usage is optimized, and the fullest benefit of the hybrid design is achieved as the vessel spends more time at low power. Because our tug assist business has attributes of "hurry up and wait", many of our ship assist tugs spend the majority of their time at low power or idle. However, when a tug needs full power it needs that power available in an instant.

A hybrid system is composed of electric and mechanical power sources with batteries playing a vital role in energy storage. The key to the design was finding the right combination of motor generators, batteries and diesel engines to provide the horsepower required by our customers and pilots to fit within the compact platform and weight limitations of a tugboat.

We had the choice of either retrofitting one of our existing tugs to hybrid or incorporating the hybrid design into a new build tug. Foss has successfully delivered nine Dolphin class tugboats, all built at the Foss shipyard in Rainier, Oregon. We decided to make a Hybrid Dolphin because of the flexibility that a new-build allows, as well as the fact that we build these Dolphin tugs in our own shipyard and would therefore have the ability to closely monitor and control the building process.

The Dolphin tugs are our newest design type. They are Robert Allan designed tugboats 78 ft in length, 34 feet wide with 5,080 horsepower and 60 tons of bollard pull.

Of course, once we decided on a course of action we needed to keep within the boundaries of certain parameters in order to achieve our goals while keeping costs and engineering to a minimum. The Dolphin is small and very powerful for its size. We did not wish to incur additional expense by changing the hull design and we needed the equipment to fit within the confines of what is a quite small engine room. We needed to retain at least the same redundancy as with a conventional tug and, indeed, the hybrid has increased redundancy. We also knew we had to deliver the same horsepower and bollard pull as a conventional Dolphin tug.

3. HARBOR TUG DILEMMA

Foss currently has two Dolphin tugs operating in San Pedro harbor. Engine data from one of these Dolphin Class tugs, operating in San Pedro harbor, was logged daily from October 26 through November 25, 2006. A total of 24 files were recorded with up to 12 hours of engine data per day. Data was recorded at 0.25 second intervals and included throttle settings, RPMs, fuel burn (GPH), engine load, and exhaust temperatures. The data collected from Dolphin-class tugs show that these boats spend up to 60% of their time at less than 20% power, and fully 95% of their time at less than 67% power. Although the main diesel engines are sized to satisfy the tug's maximum thrust requirement, they operate at substantially lower loads most of the time.

The engines operate at very low power most of the time, but the engines are designed to produce the high power levels necessary for hard pushing and emergency situations. The average percentage load on the main engines during the 24-day monitoring period was a remarkably low 16% overall. This means that these harbor tugs spend the majority of their time at the very low end of the engine's power curve. There are times when the tug needs almost its full horsepower but it tends to be for very short periods of time.

Tug operations require that the boats be able to move without the delay of starting a main engine. They must also always have electrical power available to meet hotel loads. Accordingly, both main engines, plus at least one diesel generator, run constantly when a boat is away from its dock.

Because main engines are designed for high output, that's where their specific fuel consumption and emissions controls are most efficient. Off-design operations reduce emission control effectiveness and overall engine efficiency. The result, from a fuel and emissions efficiency point of view, is that the engines run well off their peak performance most of the time.

This is important because it means the engines are not running at optimum efficiency. Emissions are directly related to the amount of fuel consumed and to the efficiency of the combustion. In the hybrid there is the double benefit of reduced consumption and more efficient combustion because the main engines run at peak efficiency. The specific fuel consumption, or gallons per horsepower hour, is much higher when the percent load on the engine is low. To summarize the dilemma, a typical harbor tug has highly variable duty requirements but a very inflexible power plant. This results in inefficiency, higher costs and negative environmental impact.

4. HYBRID SOLUTION

It was important for Foss to find a technology partner who understood our need for redundancy and fail safe operations. We found that partner in Aspin Kemp and Associates (AKA) and their affiliate XeroPoint energy. This company has extensive experience in marine electrical engineering and has successfully delivered hybrid and advanced energy solutions for the marine environment.

The design uses lower horsepower main engines than a conventional tugboat, one way of lowering emissions. Another even more important aspect of the design is that the tug will have four operating modes to take advantage of the fact the tugboats generally operate at the lower end of the total power curve. By utilizing the full horsepower for only short durations, the main engines are used a small percentage of the operating time. The majority of the time the tug will be utilizing only the motor generators and batteries.

The hybrid boat uses a combination of smaller main diesel engines and larger diesel-generator sets (as compared to a conventional Dolphin), main shaft-driven motor/generators, batteries, and state of the art power conversion and control technology. The boat can operate in direct-diesel, diesel-electric, and electric configurations.

The hybrid tug provides the same high power and bollard pull as a conventional tug, but uses a power management system that keeps the engines running at or near their design points when needed, and shuts them down when they're not required.

Typical for a hybrid design, the system takes advantage of duty cycle variability to provide a significant increase in plant efficiency. The design uses on-board energy storage to ride through load fluctuations that exceed the on-line capacity of the conventional power sources. The plant's Energy Management System (EMS) uses power sources in the most efficient configuration possible to meet propulsion and auxiliary needs and recharge the batteries.

The hybrid solution achieves the benefits of no unnecessary engine idling and attendant fuel wastage and engines running at or near their best efficiency. The minimized engine use also achieves reduced operating and maintenance costs.

Clean Technology 2009, www.ct-si.org, ISBN 978-1-4398-1787-2

5. HYBRID PLANT CONFIGURATION

The hybrid tug has two conventional main diesel engines, connected to Azimuthing Stern Drives (ASDs). Propulsion Motor/Generators (M/Gs) are fitted between the main diesels and the ASDs. The M/Gs function either as motors to provide propulsive power to the ASDs, or as generators providing electrical power back to the system.

The Green Assist™ hybrid boat has two diesel generator sets (auxiliary generators) to supply electrical power for propulsion, hotel services for the boat, and to charge the batteries as needed. One or both auxiliary generators can provide propulsive power. The number of generators in operation is determined by the demands of the propulsion system and hotel loads. In the event that these loads exceed the generators' capacity for a period longer than a predetermined limit, the system will automatically change machinery configuration and start the appropriate additional diesel(s) to deliver the required power. Energy for riding-through transient demands will be provided by the storage battery.

A conventional tug has, essentially, two operating modes – shut down and running. In the "running" mode, there are only three plant configurations in general use: main engines plus starboard, port, or both auxiliary generators. In practical terms, this comes down to a single running *propulsion* configuration: both main engines, all the time. Because the hybrid tug uses auxiliary generators and batteries as sources of propulsion power and has vastly increased flexibility in machinery configuration (including for example, the ability to allocate power from one main engine to both propellers equally), it has many more possibilities. There are thirty-two possible combinations of battery, auxiliary generators and/or main engines. In practical terms, the EMS uses fifteen of these in the running condition – an order-of-magnitude increase over the conventional situation.

6. POWER BANDS /READINESS LEVELS

The hybrid incorporates four **"Power Bands"** and four **"Readiness Levels"**. Power Bands are defined by the amount of power available to meet propulsion and auxiliary loads; the upper and lower limits of each band are expressed as percentages of full power. But, because the power available at any given time depends on the particular configuration of the propulsion and power plant, it is necessary to define what is meant by "full power" for a hybrid plant.

Full Power is defined as the full rated power available with two main engines and two auxiliary generators operating at 100%, with battery assistance.

Full Power for a Hybrid Dolphin is 5080 hp – the same as for conventional Dolphins.

The settings for each band reflect the relevant duty requirements and operating scenarios that crews can reasonably expect in the run of a day. Established from our reviews of vessel operations, engine operating data and history, boat activity logs and discussions with captains/engineers/crew and port engineers, the bands are designed to avoid unnecessary engine starting and stopping and excessive battery depletion and cycling.

The operator chooses one of the readiness levels "Stop", "Transit" or "Assist". The "Battery Recovery" level is a limitation on full power that is imposed automatically by the system under conditions when the battery's state of charge is below its minimum level. Unless the plant is in either the "Stop" or "Battery Recovery" state, full power (5080 hp) is always available.

Effectively, the use of readiness levels provides the plant control system with an advance warning of the operators' intentions. The captain can reduce vessel readiness to eliminate wasteful engine idling when a quick reaction standby capability is not really needed. For example, when the tug is standing by without imminent ship assist duties, the operator will select "Transit" level. In this situation, diesels are not required for current propulsion needs, so they remain shut down. However, when the tug is standing by during a ship assist job, the operator will select the "Assist" level, so that both main engines are always running, giving instant access to power when it is needed.

7. COSTS AND BENEFITS

The primary motivation for this tugboat is to achieve emission reductions. Current diesel engines have inefficient combustion at the low power levels tugboats actually operate in most of the time. Because of the efficiency achieved at the low power, the emissions benefits of the hybrid tug are expected to be greater than the fuel savings alone. Emissions benefits are estimated to include a reduction from the conventional Dolphin tug of 44% NOx and 44% PM. The other fuel pollutants such as CO_2 and SOx should reduce proportional to consumption. The fuel savings are estimated to be in the range of 20-30%.

This Green Assist™ hybrid tug design won an USEPA Clean Air Excellence Award for Air Technology. Foss Maritime Company was the first marine operating company to win this prestigious award.

The primary financial benefits of the design are accrued through fuel and lube oil savings and reduced life cycle and maintenance costs of the major equipment components. For example, because the main engines are off-line the majority of the time, the time span between engine overhauls is increased.

The hybrid tug design is capable of taking advantage of future energy storage improvements, whether in battery technology, hydrogen fuel cells or any other emerging technology. While all Foss tugs have the capability to utilize shorepower while at the pier, the hybrid tug has the potential for even further emissions reduction by utilizing shorepower not only for hotel loads but also for recharging batteries. The hybrid tug will also have the capability of utilizing biodiesel fuels. Another potential advantage of the hybrid tug design is that the boat could be fitted to act as a mobile generating station as a planned event or in an emergency.

It is important to point out that the emissions benefits and fuel consumption savings are dependent on the duty cycle which differs depending on the operation. San Pedro harbor is an ideal place for hybrids because there are short transit runs and a considerable amount of idle time. Although there are still benefits for applications such as ocean towing boats they are not as great because these boats tend to run at higher horsepower for longer periods of time.

Because of the hybrid tug's flexible design, the concept can be applied as a retrofit technology for existing tugboats. The combination of generators, batteries and mechanical power will vary with each tug but all harbor services tugs are candidates for retrofits as well as future new-builds.

The flip side of the operational cost benefits is increased capital costs. Of course the first application of any new technology bears the burden of higher engineering and design costs. We do expect that the costs of hybrid technology for tugboat applications will decrease over time as this technology is more widely adopted.

We are very fortunate that the ports of Long Beach and Los Angeles decided to financially support our efforts. We are grateful that the ports have recognized the value of the project and in recognition of their generous support Foss has agreed to operate this hybrid tug in San Pedro Harbor for a period of 5 years. The contributions from the Ports certainly help but do not cover the entire incremental costs of the project. These costs are borne by Foss. The quantifiable benefit of the emissions reduction is difficult to calculate in terms of dollars but reducing our emissions footprint does have great value to us as a company.

8. CAROLYN DOROTHY

The Foss shipyard in Rainier, Oregon completed construction and successfully launched the hybrid tug in November 2008. This tug has been christened the *Carolyn Dorothy* and underwent sea trials in December 2008. The results of these trials proved that the *Carolyn Dorothy* has met or exceeded all expectations.

This tug is also the first tug in North America to receive a "Green Passport" certification from Lloyd's Register. This program stems from the International Maritime Organization guidelines on ship recycling.

The tug has been operating in San Pedro harbor providing Green Assist™ to vessels entering and leaving the Ports of Los Angeles and Long Beach since January 2009. The *Carolyn Dorothy* is not a concept vessel-it is a working tug in one of the busiest harbors in the world. At Foss we are focusing on currently available practical solutions that can be applied to boats currently in service or under construction.

We believe that this low emissions tug is a significant technological advance for the tug and barge industry. It is our hope and expectation that the success of the *Carolyn Dorothy* will mark the beginning of a new trend in our industry, but for us it is a natural progression of our continuing efforts to reduce our emissions profile.

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