BY PETER MARSH

The new Foss Maritime Co. Dolphin class diesel-electric hybrid tugboat *Carolyn Dorothy* was recently delivered for use in the United States ports of Long Beach and Los Angeles. The primary motivation behind the project was achievement of emission reductions and improved efficiency by optimizing the propulsion system to the unique load profile of a tugboat's application.

Hybrid Tug Addresses Operating Profile Dilemma

Advanced propulsion system design to significantly reduce emissions

When Foss Maritime Co. announced in 2007 that it would build what was reported as the world's first hybrid tug for service in the ports of Los Angeles and Long Beach, it made headlines throughout the maritime world. The two southern California harbors, the United States' leading container ports, embraced the vessel as a welcome addition to the San Pedro Bay Ports Clean Air Action Plan. There was more than just moral support as the Port of Los Angeles pledged US$850 000 to the vessel's construction, in association with the South Coast Air Quality Management District, and the Long Beach Harbor Board approved a US$500 000 contribution.

Ship-handling tugs are excellent candidates for hybrid systems since they only need full power for short periods of time while actually assisting ships. The majority of the time, they are only using a small fraction of their maximum power while escorting ships or standing by.

The primary motivation for this project was to achieve emission reductions. Emission benefits are estimated to include a reduction from the conventional Dolphin class tug of 44% NO_x and 44% PM. Other pollutants such as CO_2 and SO_x should be reduced proportionally based on fuel consumption. The vessel was based on Foss' 23.7 m Dolphin tug, designed by Robert Allan of Vancouver British Columbia, Canada.

The diesel-electric hybrid tug is the 10th hull built to this design at the Foss shipyard in Rainier, Oregon, U.S.A. Now named the *Carolyn Dorothy*, it was launched in December 2008, moved to Seattle, Washington, U.S.A., for commissioning and trials and was unveiled in Los Angeles in January.

Rick McKenna, project manager for Foss, explained how the hybrid concept came together. The Foss Engineering Group had researched the hybrid systems of rail yard shunting locomotives. They found these did not match the load profile of a harbor tug, especially because of the huge weight of the batteries. Searching for an alternative, Foss contacted Canadian engineering company Aspin Kemp and Associates (AKA).

AKA had extensive experience in marine electrical engineering and had successfully delivered hybrid and advanced energy management systems for ultra-deepwater oil-drilling rigs that are held in position with dynamic-positioning thrusters.

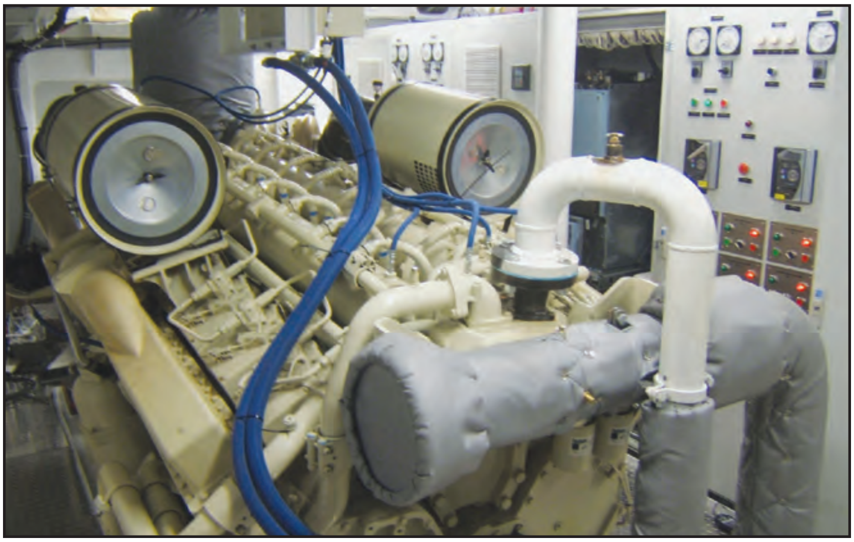
AKA's engineers designed a method of running a diesel engine and an electric motor/generator on the same thruster drive shaft. "It was AKA who took us away from using a battery-centric system and going with a system that employs a mixture of main engines, generators, motor/generators and batteries," McKenna said.

AKA and its affiliate XeroPoint Energy proposed a design based on their "Quanta" hybrid technology, customized for the operating profile of the Dolphin tugs already used in the Southern California ports, based on the engine operating data.

The Xeropoint system addresses the harbor tug dilemma of power usage. Instead of idling the main engines all day while in standby mode, the hybrid tug will run on battery power with the main engines shut down. The majority of the time the tug will be utilizing only the diesel generators and batteries to provide the boat's electrical needs and turn the propeller shafts.

This approach is powered with three independent power sources.

Peter Marsh is a freelance writer based in Astoria, Oregon, U.S.A.



A view of one of the two Cummins QSK50 main diesel engines; each produces 1342 kW at 1800 r/min. In this hybrid system, these engines are used to power mechanical drive propulsion system as well as recharge the batteries. In the background is the housing for the power management system, which fills the center of the engine room.

These are the two main engines turning the propellers via shafts, two 330 kW generators and a bank of 126, 12 V, marine deep-cycle gel lead-acid storage batteries. Both the gen-sets and the batteries turn the shafts via two 746 kW electric Siemens shaft motor/generators, co-located on the main propeller shafts, with Ortlinghaus clutches on both ends.

AKA calculated that when the output was combined, these three power sources should produce the same 3788 kW maximum power as the conventional Dolphin tugs, giving a bollard pull of 60 tons.

To create the hybrid tug, the design and engineering was divided between Robert Allan Ltd., responsible for modifying the engine room layout to accommodate the different equipment, and AKA, responsible for the design, implementation and testing of the hybrid Energy Management System (EMS). AKA was also responsible for the procurement and manufacture of the major EMS components. Foss was responsible for the re-engineering of the physical boat plant, the purchase of all the engines and z-drives, the construction of the boat and the installation of the equipment.

Compared to the standard Dolphins, the most visible changes in the engine room are the energy management system housed in a large switchboard cabinet next to the starboard main engine, the battery bank, housed on shelves in a new compartment on the forward engine room bulkhead, and the large electric shaft motor/generators. The battery bank is split in half, giving two equal outputs of 760 V that are stepped up to 1000 V.

The twin Cummins QSK50 main engines each produce 1342 kW at 1800 r/min. The drive shafts and couplings were provided by Centa. The Rolls-Royce Aquamaster US 205 ASD units are located in a water-tight compartment in the stern. They have a built-in reduction gear of 6.67:1, reducing the 1800 r/min shaft speed to 270 r/min at the propellers. The units are supplied complete with a 2.4 m diameter four-bladed propeller and duct.

Each of the twin Cummins QSM 11 generator sets produce 300 kWe and are capable of running at 10% overload for short periods. They produce 480 Va.c. current that is used for both ship's service at the 480 V bus, and is transformed to 690 and 1000 Vd.c. to drive the shaft motors and two winches on deck.

The tug can operate in direct-diesel, diesel-electric and electric configurations and has a total of 32 possible combinations, 15 of which are used in normal running conditions. However, there are only four operating modes, which are seamless to the operator: Minimal Emission, Eco-Cruise, Mid-Range and Full Power.

The Minimal Emissions mode is for inactive periods while secured, but not connected to shore power or while stopped at sea. The typical configuration in this band is with batteries providing the power for the boat's service needs, and minor maneuvering and propulsion via the motor/generators. In this mode, an auxiliary generator will come on as needed to recharge the batteries. This mode is effective for minimal duration transiting at up to 4 knots.

The Eco-Cruise band provides the capacity for continuous slow transit and low power work such as barge moves. A typical configuration is one or both auxiliary generators on, providing power for propulsion via the motor/generators as well as the boat's service needs. The battery storage can provide temporary ride-through of transient demands. This improves the efficiency of the generators by bringing their load into the optimal range. This mode may also have one main engine online providing mechanical power to its shaft as well as augmenting electrical power via its motor/generator acting as a generator. This mode is effective for continuous transiting at up to 8 to 10 knots.

The Mid-Range band provides the capacity for continuous fast transit and a high percentage of ship-assist scenarios where maximum continuous load does not exceed 46% for extended periods. The typical configuration is two main engines, or when required for battery recovery, main engines and one or both generators.

The Full Power band provides the capacity for continuous fast transit and full power ship-assist requirements. Typical configuration is two main engines plus two auxiliary generators. Battery-stored energy is available to reach full power and to meet transient demands.

Full power is defined as the full rated power available with two main engines and two auxiliary generators operating at 100%, with battery assistance at the 15-minute discharge rate. Based on data downloaded from the standard Dolphins, 65% of the time is spent in the Minimal Emissions band, 13% of the time is spent in Eco-Cruise, 15% in the Mid-Range and 7% in Full. So overall, the hybrid tug will be much quieter than traditional tugs.

The use of readiness levels provides the plant-control system with an advanced warning of the operators' intentions. The captain can reduce vessel readiness to eliminate wasteful engine idling when a quick-reaction standby capability is not needed. These levels include stop, transit, ship assist, battery recovery and shore power charging.

At the stop level, the vessel is in a shutdown condition and does not require any onboard power sources. This level is used during crew changes, when shore power is available.

The transit level is used for moving the boat from place to place and when standing by for orders. Typically, the vessel is under way, but is not required for ship-assist duties at the present time. At this level, the operator is usually operating in the Minimum Emissions or Eco-Cruise power bands.

In the ship-assist level, the vessel is ready to perform ship-assist duties. Both main engines are always running, no matter what power band of the boat's operation.

In battery recovery, the batteries are nominally rated at 450 kW for 15 minutes, and will power the tug at low speeds up to 4 knots for approximately 30 minutes. All four engines are able to provide battery charging, propulsion and auxiliary power requirements. However, the system is designed to use the batteries, mainly when the tug is stopped in the water and only needs power for ship's service and minor maneuvering.

During shore power charging, the 150 Amp shore power plugs into the ship's service bus, through which it can recharge batteries. The EMS monitors the process and slows down the charging rate to a trickle as the batteries approach full charge.