Energy Control Technologies
on the *Queen Mary 2*

Courtesy: Cunard Lines

With her maiden voyage across the Atlantic in early 2004, Cunard Lines' *Queen Mary 2* became the largest and most expensive passenger ship yet to enter commercial service. Designed especially for ocean liner service, the *Queen Mary 2* is powered by an advanced CODAG (combined diesel and gas turbine) electric propulsion system that provides the high power output required for trans-Atlantic crossings throughout the year.

"*QM2* is resplendent with grandeur and elegance," noted *The Motor Ship* (Jan. 2004) "while at the same time featuring contemporary style and amenities and the latest technological innovations." Among those innovations is the application of Woodward energy control technologies on both the engine and turbine power plants.

Propulsion System

The *Queen Mary 2* is powered by four Wärtsilä 16V46D-CR EnviroEngine medium-speed diesel engine generators having a combined output of 67.2 MW, supplemented by two GE LM2500+ gas turbine generators having a combined output of 50 MW. The engines and turbines provide electric power for all shipboard services, as well as propulsion through four electrically driven podded drives.

Running on heavy fuel oil, the diesels alone can drive the ship at cruising speeds up to 24 to 26 knots. With the addition of the gas turbines running on marine gas fuel oil, the ship can cruise at speeds up to 30 knots.

The four diesel engines are located on the lower decks, while the gas turbines are located in a machinery house beneath the funnel.

Type of Plant

Combined Diesel and Gas Turbine electric propulsion

Prime Movers

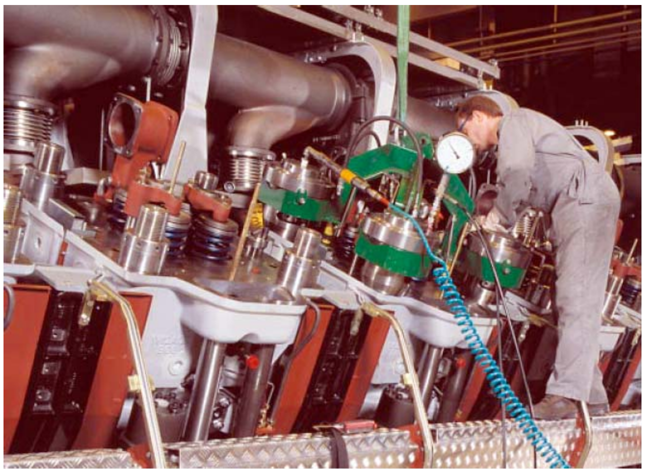
- Wärtsilä 16V46D-CR diesel engines (4)
- GE LM2500+ gas turbines (2)

Woodward Energy Control Technologies

- Woodward LCR common rail fuel injection systems (4)
- 723 digital engine controls (4)
- Custom GAP™ application software
- MicroNet™ digital turbine controls in redundant configuration (4)
- Networked HMI stations (4)
- 1907 liquid fuel valves (2)
- Digital Speed Matching (DSM) synchronizers (2)
- Real Power Sensors (2)

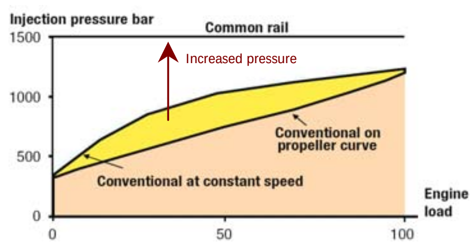
Common Rail Fuel Injection for Smokeless Operation

Development of the Wärtsilä EnviroEngines arose from a joint project with Carnival Corporation, the parent company of Cunard Line, to develop a new "earth-friendly" power system. The Wärtsilä 46 EnviroEngines use a Woodward electronically controlled common rail fuel injection system.

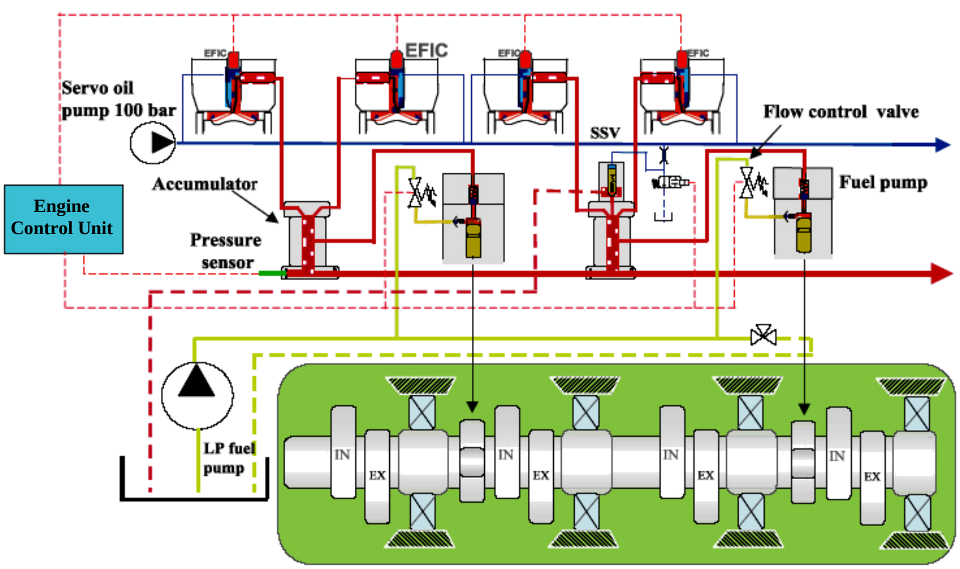


Courtesy: Wärtsilä

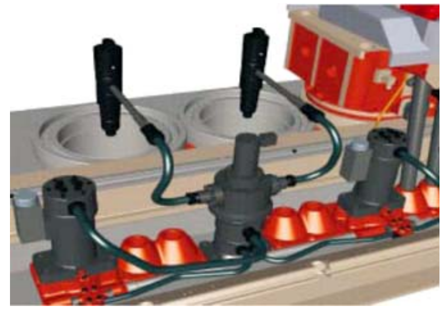
"Developed by Woodward specifically for heavy-fuel medium-speed engines," writes *Diesel & Gas Turbine Worldwide* (March 2004), "the common rail system enables injection pressure to be kept sufficiently high at all engine loads to achieve smokeless operation."



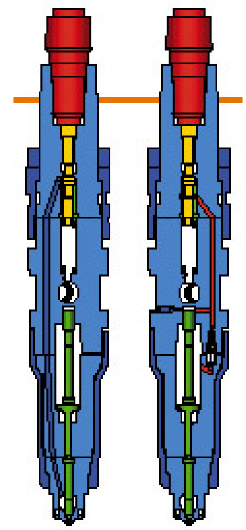
Smokeless operation is particularly beneficial when the ship is in port, as the engines can run lightly loaded to produce electric power for lighting, air conditioning, and other hotel loads.



The Woodward LCR (large common rail) fuel system is modular, with sub-systems designed to serve engines with from four to 18 cylinders. The system is based on a camshaft-driven high-pressure pump and an accumulator for every two cylinders. The accumulators are connected together by the common high-pressure fuel rail, and connections from every accumulator feed the injectors of two cylinders.



Each cylinder has a solenoid-operated fuel injector that is electronically controlled to match injection pressures, timing, and profile to the speed and load of the engine. Combustion is optimized under each loading condition to minimize emissions and smoke, and increase engine fuel efficiency.



Pressurized engine oil is used in the injectors to generate the necessary forces for high-pressure injection. This injector design is capable of operating at fuel pressures of 2000 bar, while providing crisp injection starts and stops.

The engine camshaft has two lobes, located 180 degrees apart, to drive each pump. Optimized to drive the common rail pump, the lobe profile is considerably less aggressive and less expensive to produce than that required by a conventional jerk pump, which must fuel the injector completely in only a few microseconds. The result is reduced mechanical drive noise and drive energy consumed.

"Functionally," says *Marine Propulsion & Auxiliary Machinery* (Nov. 2003), "the main reason for choosing such a system is that by splitting up the fuel volumes in several accumulators, the risk of pressure waves in the common rail is avoided. From a safety viewpoint, an advantage is that high-pressure fuel exists only in the same area as in a conventional engine (in the hot box.) A third merit cited is economic, the system using a camshaft that is present anyway to drive the gas exchange valves."

To maintain high efficiency, fuel flow is controlled on the suction side of the pump by an electronically controlled flow control valve.

Operation on heavy fuel oil presents special challenges to a fuel injection system, but Woodward's LCR design incorporates a number of features to handle HFO. Among these is the stop/safety valve (SSV), which allows heated HFO to flow continuously through the piping systems when the engines are stopped. Also, the fuel injectors use servo oil in the solenoid armature area, rather than HFO.

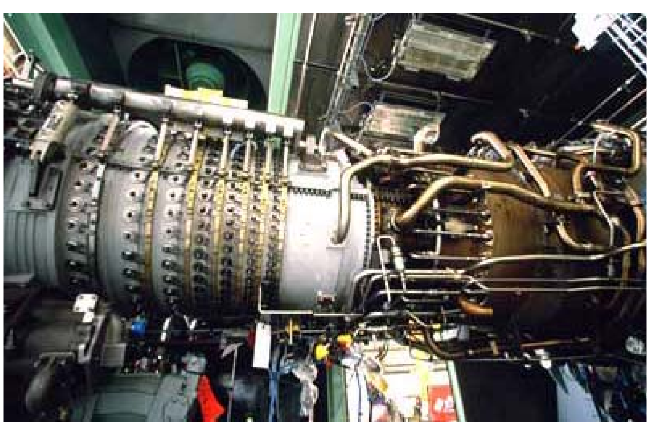
In this application, the common rail system is controlled by a Wärtsilä WECS engine control system, while speed and load sharing is handled by a Woodward 723 digital control hardware and GAP™ application programming software customized specifically for Wärtsilä. The WECS system controls fuel pressure in the rail, and injection quantities and timings according to specified maps.

For other applications, Woodward offers the powerful, new In-Pulse™ II control, which combines electronic fuel injection control and advanced speed control into a single, engine-mountable hardware platform.

QM2 is the sixth ship equipped with Woodward LCR technology, and LCR systems are planned for three ships under construction, including the 290 m long *Queen Victoria* cruiser being built for Cunard Lines.

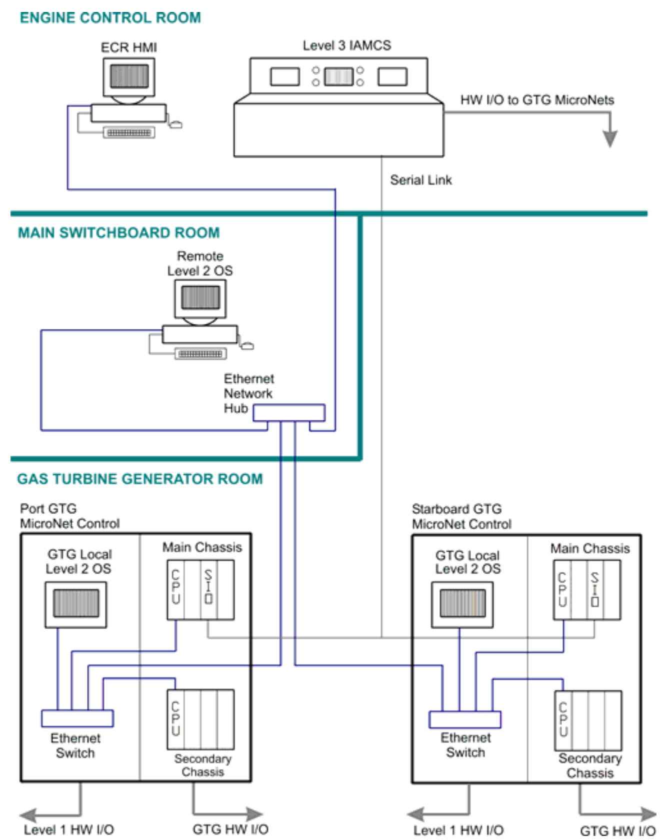
Advanced Digital Control for Marine Gas Turbines

To achieve top speed, the diesel engines on the *QM2* are supplemented by two GE LM2500+ gas turbines, produced by GE Marine Engines and packaged by GE Energy. GE designed the two LM2500+ packages to be some 35 tons lighter than previous LM2500+ marine gas turbine installations.



The 40,500 shaft horsepower LM2500+ is GE's newest aeroderivative gas turbine. Based on the design of the GE LM2500, this machine delivers up to 25% more power at a simple-cycle thermal efficiency in excess of 39%. It is designed to achieve reliability equal to the 99.6% reliability of the LM2500. The LM2500+ gas turbine's high efficiency, reliability, and installation flexibility make it an attractive choice for a wide variety of marine power generation and mechanical drive applications.

The LM2500+ gas turbines are equipped with Woodward MicroNet™ digital controls, which provide engine fuel management, package sequencing, and condition monitoring, as well as the communications interface with other relevant shipboard systems. For the *QM2*, the MicroNet controls are set up in a redundant configuration, with a secondary MicroNet chassis serving as a hot backup control the case of failure of the primary unit.



As in other commercial marine applications, the MicroNet controls on the *QM2* use an aggressive control algorithm developed by Woodward especially for gas turbine-powered cruise ships, giving the gas turbines the responsiveness needed to meet the load acceptance and rejection requirements of the classification societies.

The controls are supplied by Woodward as a total package, including four HMI systems that are networked to allow operation of either or both gas turbines from any of the four HMI stations.

Fuel is metered into the gas turbines with a Woodward 1907 large liquid fuel valve. With its constant-pressure-drop design, the 1907 valve provides accurate fuel metering regardless of variations in discharge or inlet pressures. An orifice and relief valve eliminates bypass damping when a sudden increase in bypass flow is needed.

Power management functions are handled by Woodward DSM digital speed matching synchronizers and Real Power Sensors. The Real Power Sensor accurately measures the real power output of the gas turbine generators. The DSM synchronizes the gas turbine generators by providing speed raise-lower commands to the MicroNet control, and voltage raise-lower commands to the generator voltage regulator

The *Queen Mary 2* order brings the total to 22 LM2500+ and four LM2500 aeroderivative gas turbines operating or slated for service on 17 cruise ships, either in combined gas turbine and steam turbine integrated electric drive systems (COGES) or CODAG arrangements.

Conclusions

Built by Chantiers de l'Atlantique in Saint Nazaire, France, for Cunard Lines, the Queen Mary 2 is one of the most impressive ocean liners ever made. The QM2 has an overall length of 345 m, a beam of 40 m, and a draft of 10 m. She carries 2620 guests and a crew of 1254.

The combined diesel and gas turbine (CODAG) prime mover configuration is critical to the QM2's ocean transport role. The six prime movers on line together can generate 16 MW for the hotel services, plus 86 MW of propulsive effort to achieve top speeds of about 30 knots. The CODAG generating plant provides excellent operational flexibility as well as redundancy in normal deployment.

Integral to the success of the diesel and gas turbine prime movers are Woodward energy control technologies. On sea, on land, and in the air, Woodward's innovative control, fuel delivery and combustion, and automation systems technologies help customers worldwide operate cleaner, more cost effective, and more reliable equipment.

WOODWARD

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