Energy Efficient Gas Propulsion System with Hybrid Shaft Generator

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Several factors are attracting shipowners to specify gas-fuelled ships. Emission regulations are getting stricter with SOX and NOX emissions in the focus. IMO Tier II regulations are now in force, but Tier III will be very much tougher, and the question is how much in the way of additional off-engine exhaust treatment systems will be needed. European and Scandinavian Emission Control Areas (ECA) are now in place, while corresponding ECAs will soon cover the east and west coasts of North America and other parts of the world.
Furthermore the recent implementation of the Energy *efficiency design ind*ex (EEDI) by the IMO has a huge impact on future ship designs and is in many cases limiting the engine size and ship speed of diesel powered vessels.
But the most important argument toward gas as a ship fuel are the unknowns about liquid fuels in future, particularly the price and the availability of ultra low sulphur fuel.

Natural gas as a fuel is a way of circumventing many of the problems. The difficulty has been lack of an infrastructure capable of supplying bunker quantities of the order of a few hundred cubic metres at locations convenient for shipping. This situation is now beginning to change, with ferry operations covering fixed routes with intensive traffic leading the way. Here, demand is known, and suitable supplies can be delivered by truck or ship. RoRo vessels are another early adopter, while shipowners operating offshore service vessels are also beginning to see the point in investing in LNG fuelled vessels for North Sea work. The next few years are likely to see a rapid uptake and corresponding building out of infrastructure for coastal and short sea operations, while classification society DNV has been promoting designs of ocean-going ships based on using LNG for propulsion. In liquefied form, as LNG, natural gas has a high energy density.

Rolls-Royce has invested heavily in gas engine technology and is in a position to provide not only medium speed gas engines, but also the onboard LNG storage and gas supply system to the engines. Rolls-Royce has also developed a variety of ship designs that optimise the use of gas as fuel, maximising engine and propulsion system efficiencies and using hullforms that combine low resistance with maximum cargo capacity and good sea keeping qualities.

Rolls-Royce started to gain experience on gas technology when the company's lean burn Otto cycle technology was developed in the 1980s - applied to the Bergen K-series engines, first launched as power plant gas engine in 1991. No marine market emerged at that time, but several hundred engines were built for land power generation, burning various types of gas, before the recent arousal of interest in LNG as a marine fuel, and the K-series was then adapted for marine application, with launching in 2006.
After four design generations, the K-series has reached its development limit, and has been superseded by the C-series, which embodies all the latest gas engine technology. Test bed trials started in 2010, and the first C26:33 production engine, a nine cylinder in line unit, has now been delivered for the conversion of an existing Norwegian fjord ferry named *Tresfjord* for operation on LNG.

The C26:33 series combines well-proven Rolls-Royce lean burn gas engine technology with the main mechanical components of the C 25:33 diesel engine range. The first-generation engines will be produced with six or nine cylinders in line, and an introductory power range from 1,460 to 2,430kW at 900/1,000rpm.

Like other Rolls-Royce gas engines, the C26:33 is designed for both constant-speed generator set drive and for variable speed mechanical power transmission to a controllable pitch propeller, unlike some gas engines which cannot cope with the load/speed variations of direct propeller drive. It can also be used in a single engine propulsion system, as it includes all the redundancy requirements for this application. The above represents huge benefits and flexibility for shipowners wanting a marine gas solution for their newbuildings.

A further advantage is that it can be installed in accordance with the *gas safe machinery spaces system* configuration as defined by IMO interim guidelines for natural gas fuelled installations in ships.

In the new C26:33 engine CO2 emissions are reduced by 22 % compared with engines burning liquid fuel, NOx emissions are cut by 92%, while emissions of SOx and particulates are negligible. The design of the C26:33 cuts methane slip, more than other marine gas engines available, to very low levels. Bearing the EEDI in mind and considering the fact that Methan has about 20 times the greenhouse impact as CO2, the reduction of CO2 equivalent emissions is still about 20%. Of course the new engine range meets IMO Tier III requirements without any exhaust gas treatment.

The running gear is largely based on the C-series diesel engine but the bore is increased from 250mm to 260mm, giving an increase in cylinder displacement of just over 8%. The upper part of the engine uses spark ignition lean burn technology incorporating experience from the Bergen K and BV gas engines.
A lean gas mixture is supplied to the cylinders by port injection of gas, and a separate richer mixture to the prechamber which is ignited by the spark and initiates combustion of the cylinder contents. Variable turbine geometry in the turbocharger, an advanced control system with individual cylinder knock sensing, variable inlet valve timing and adjustable Miller cycle give full control of power, thermal efficiency and emissions over the whole load/speed range.

For generator drive applications an important criterion is the ability of the engine to accept rapid load changes at constant speed.
An engine driving a CP propeller mechanically sees variable loads, and in the case of the C26:33 can also operate at variable speed, retaining a high thermal efficiency also at low loads and speeds. The *gas safe machinery spaces* requirements are met by making all gas pipes double walled, with the intervening space ventilated and monitored to detect leakage. This means that the engine can be installed as if it were a diesel engine in an ordinary engine room with electric pumps, compressors and other equipment that are not explosion protected, avoiding the cost and complexity of dedicated gas engine rooms.

In 2007 sixteen Rolls-Royce K gas engines went into service in a series of five Fjord 1 double ended vehicle/passenger ferries that form two links in the main E39 road system on the west coast of Norway. Individual engines have now run for around 30,000 hrs giving reliable service in the intensive operating profile of these ferries.
Fjord 1 has now placed an order with Rolls-Royce for C-gas engines for their 6th gas ferry. This includes Azipull thrusters for main propulsion, to provide a service speed of 21 knots to handle the increasing traffic on these routes.
An additional reference is the 70m long vessel being built in Turkey to carry feed to fish farms at numerous locations along the coast of Norway operated by NSK Shipping. LNG has been selected as the fuel, and Rolls-Royce is to supply the complete propulsion system including the C gas engine, the gas system, the hybrid shaft generator and the automation system. This ship will have the first production six cylinder version of the C-series gas engine, rated at 1,620kW, and will take full advantage of the engine's suitability for direct mechanical drive.
Power from the main engine is transmitted through the reduction gear to the CP propeller. The propeller forms part of the Promas (Propulsion and manoeuvring system) with a twisted leading edge flap rudder and bulb in an efficient hydrodynamically integrated system.
The system includes the Rolls-Royce Hybrid shaft generator (HSG). This device is a combined PTO (power take off) and PTI (power take in). In PTO mode the HSG is suitable to supply 1,200kW of electrical power. As a PTI the same machine can also function as PTI to act as a motor supplying 650kW to the propeller for emergency operation.
In general the HSG can be uses as generator, as a "take me home device" or as a booster - making full usage of the fact that the Rolls-Royce Gas engine can be used in a wide shaft speed range. Especially at low ship speeds the engine speed can be reduced so that power consumption decreases significantly whilst the PTO can still be used without the need of using auxiliary engines. Decreasing the shaft speed at low ship speeds furthermore decreases the risk of erosive face side cavitation and reduces the onboard noise and vibration level drastically. Additionally the HSG contributes to reduce under water noise having in mind upcoming regulations that are already discussed at IMO.
As this vessel will operate in Norwegian waters it is important to know that Norway imposes a tax on NOx emissions from vessels in its coastal waters. Part of the revenue goes into a so-called NOx Fund, from which grants are made to support projects that reduce NOx emissions. This fish feed vessel, with its innovative design and efficient propulsion systems with very low NOx emission from its gas engine, is consequently qualified for financial backing.

RoRo vessel owners operating on routes in the North Sea and Baltic, are ordering vessels fuelled with LNG, and Rolls-Royce is there to meet their requirements. Designing ships and designing, engineering and supplying systems complete 'from bunkering flange to propeller thrust.' The very experienced short sea operator Sea-Cargo has ordered two RoRo ships that are currently being built in India. Rolls-Royce is responsible for the overall vessel design, derived from Sea-Cargo's long experience with coastal and short sea shipping, and will supply all the major equipment and systems including main engine, reduction gear, propeller, HSG, bow thruster, rudder and steering gear, automation, and the LNG fuel storage and handling system.
Because the Bergen B35:40V12PG main gas engine is classed for the load/speed operational pattern that comes with mechanical coupling to a controllable pitch propeller, a simple single engine propulsion system is suitable for the Sea-Cargo RoRo vessels - conventional in all but the fact that LNG is the fuel.

Another prominent RoRo shipowner is renewing its fleet, and to meet the requirements Rolls-Royce has developed a new ship design, type NVC-405-LNG, 122m long and 5,000dwt, and currently tenders from shortlisted yards are being evaluated. Natural gas, bunkered as LNG, has been chosen as the fuel. The vessels will carry enough gas in a single cylindrical tank for ten days operation at full load service speed before refuelling, at which point a three day reserve remains. A single Bergen B35:40 gas engine powers the NVC 405 LNG, developing 3,930kW.

Another important business stream is the offshore industry. Offshore vessel operators are now investing in low-emissions vessels, and where a gas supply can be assured there is a strong case for this fuel. The Norwegian shipowner Island Offshore is adding more Rolls-Royce designed and equipped vessels to its fleet, this time with LNG as the principal fuel.
The latest order is for two UT 776 CDG platform supply vessels, incorporating detail improvements from the four UT776-series the company has in service and the further two it has under construction. The new vessels will operate on LNG, driven by two Bergen C26:33 gas engines, with the option of going to diesel oil on their two Bergen C25:33L6ACD generator sets on the same vessel, should gas not be available.

These orders indicate that gas fuel is attractive in practice, not merely a theoretical alternative. On the one hand LNG as a fuel easily fulfils the new emission regulations and is an interesting opportunity to avoid potential disadvantages rising from the EEDI. On the other hand LNG as a fuel is simply reducing operational costs.
The technology is in place, together with a workable regulatory environment, so more shipowners can be expected to go for gas.

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