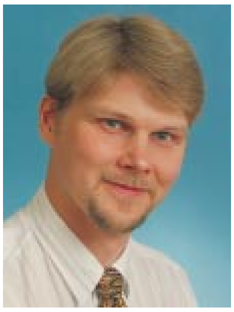
Propulsion systems for future LNG carriers



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The increasing demand to supply gaseous fuel for the needs of more environmentally focused energy production is also affecting the volume of marine transport of gas. A clear need for more Liquefied Natural Gas (LNG) carriers is already evident: 10-12 ships are predicted to be built a year over the next few years compared to the 6-8 ships built every year over the past decade. Furthermore, the need to replace existing capacity will amplify this need – in fact nearly all the gas carriers built since this trade began in the early 1970s are still operational.

The LNG trade has been based on long-term shipping contracts and dedicated fleets of ships sailing on fixed routes and schedules between the rather limited number of LNG terminals in the world. The increasing demand for and supply of liquefied gas has steadily raised the number of spot cargoes and will do so even more rapidly in the future. From the shipping point of view this means that operators are looking for ships with more operational flexibility and efficiency in response to varying contractual situations. This primarily calls for a flexible and efficient propulsion plant able to accommodate different ship speeds and alternative operating profiles.

Steam turbine propulsion dominates in the vessels currently operating in the global LNG carrier fleets. One reason for this is the availability of high power output combined with the possibility to use low-grade fuels. Maintenance of the turbines is relatively low cost and infrequent and the systems are considered reliable. The key issue, however, is the possibility to use the boil-off gas (BOG) from the cargo tanks. The boil-off must be disposed of somehow and the simplest way is to burn it in a boiler. The drawback of the boiler and steam turbine system is the inefficiency, and hence high fuel consumption, of the propulsion plant. In modern LNG carriers the amount of natural boil-off is decreasing due to advances in tank insulation technology and design. Hence the energy in the natural boil-off gas is far from sufficient to produce the propulsion power needed for the relatively high operating speeds. Therefore forced boil-off gas or fuel oil is needed to top up the fuel demand of the boilers, which is yet another argument encouraging shipping companies to look for a propulsion plant with higher efficiency.

The diesel engine has for decades dominated all other sectors of merchant shipping except LNG carriers. The accumulated experience of thousands of propulsion plant installations based on diesel machinery has helped to ensure the successful development of this technology. Meanwhile steam plant development has virtually stood still as there has been practically no market for marine applications since the 1973 Oil Crisis. The recent development of dual-fuel operated diesel and gas engines has made it possible to use the boil-off gas efficiently and therefore propulsion based on diesel engines is a strong option for modern LNG carriers today.

Fig. 1 The LNG Carrier Al Hamra is equipped with one Wärtsilä Vasa 32 engine with an output of 2960 kW at 720 rpm.

Optional propulsion concepts based on diesel and gas engines

When specifying propulsion machinery options for LNG carriers it is essential to consider the differences in operating profiles, fleet configurations and shipping routes. The basic case is a 138,000 m^3 vessel with an operating speed of around 20 knots and a corresponding power required at the propeller of approximately 26 MW. The electrical power required for cargo pumping and other consumers is roughly 6 MW (when electrically driven cargo pumps are used). The available amount of natural boil-off-gas depends on the ship design specification and operating conditions. A natural boil-off rate of 0.15 % per day is typically considered as the design point

nowadays but values as low as 0.10 % have been reported in modern vessels. On the other hand the rate can also be higher in unfavourable conditions. Similarly the gas composition varies during the voyage. The nitrogen content of the boil-off is high at the beginning of the journey and decreases during the trip. This means that the energy content of the gas is not constant, a factor which must be kept in mind when configuring the propulsion system.

When converting the energy content available in the boil-off gas into mechanical power at the flywheel of a modern dual-fuel gas engine, figures ranging from 12 MW in a worst case up to 25 MW in the best situation can be calculated for the laden voyage. In ballast conditions the figures are roughly half of the above. This means that even in the best case the natural boil-off would not be enough to cope with the energy consumption and either forced boil-off or supplementary liquid fuel is needed to make up the shortfall. The selection of the supplementary fuel depends on the result of a feasibility study taking into account not only the operating profile of the ship but also the trends and effects of the unstable oil price as well as the availability of liquid fuel in the vicinity of the LNG terminals.

The following optional configurations have been evaluated to offer the most feasible propulsion plant for modern LNG carriers.

Single-screw ship solutions:

- A single-screw, **single two-stroke main engine** would be the simplest solution. However, this arrangement would not provide any redundancy in case of failure. The use of high-pressure gas as fuel in two-stroke diesel engines has been tested, but further development and design would be necessary to make it commercially available. The biggest obstacle is the parasitic energy consumption of the high-pressure fuel gas compressor and the very complex control system required.
- A single-screw **twin two-stroke** option requires a large gear box and elastic couplings and a CP propeller. The use of high-pressure gas as fuel has the same drawbacks mentioned above.
- A single-screw **twin four-stroke** diesel engine option requires a moderate gear and couplings and a CP propeller. High-pressure gas would be used as fuel in such a mechanical drive. The technology is available and used in marine (offshore) installations. A PTO and shaft generator would probably not be feasible owing to low load in port

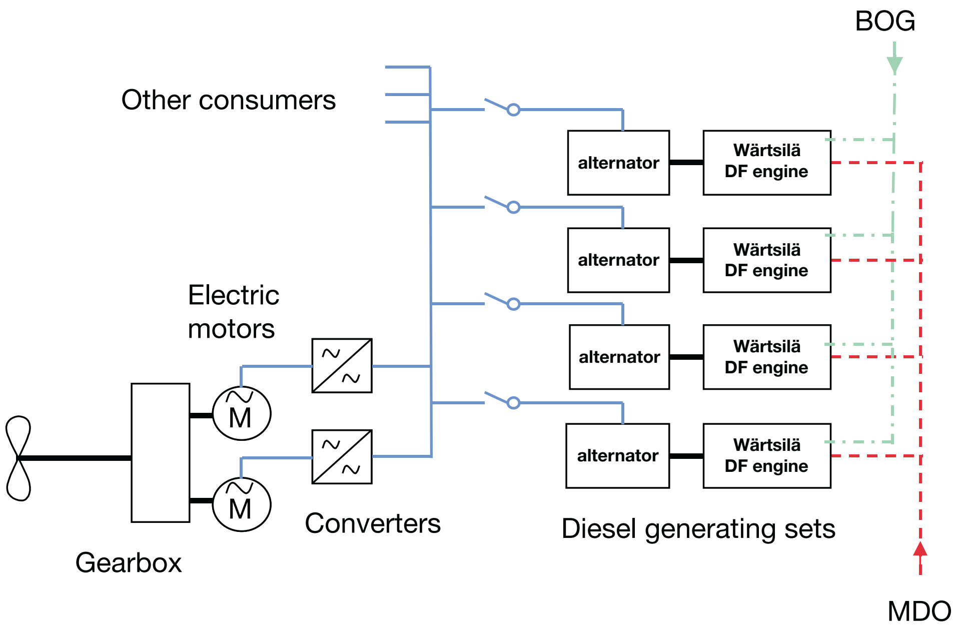

Fig. 2 LNG carrier engine room equipped with four Wärtsilä dual fuel (DF) gas engine electric propulsion system.

for the running main engine (electrical cargo pumps). The drawback of high-pressure gas operation is the same as described above.

- A single-screw **diesel-electric** option with FP propeller may be selected if appropriate redundancy is built into the electric motor or if two motors coupled to a gearbox are used. With electrical cargo pumps one diesel generating set should be sufficient for cargo operation. A feasible choice for the power generation would be a plant with, for example, four 9L46GD high-pressure gas diesel engines. To overcome the problems associated with high-pressure gas operation an alternative solution is to use low-pressure gas operated engines as prime movers. In this case the plant would consist of four 9L50DF dual-fuel lean burn engines, for instance.
- A single-screw **two-stroke main engine with** CP propeller and tunnel gear to enable an electric **booster drive**. Either dual-fuel lean burn engines or high-pressure gas diesel sets can be used (e.g. 3 x 6L46GD or 3 x 18V32GD or 3 x 18V32DF). The tunnel gears and booster drives are available and approved technology. However, the system is rather expensive and complicated.

2. Twin-screw solutions

- A twin-screw diesel-mechanical solution could well compete with a single-screw diesel-electric in fuel consumption, offering also redundancy, manoeuvrability and lower investment costs in machinery. **Two direct coupled low-speed engines** could do the job, but they would have CP propellers. Again the gas would have to be delivered at high pressure to the engines.
- A twin-screw **diesel-mechanical medium-speed** solution could have two (single-in-single-out gearbox) or four engines (twin-in-single-out gearbox). One main engine could drive a primary generator suitable for cargo operation, which leads to a four-engine concept. When the gas available during the ballast trip is also taken into account the four-engine solution is most feasible. Suitable main engines would be, for example, four 8L46GD high-pressure gas diesels.
- A twin-screw **diesel-electric** system can be configured with either FP propellers or podded drives. Here the propulsion plant could be based on high-pressure gas diesels (e.g. 4 x 9L46GD) or on lean burn low-pressure dual-fuel engines (e.g. 4 x 9L50DF).
- A single-screw **low-speed main engine** with FP propeller complemented by a **podded driv**e replacing the rudder. Considerable propulsive efficiency gain is possible using the “contra-rotating propeller principle”. The main engine would run on HFO and would cater for approximately half of the required propulsive power. The other half would be provided by the podded drive and a power plant consisting of dual-fuel lean burn or high-pressure gas diesel generating sets (e.g. 3 x 6L46GD or 3 x 18V32GD or 3 x 18V32DF).

Although high-pressure gas diesel options have their undisputed merits in offshore oil and gas production installations they are not the best choice for LNG carriers. In most offshore installations the gas is available at somewhat higher pressure and includes heavier hydrocarbons and impurities. Compressing the gas to high pressure improves the quality of the gas and a relatively small amount of power is needed to boost the pressure to the level suitable for the gas diesel. On the other hand the pressure of the available boil-off gas in an LNG carrier is atmospheric and is in essence nearly pure methane. Hence, a large high-pressure compressor would be necessary and would burden the system with a high parasitic load (approximately 6 % of the power output of the engines).

The only considerable variation in the boil-off gas composition is the nitrogen content, which would not be affected by compression. Nitrogen as such is not harmful to the engine – the air that we and also the engines normally breathe contains more than 78 % nitrogen. However, as it is an inert

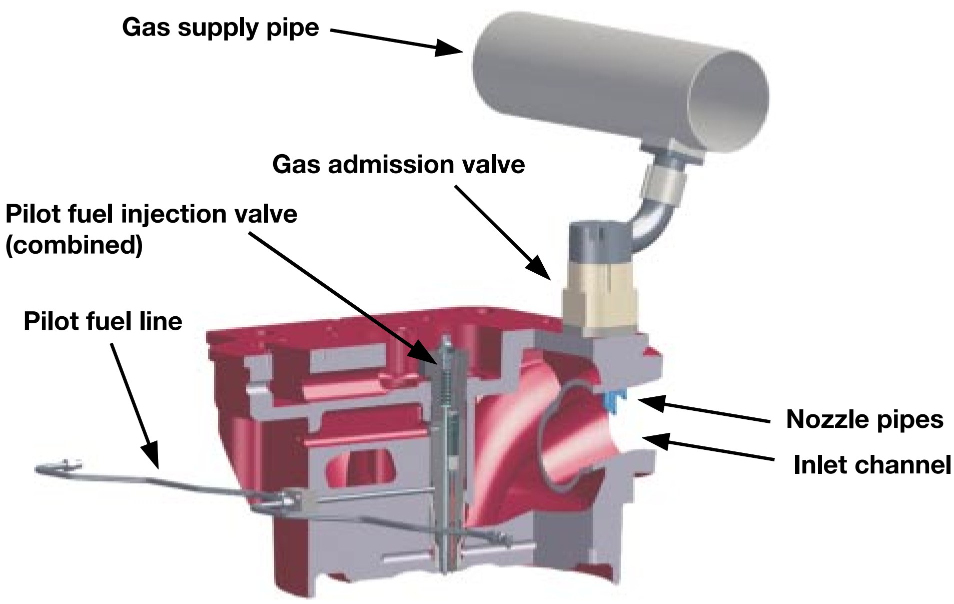

Fig. 3 Wärtsilä DF engine cylinder head and fuel injection arrangement.

	Wärtsilä 32DF	Wärtsilä 50DF
Cylinder bore	320 mm	500 mm
Piston stroke	350 mm	580 mm
Engine speed	720/750 rpm	500/514 rpm
Mean piston speed	8.40/8.75 m/s	9.7/9.9 m/s
Mean effective pressure	19.9 bar	20.0/19.5 bar
Cylinder output	336/350 kW	950 kW
Cylinder configuration	4, 6, 8, 9 L 12, 16, 18 V	6, 8, 9 L 12, 16, 18 V

Table 1 Main data of the Wärtsilä 32DF and Wärtsilä 50DF engines.

gas and does not contribute to the combustion, the energy content (heating value) of the BOG is lower than that of pure methane. The N content in the vapour phase of the LNG can be as high as 30 % in volume especially at the beginning of the loaded trip. This is not a problem for the Wärtsilä dual-fuel engine as the engines can be operated at their nominal output without derating for such a gas mixture.

Electric propulsion based on dual-fuel gas engines

The approach Wärtsilä considers most feasible for LNG carriers is based on electric propulsion where the prime movers in the power plant are four-stroke low-pressure dual-fuel gas engines. The main arguments in the comparison are high thermal efficiency and safety as well as flexible and efficient use of the installed machinery. The selection of either single-screw or twin-screw ship will be based on the operating profile and redundancy requirements specific for each project.

The number of engines and the power output of each unit are determined by the shaft power needed and also by the degree of redundancy requested. Generally speaking on a typical 135,000 m^3 ship with the need for approximately 30 MW total engine output the power plant would consist of four gas engine generating sets of the Wärtsilä 50DF type. The MCR output of these engines is 950 kW/cylinder and the thermal efficiency as high as 46.5 %!

The recommended plant would consist of a combination of eight or nine cylinder units. For example a plant with four 9V46GD would provide nearly full redundancy even if one of the engines were out of service. On the other hand it would also provide welcome flexibility for the different operating modes such as manoeuvring, waiting for port access, loading and unloading.

Recent studies suggest that the most beneficial solution to top up the need for additional energy is to use forced boil-off instead of fuel oil. This solution in combination with dual-fuel engine electric propulsion is economically superior both in installation cost and operation.

As the dual-fuel engine is operated on low-pressure gas, between four and five bar at the engine inlets, the fuel gas compressor package is essentially identical to the one already in use in the current fleet equipped with steam boiler and turbine propulsion. The main difference is that the total efficiency of an electric propulsion plant based on dual-fuel engines is well above 40 % compared to the reported 30 % or less of the steam plant.

Moreover, flexible preventive maintenance at sea and during port calls is possible, which has not been the case with the steam plant or with large single two-stroke alternatives. Diesel-electric propulsion technology is also available today and has been proven in various marine applications. Wärtsilä dual-fuel engines have accumulated a considerable number of operating hours in land-based installations and are mature for marine installations. In other words, everything is ready for taking the next step towards modern, efficient LNG carrier propulsion. ■