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## LABY-GI COMPRESSOR DEVELOPED FOR LNG CARRIER SERVICE

*High-Pressure, Boil-off Gas Fuels Dual-Fuel Propulsion Engines*

By Roberto Chellini

The increasing cost of energy has imposed a revision of the propulsion system of LNG carriers from steam turbines to diesel or dual-fuel engines. The boil-off gas (BOG) available onboard at very low temperature can be reliquefied and conveyed back to the cryogenic tanks or used onboard as engine fuel in four-stroke, medium-speed or two-stroke, low-speed, dual-fuel engines. Depending upon the engine configuration, the fuel gas may be fed at low or high pressure.

MAN Diesel and Burckhardt Compression have made a strategic partnership agreement to develop a compressor able to handle on one end the BOG at  $-256^{\circ}\text{F}$  ( $-160^{\circ}\text{C}$ ) and virtually at atmospheric pressure. On the other end, it can handle up to 4348 psi (300 bar) for injection into the

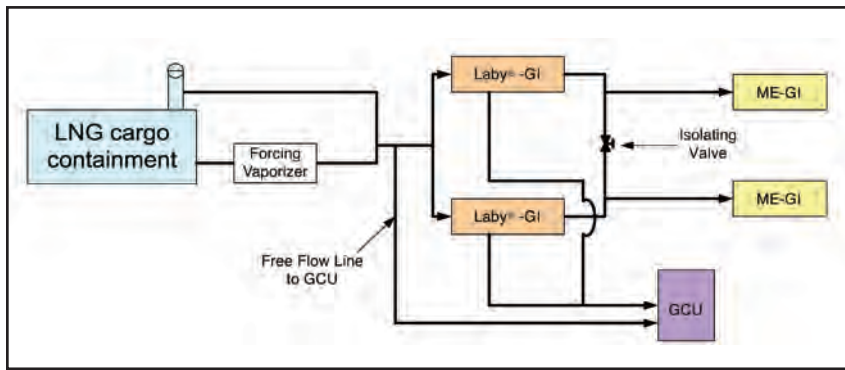
ME-GI (Gas Injection) two-stroke, dual-fuel engines developed by MAN for LNG carrier propulsion systems. The function is accomplished with one common frame, which compresses the cold BOG directly to the required injection pressure.

The Danish subsidiary of German-based MAN Diesel has already sold 90 MAN-B&W two-stroke engines type 7S70ME and 6S70ME to partners in the Qatargas projects.

According to MAN, these two-stroke engines — featuring a 50% thermal efficiency in the dual-fuel version — are sized to propel large LNG carriers with capacities of 5.124 to 95.41 MMcf (145,000 to 270,000  $\text{m}^3$ ) of LNG. These vessels can be powered by a single main engine, with power take home system, or in the more common config-

uration with two main engines directly coupled to the two parallel propeller shafts. The gain in efficiency, compared to single-engine propulsion systems, can reach up to 9% depending on the vessel size and its beam/draft ratio. The engines can burn 100% heavy fuel oil (HFO) or diesel oil or a mixture of liquid fuel (a minimum percentage is needed to ensure gas ignition) and natural gas.

The GI system is an add-on to an existing electronically controlled ME engine and, in principle, the system is quite simple. The gas is fed to the cylinders via high-pressure double-walled gas pipes and a set of electronically controlled gas valves, which allow gas injection into the combustion chamber. These valves are grouped in a block bolted to the cylinder head.



■ Diagram showing two Burckhardt Laby-GI compressors feeding two MAN ME-GI dual-fuel engines or a GCU in parallel.

The control system, developed in cooperation with Burckhardt and Kongsberg, adjusts the amount of gas injected into the ongoing combustion. The gas injection pressure is modulated between 2174 and 4348 psi (150 and 300 bar) according to the engine load. The slightly modified cylinder head also features an internal gas accumulator. These are the only modifications made on the original ME engines to transform them into the ME-GI version, which has obtained approval for ship propulsion by all major classification societies.

An ME-GI land-based unit in a power generation plant has already performed over 20,000 operating hours, demonstrating the high reliability of the dual-fuel diesel engine. This dual-fuel engine is capable of burning HFO and natural gas in almost any ratio according to the diesel cycle (up to 92% natural gas). The high-surplus air volume and the high-pressure gas injection system can sustain combustion when the engine is burning a variety of gases, other than natural gas, even with low methane content.

The BOG, naturally available from tank evaporation, is estimated to be about 80 to 90% of the fuel required for laden voyages and 40 to 50% on ballast voyages — with the engines driven at full power to maintain a cruising speed of 19 to 21 knots. The fuel-gas supply system placed inside a house on the top deck can be provided with different compressor combinations depending upon product availability. With two 100% capacity Laby-GI compressors, one of which is kept in standby, a theoretical availability of 99.25% can be reached.

However, this solution entails a poor part-load performance of the compressor in service. Two 50% capacity Laby-GI compressors could also be installed to increase their part-load efficiency and integrate HFO with gas injection in case of an outage

of one unit. However, two 75% units are estimated to be the right size for a reliable and efficient system. In fact, BOG is very clean, and compressor maintenance — including the valves (the most delicate components of a compressor) — can be performed at long intervals.

The 6LP250-5S\_1 Burckhardt Laby-GI compressor, of the vertical type, features six 9.84 in. (250 mm) cranks driving the pistons through cross-heads. Four cylinders of the Laby type serve as the first three compression stages (the first stage compression is carried out by two separate cylinders working in parallel). Two high-pressure cylinders serve process requirements. For application on smaller-sized LNG carriers, with reduced BOG to be handled, Burckhardt has developed the 4LP250-5S\_1 Laby-GI compressor featuring four compressor cylinders instead of six for mass balancing.

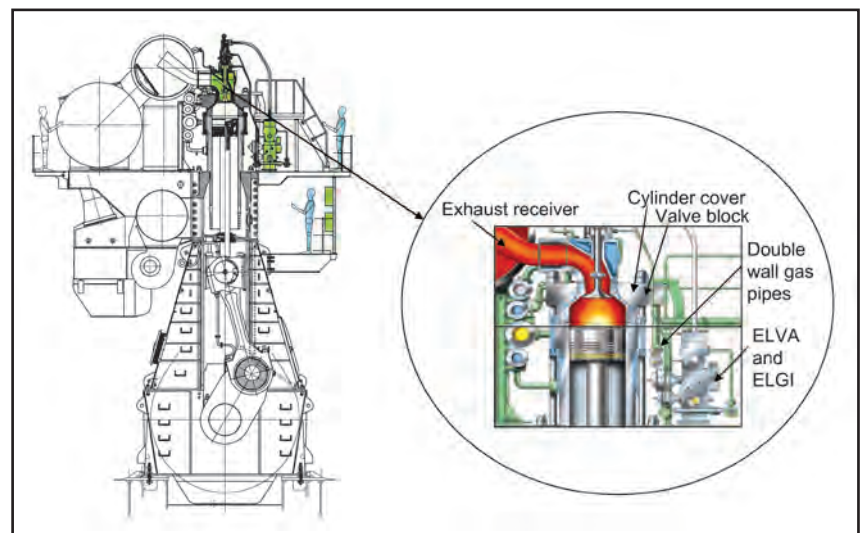
The low-pressure section of the compressor is similar to those Burckhardt has supplied to many producing and receiving LNG terminals

for compression of BOG to discharge pressures in the range of 145 to 725 psi (10 to 50 bar). These double-acting, nonlubricated cylinders feature contactless labyrinth seals on the pistons and piston rod packings to avoid mechanical friction of the sliding parts, thus ensuring extremely long life to the sealing components and high availability and reliability.

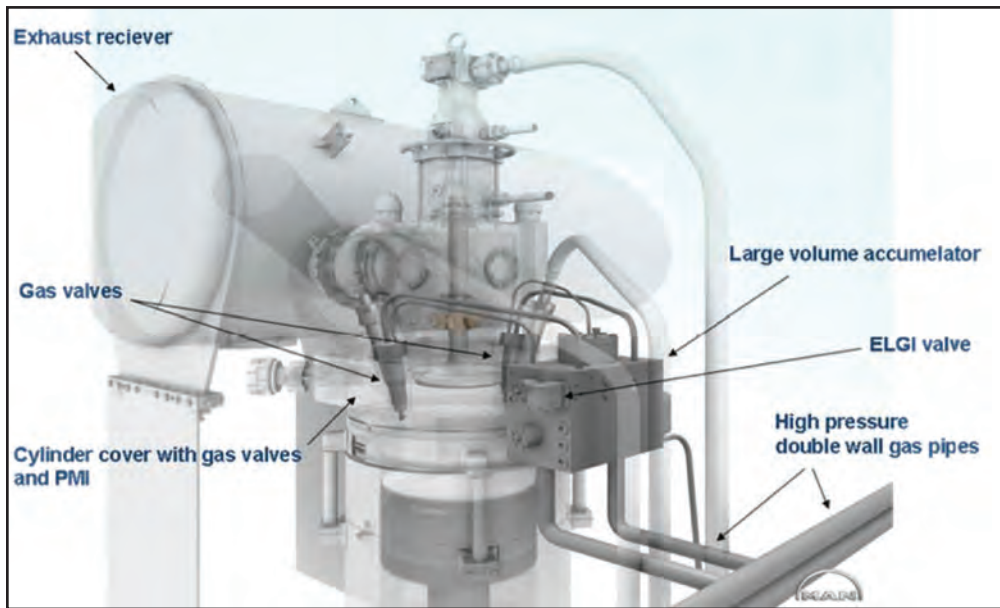
The two first-stage cylinders, which are exposed to very low temperatures, are cast in nodular cast-iron GGGNi35 (Ni-Resist D5) with 35% nickel, which exhibits a remarkable ductility at low temperatures and a very low thermal expansion coefficient. The pistons are of cast iron with lamellar graphite. This piston-cylinder material combination enables starting the compressor at ambient temperature 86°F (30°C) and cooling it down to BOG temperature -256°F (-160°C) without the need for special precautions or pre-cooling of the compressor.

The second- and third-stage labyrinth cylinders operate at higher temperatures and are provided with cooling jackets. Nodular cast iron is used for the second-stage cylinder block and grey cast iron for the third stage.

The oil-lubricated, high-pressure, forged steel cylinders are provided with water jackets to remove the heat of compression. They are designed to perform the fourth compression stage on the top and the fifth on the lower end of the same cylinder block. Piston and piston rod are machined from a single steel forging. Any gas leaking from the fifth stage piston rod packing is returned to the fourth-stage suction. The two identical four and five compression stage cylinders are placed side by side on the upper part of the compressor frame. The compressor



■ Elevated drawing of a MAN ME-GI, dual-fuel engine for LNG carrier propulsion. Inset shows new components for conversion to dual-fuel from straight diesel fuel.



■ Detail of cylinder head for a MAN ME-GI gas-injected, dual-fuel propulsion engine showing location of components necessary to convert the engine from straight diesel to gas-injected, dual-fuel operation.

frame is of conventional vertical, slow-speed crosshead design.

The forged steel crankshaft and connecting rods are supported by heavy tri-metal, forced lubricated main bearings. A single distance piece in the upper frame section provides separation between the lubricated crank mechanism and the nonlubricated compressor cylinders. Piston rods, actuated by the crossheads at their lower end, are guided in their rectilinear reciprocating motion by a lubricated bearing placed at the distance piece lower section, which prevents metal contact of labyrinth seals.

The passage of the crankshaft through the wall of the crankcase is sealed off by a rotating double-sided ring seal immersed in oil. Thus, the entire inside of the frame is integrated into the gas-containing system with no gas leakage to the environment.

The crankshaft is directly connected to the driving electric motor. Size is selected according to the LNG carrier size and the amount of BOG to be handled.

Design natural BOG rates are typically in the range of 0.135 to 0.15% per day of tanker liquid capacity. During steady-state loaded voyage a BOG rate of 0.10 to 0.12% may be expected. During ballast voyages the amount of BOG naturally evaporating may increase by forced evaporation.

Three compressor sizes are sufficient to cover the needs for LNG carriers ranging from 5.1 to 9.5 x 10<sup>6</sup> MMcf (145,000 to 270,000 m<sup>3</sup>) capacity. As an example, a 7.421 MMcf (210,000 m<sup>3</sup>) LNG carrier will make available a BOG mass flow of 12,335 lb./h (5600 kg/h) that can be handled by a compressor with 2146 hp (1600 kW) of shaft power.

In order to handle different amounts of BOG, made available naturally from the tanks and the amount of gaseous fuel required by the engines, the compressors have to be provided with a very robust and simple control system.

This control system must take into account two main factors: the amount of BOG to be handled during the laden voyage, which is much higher than that available during the ballast voyages [also the cryogenic temperature can vary substantially, from -256° to -40°F (-160° to -40°C)] and the delivery pressure to the engines, which can reach peaks of 4348 psi (300 bar). In practice, delivery pressure can vary from 2674 psi (150 bar) when the engines are running at low load to 3841 psi (265 bar) and 113°F (45°C) when engines are at full load. Furthermore, if the engines are not running, the compressor has to handle the gas at low pressure, 58 to 94 psi (4 to 6.5 bar) (after the first compression stage) to the gas combustion unit (GCU).

Capacity control by valve unloading is extensively employed in LNG receiving terminals where very large variations of BOG are experienced during LNG transfer from ships to storage tanks. The capacity of the 6LP250-5S Laby-GI compressor can be reduced simply and efficiently to 50% in one step by the use of nitrogen-actuated suction valve unloaders unloading one half of the double-acting cylinders.

Additional stepless regulation required to control compressor capacity corresponding to the rate of BOG and the demand of the engines, is provided by returning the gas from the discharge to the compressor suction by using several bypass valves.

Combining the two systems enables the maximum capacity flexibility (100 to 0%) to be obtained.

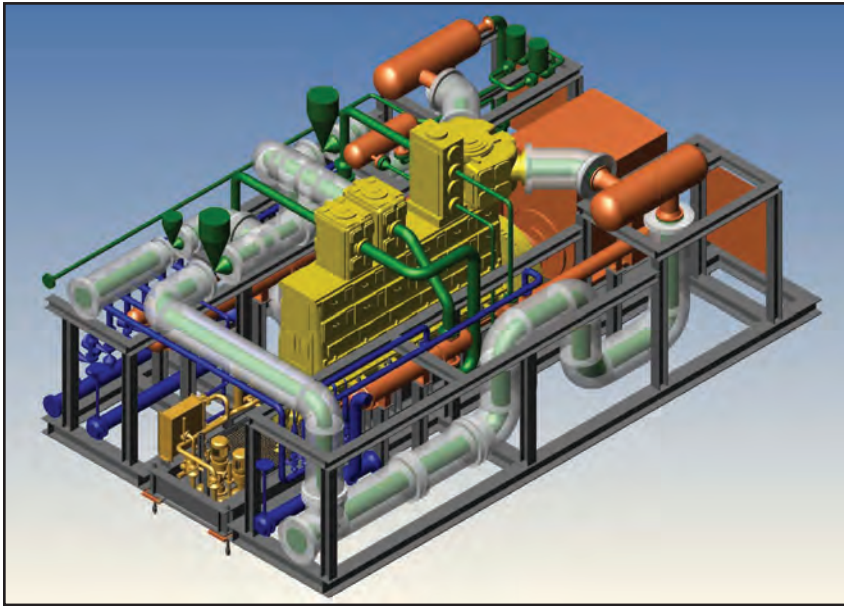
If the amount of natural BOG is higher than that required by the engines, resulting in a higher than acceptable suction pressure, the control system will send the excess gas to the GCU via the side stream of the first compression stage. Safety relief valves are provided at the discharge of each compression stage to protect the cylinders and the entire gas loop against overpressure.

Installation of such compressors onboard a ship poses additional problems as compared to land-based installations because of the flexible structure of the ship as opposed to a concrete foundation block.

Burckhardt, as a consequence, engineers the whole compression system — starting from the static and dynamic mechanical analysis, thermal stress analysis, pulsation analysis of the compressor itself and of the auxiliary system consisting of the gas piping upstream and downstream of the compressor, pulsation vessels, gas intercoolers, etc. Included are all components that are considered standard parts of the compressor supplier's responsibility.

The compressor is mounted on a steel baseframe having a 36.1 x 23 ft. (11 x 7 m) footprint and designed to be supported by the ship structure. The main motor drive is designed for hazardous conditions and is integrated into the machinery room without requiring a dividing bulkhead.

The improved design of the fully balanced Laby-GI crank gear develops very low unbalanced forces and moments compared to a conventional reciprocating compressor. Maintenance in-



■ Plant layout for a Burckhardt Compression, electric motor drive four-cylinder Laby 4LP250-5S\_1 compressor.

interventions are recommended every 20,000 to 24,000 hours. BOG is very clean and an excellent gas to be compressed and the lifetime expectancy for valve plates can be estimated at 24,000 hours. Maintenance intervention for valve replacement will take approximately seven to nine hours including compressor shutdown and isolation.

A GI retrofit on an LNG carrier provided with a MAN ME-C two-stroke engine propulsion system is feasible. These vessels go into dock for general maintenance every five years. MAN Diesel requires the order for the new components (cylinder heads, control system, etc.) two years in advance in order to perform the retrofit. At the same time the compressor house of the reliquefaction plant on the top deck is enlarged to make room for the new BOG compressors, thus limiting the off-hiring period. ■

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