Everllence B&W
two-stroke
marine engines

Photo courtesy of: A.P. Møller – Mærsk

This paper describes the service experience gained from both G50- and G95-LGIM engine types.

Service experience for Everllence B&W ME-LGIM engines

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1. Introduction

The Everllence B&W ME-LGIM engine is the methanol-burning version of our dual-fuel solution for liquid injection of fuels, the ME-LGI engine platform. Similar to all gas injection (GI), gas injection ethane (GIE), and liquid gas injection (LGI) engines, the LGIM engine operates according to the Diesel combustion principle.

Our LGIM engine type has been in service for nearly one decade, following the market introduction in 2012 and the first vessel in operation by 2016. During the first approximately nine years, all LGIM engines were of the G50 size and installed on methanol carriers. In recent years, Everllence has received orders for LGIM engines for other ship types, such as pure car and truck carriers (PCTCs), bulk carriers, tankers, and more than 100 large container vessels powered by G80 or G95 engine types.

This paper describes the service experience gained from both G50- and G95-LGIM engine types.

2. LGIM engine components

Fig. 1 gives an overview of LGIM engine components.

1. Hydraulic pipe for exhaust valve
2. High-pressure primary fuel oil pipes
3. Hydraulic accumulator
4. Double-walled pipe inlet
5. Double-walled pipe outlet
6. Hydraulic oil pipes
7. Sealing oil pipes
8. Fuel booster injection valve - methanol (FBIVM)
9. Hydraulic control valves for fuel injection timing

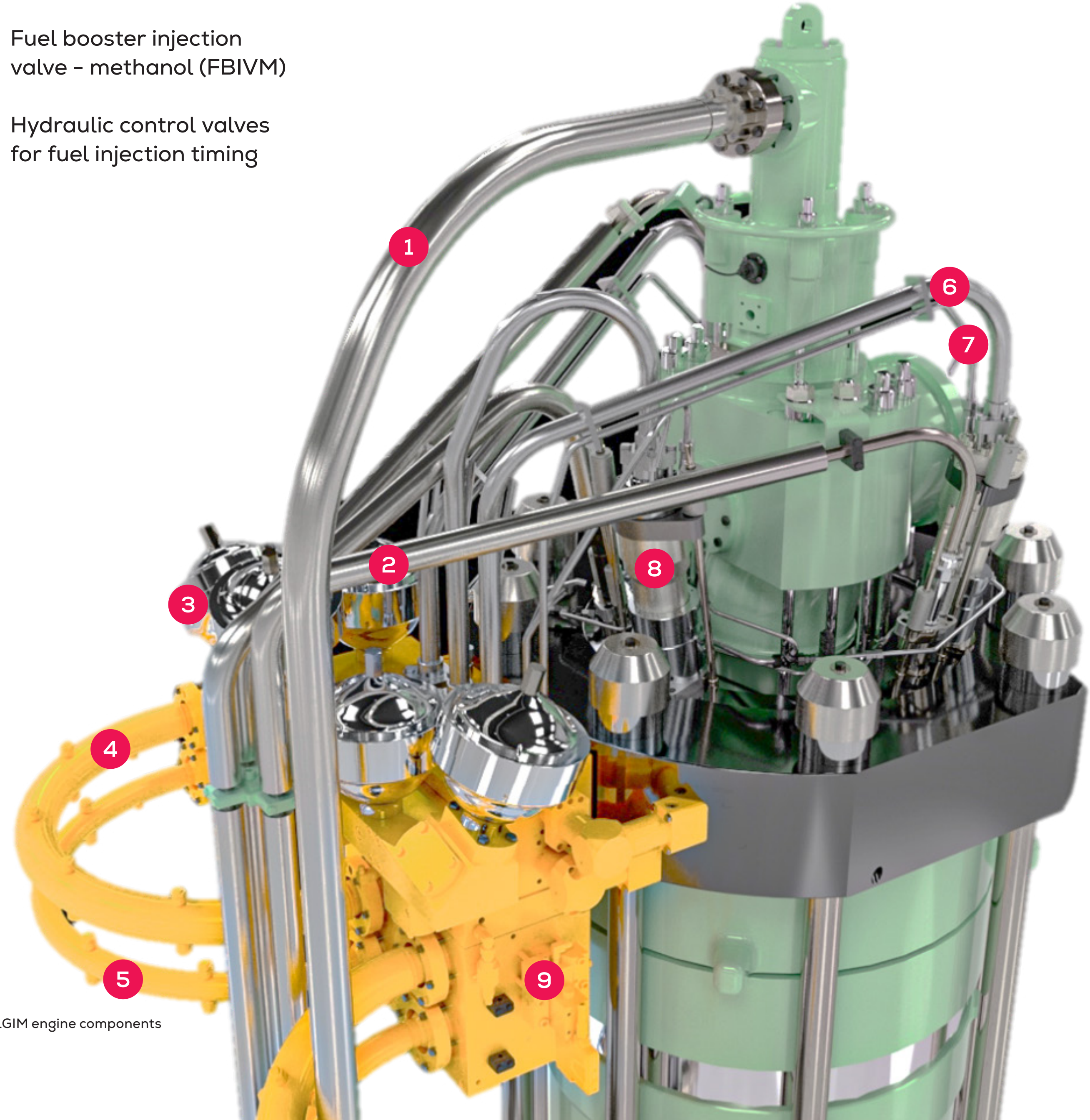


Fig. 1: LGIM engine components

3. Tier III operation of G50-LGIM-W engine

To comply with Tier III NO_X regulations of the International Maritime Organization (IMO), a methanol-and-water blending system was introduced to some of the G50-LGIM engines to lower the NO_X level to Tier III. This engine type, which is denoted LGIM-W, utilises one of two different blending units to introduce water either into methanol or diesel fuel, the latter resulting in water-emulsified diesel fuel. Presently, the LGIM-W engine is not part of our two-stroke engine programme.

The following sections detail the service experience of the G50ME-C-LGIM-W engine in Tier III operation, along with our ongoing development initiatives.

3.1 Fatigue damage of nozzles

Some G50ME-C-LGIM-W engines have experienced increased thermal fatigue loads on injector nozzles due to the prolonged injection duration. Fig. 2 shows examples of fatigue damage on injector nozzles after Tier III operation of the LGIM-W engine.

In this case, the fatigue damage occurred more or less simultaneously on the five nozzles during Tier III operation.

3.2 Continuous design and test initiatives

We have developed three test designs to mitigate thermal fatigue damage on the methanol nozzle. Table 1 summarises the countermeasures integrated into these test designs, along with their respective main advantages and disadvantages.

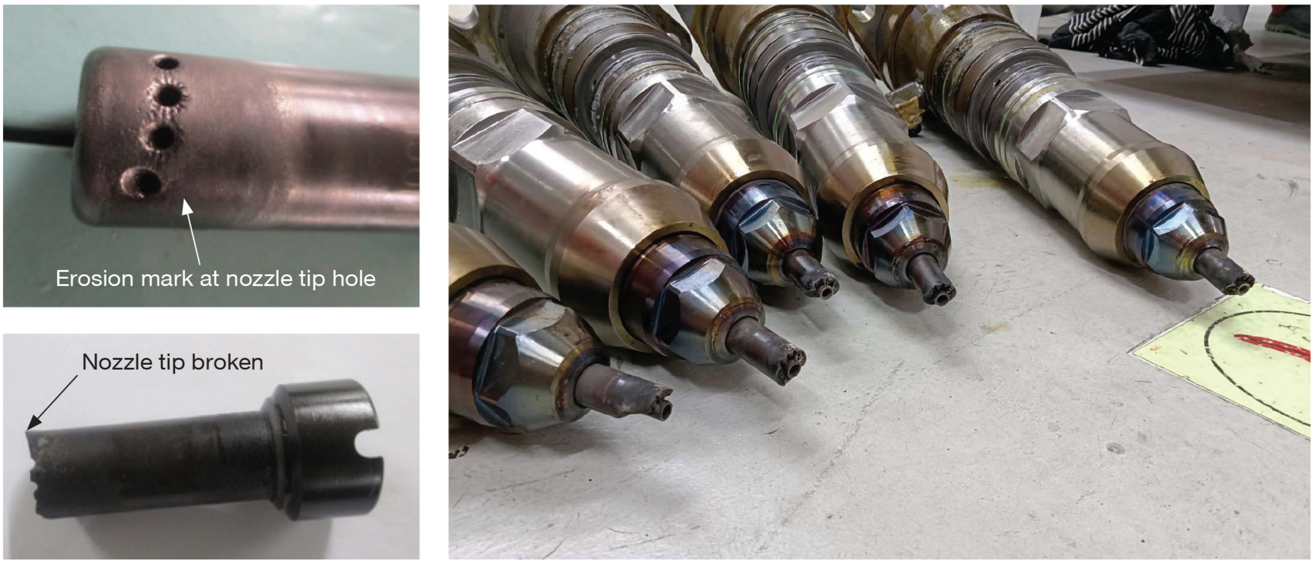


Fig. 2: During Tier III operation, fatigue damage occurred on injector nozzles from a G50-LGIM-W engine

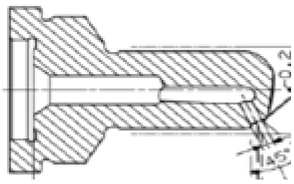
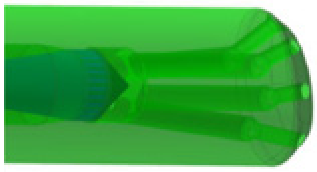
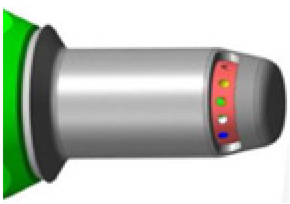
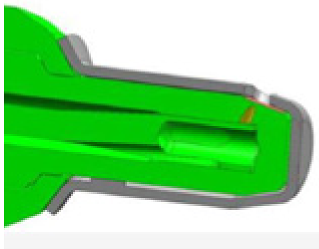
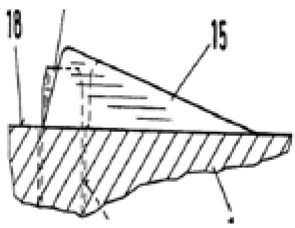
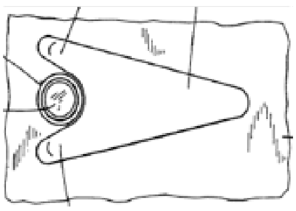
Countermeasure	Test design	Test design	Advantages and disadvantages
1. New injector/nozzle design with shortened cut-off shaft slide (mini-sac design)			- Shortest delivery time - Easy to install
2. Heat shield on the nozzle			- Requires machining of the cylinder cover to accommodate the larger nozzle - The possibility of in-situ machining should be investigated
3. Protective bulb welded onto the cylinder cover			- Requires welding on the cylinder cover in a shop and a pool of exchange covers

Table 1: Three test designs aimed at reducing thermal load on the methanol nozzle

3.2.1 New nozzle design
The new nozzle design shown in Fig. 3 (blue) was partially inspired by similar nozzle designs that were successfully tested on GI and liquid gas injection – LPG (LGIP) engines.

The main technical characteristics of the new injector and nozzle designs are:
- Shortened cut-off shaft slide, which means reduced wear and risk of seizure, or sticking of the cut-off shaft
- Shorter nozzle design and, therefore, smaller temperature gradient and stress amplitudes
- Increased distance between nozzle holes (4.6 mm versus 3.3 mm for the old design).

Finite element method (FEM) calculations have validated the nozzle design. Furthermore, when the design has been successfully tested in service, the new nozzle design will be class approved.

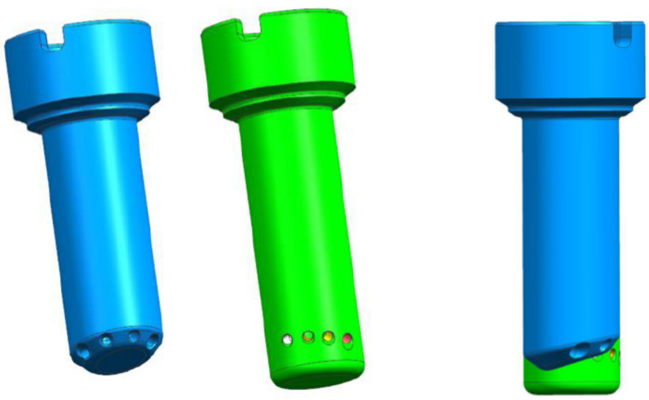


Fig. 3: Comparison of the new LGIM mini-sac nozzle design (blue) with the old design (green)

3.2.2 Heat shield-protected nozzle

Fig. 4a depicts the nozzle design with a heat shield installed in a cylinder cover that has been modified with an increased bore to accommodate the heat shield. Fig. 4b shows a nozzle design where the heat shield has been 'cut back' to accommodate any unforeseen issues during heat shield testing. However, no issues have been reported at the time of writing.

3.2.3 Protective bulb on cylinder cover

Fig. 5 illustrates the design of the methanol nozzle with its heat shield and the welded protective bulb on the cylinder cover. The (diesel) fuel nozzle is also visible in Fig. 5.

As part of the design validation process, the new test designs are tested in service on G50-LGIM and G50-LGIM-W engines. Available test results will be discussed in a later section.

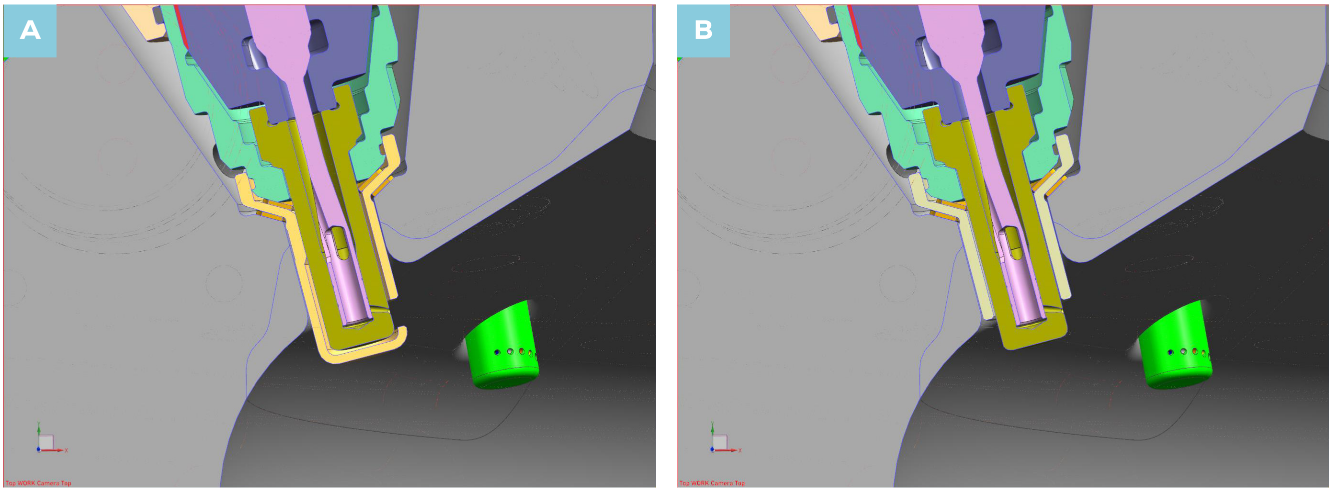


Fig. 4: a) Heat shield-protected nozzle installed in a cylinder cover with increased nozzle bore and b) cut-back heat shield to counteract potential issues with heat shield tests

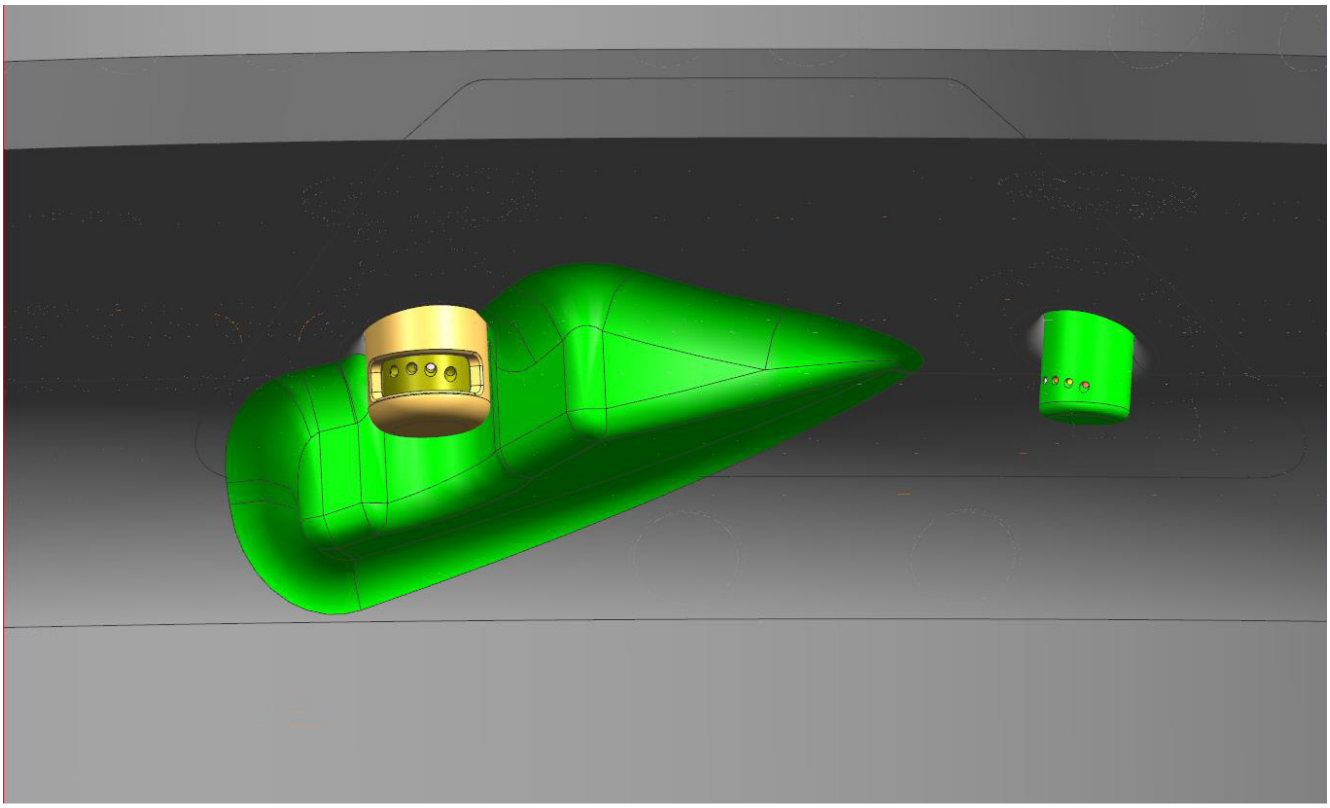


Fig. 5: Artist impression of (diesel) fuel nozzle, methanol nozzle with heat shield, and protective bulb welded onto the cylinder cover

4. G50-LGIM engine technology

4.1 Cut-off shaft material

The cut-off shaft in the fuel booster injection valve for methanol (FBIVM) was initially made of stainless steel (X90). During fuel operation, the cut-off shaft is subjected to high temperatures, which can alter the properties of the stainless steel even after a relatively short exposure.

The curves in Fig. 6 show the decline in stainless steel hardness after less than five hours of operation in 550°C and 500°C environments, respectively. The last picture in Fig. 6 shows the result of exposure to high temperatures, a broken cut-off shaft.

To prevent the observed changes in the properties of stainless steel, we have switched the cut-off shaft material to tool steel (S85W6Mo). Fig. 6 demonstrates that the properties of tool steel are significantly less sensitive to high temperatures compared to stainless steel. However, the choice of tool steel as the nozzle material necessitates coating on the cut-off shaft.

In the search for an optimal coating, the current standard, Diamond-Like Carbon (DLC), has been tested. Presently, Alcrona coating (Fig. 7a) is undergoing service testing. As Fig. 7b shows, the DLC-coated nozzle suffers from erosion on the tip of the cut-off shaft.

While the nozzle test is ongoing, plans are in place to test also the new mini-sac nozzle in service. The results of this test will be detailed for the G95 engine in a subsequent section.

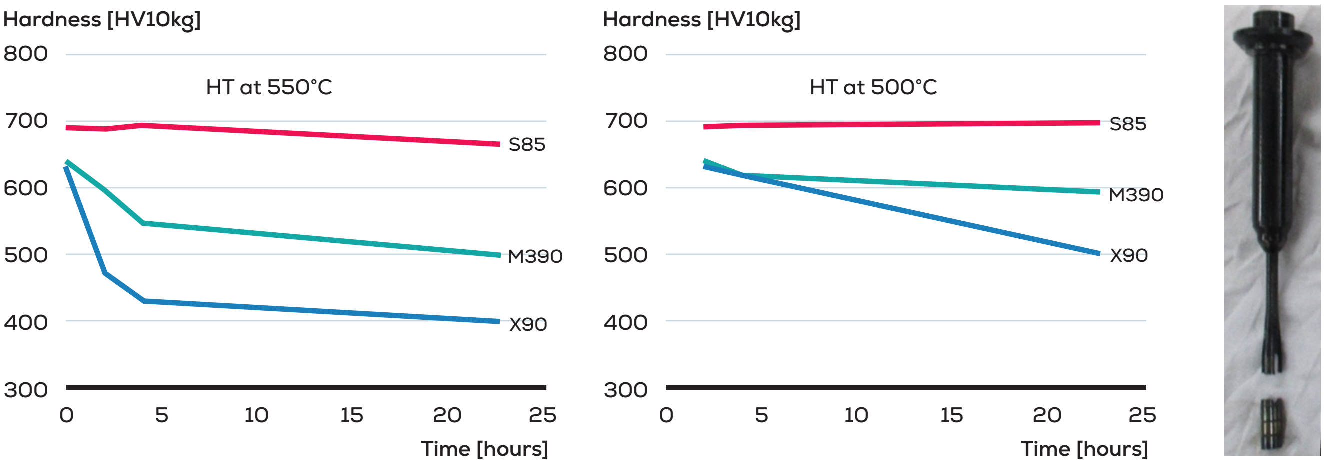


Fig. 6: Measurement of material properties (hardness) of stainless steel (X90), tool steel (S85W6Mo), and M390 as a function of operating time in two high-temperature environments, a) 550°C, b) 500°C. c) Broken cut-off shaft as a result of high-temperature operation

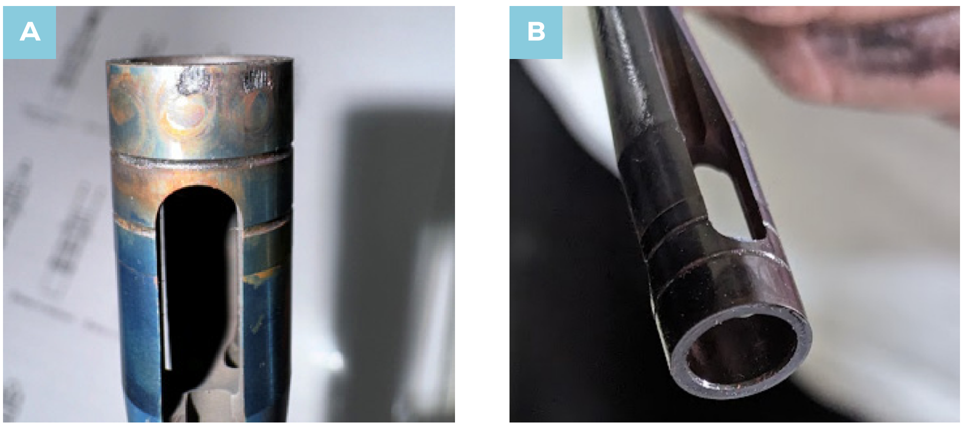


Fig. 7: a) Cut-off shaft with Alcrona coating, currently undergoing a full-scale test in a G50-LGIM-W engine, and b) cut-off shaft with DLC coating and erosion at the tip of the cut-off shaft

5. Service tests and data analysis

5.1 Service tests of heat-shielded nozzle

Service tests of the heat shield-protected nozzle are carried out on G50ME-C-LGIM and G50ME-C-LGIM-W engines onboard the 2,100 teu container vessel and methanol carrier in Fig. 8 and Fig. 9, respectively. The extent and status of the tests as of May 2025 are listed alongside the figures.

5.2 Data analysis

5.2.1 Heat shield test

Nozzle temperature data were collected from the G50ME-C-LGIM engine during service in both dual-fuel and fuel modes. For each operating mode, nozzle temperatures were measured in two series: one without heat shield-protected nozzles (reference) and one with heat shield-protected nozzles, both mounted in instrumented FBIVMs. Fig. 10 shows maximum nozzle temperatures in dual-fuel mode for the two measurement series as a function of engine load (0–75%). The two FBIVMs in cylinder 1 each had two measurement positions, as indicated in the legends on Fig. 10 – Fig. 13.

1. Reference test (without heat shield) and data analysis – done
2. Heat shield test
   Nozzle temperature with heat shield measured when the engine operated in dual-fuel and fuel modes – done
3. Test of protective bulb – done

Fig. 8: G50ME-C-LGIM tests onboard a 2,100 teu container vessel (Courtesy of: A.P. Møller – Mærsk)

1. Reference test (without heat shield) – done
2. Heat shield test – done
3. Test of protective bulb – cancelled
4. Full-scale test of cut-off shaft with Alcrona coating – ongoing
5. Tests of nozzles with new design – ongoing

Fig. 9: G50ME-C-LGIM-W tests onboard a methanol carrier (Courtesy of: Stena Proman)

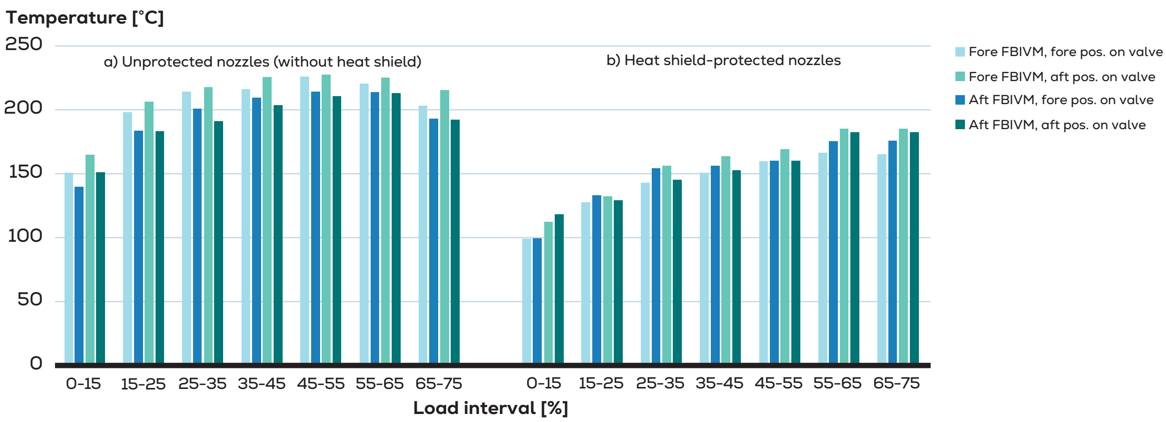


Fig. 10: Maximum nozzle temperatures [°C] in dual-fuel mode (G50ME-C-LGIM) for a) unprotected nozzles versus b) heat shield-protected nozzles

Fig. 11 shows the temperature difference (reduction) between nozzles without and with heat shields in dual-fuel mode.

As Fig. 11 shows, the nozzle temperature is reduced significantly when operating with a heat shield-protected nozzle. Identical measurement series and calculations (Fig. 12 and Fig. 13) have been conducted for the G50 LGIM engine operating in (diesel) fuel mode.

Fig. 13 shows the temperature reduction in fuel mode for the nozzles protected by a heat shield.

The maximum temperature of heat shield-protected nozzles were reduced approx. 100°C compared to unprotected or reference nozzles.

We have also tested heat shield-protected nozzles together with cylinders with protective bulbs, however, this does not reduce the nozzle temperature further. Therefore, the protective bulb will not be introduced as standard on LGIM engines.

5.3 Result of service tests

The service tests conducted on the G50-LGIM engine demonstrated that the selected countermeasures and designs led to successful engine operation, owing to the following design features, including material properties:

1. Nozzle material: Tungsten (Wolfram)
2. Nozzle heat shield in NiCr alloy
3. Cut-off shaft in tool steel (S85W6Mo)

The above configuration works for both G50-LGIM and G50-LGIM-W engine versions.

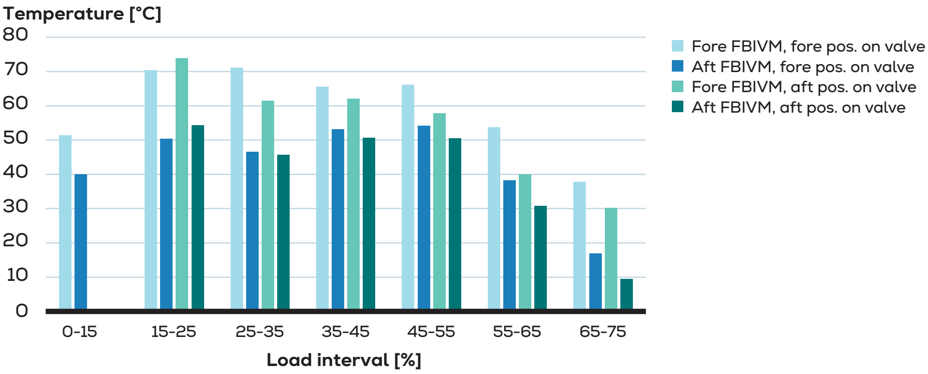


Fig. 11: Nozzle temperature reduction [°C] in dual-fuel mode (G50ME-C-LGIM) for heat shield-protected nozzles compared to unprotected nozzles

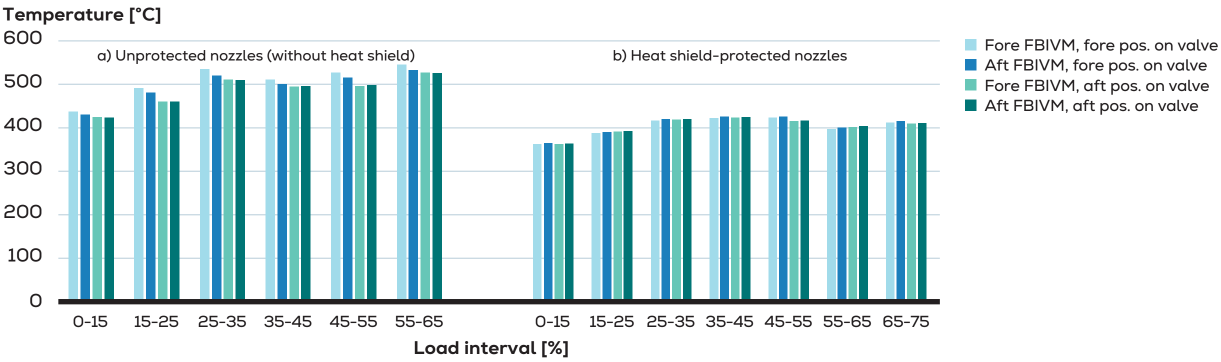


Fig. 12: Maximum nozzle temperatures [°C] in (diesel) fuel mode (G50ME-C-LGIM) for a) unprotected nozzles versus b) heat shield-protected nozzles

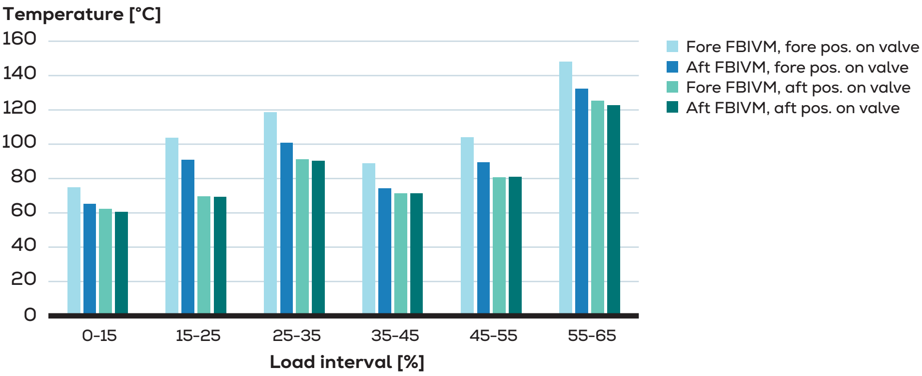


Fig. 13: Nozzle temperature reduction [°C] in (diesel) fuel mode (G50ME-C-LGIM) for heat shield-protected nozzles compared to unprotected nozzles

6. G95-LGIM engine technology

The following sections describe recent updates, service experience, and further development of our G95-LGIM engine technology.

6.1 Updated deaeration point on hydraulic high-pressure pipe

Extremely high pressure spikes have been observed in the high-pressure hydraulic pipes for actuation of the FBIVM. In the short term, the pressure spikes pose a significant risk of damaging the high-pressure pipe and can also lead to engine start failures. Fig. 14 presents a measurement of the hydraulic pressure in the high-pressure pipe, highlighting the observed pressure spike in green.

To avoid the pressure spikes, the deaeration points are relocated to the highest point on the high-pressure pipe and the pipe design has been improved. Fig. 15 compares the old and new high-pressure pipe designs.

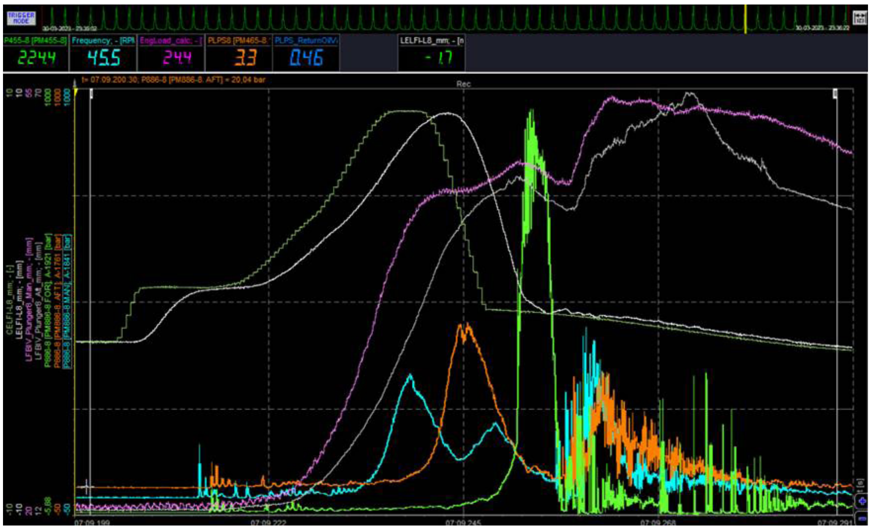


Fig. 14: Measured pressure spike (green) in high-pressure hydraulic pipe for the FBIVM

Relocating the deaeration point to the highest point on the high-pressure pipe has resolved the issue with pressure spikes. The high-pressure pipe design was updated to the new design before any G95 engines went into service.

6.2 Improved fuel changeover with sequential methanol filling

During an engine changeover from operation on diesel fuel to methanol, a knocking sound was observed. This knocking sound occurred because nitrogen accumulated in the FBIVM chamber acted as a gas spring. To mitigate the knocking sound and potentially unstable combustion during changeover, each FBIVM chamber is filled with methanol cylinder by cylinder. A high-capacity low-pressure supply (LPS) pump ensures that the FBIVM plunger is positioned at the bottom during methanol filling, preventing the remaining N_2 from acting as a gas spring. The methanol filling sequence is controlled by software.

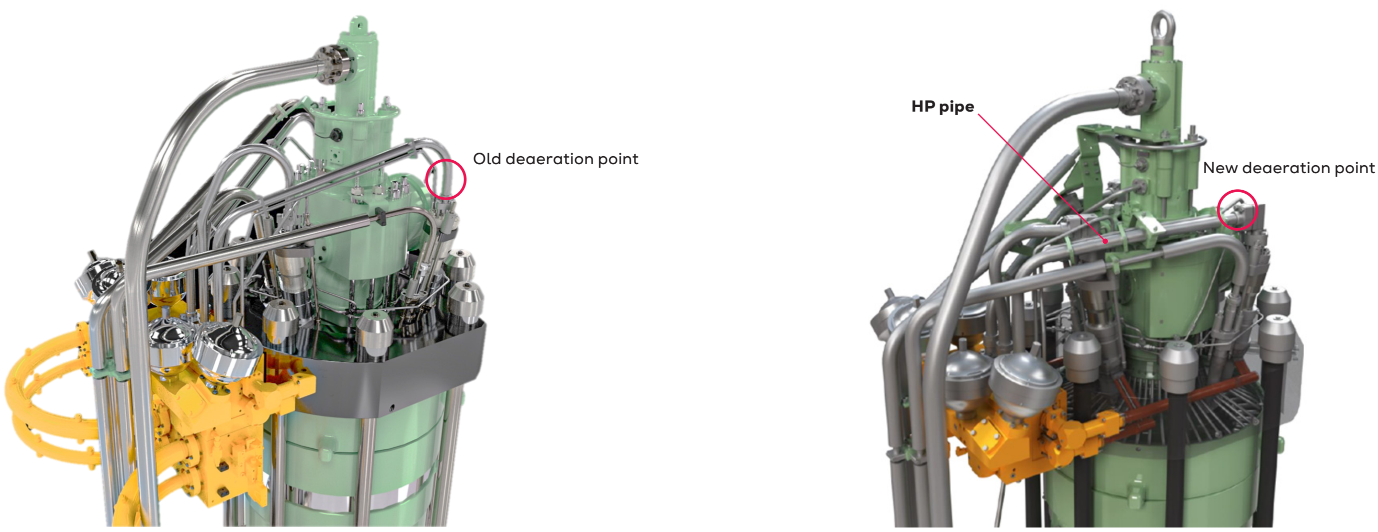


Fig. 15: Old and new high-pressure hydraulic pipe designs with deaeration points marked

Fig. 16 depicts the initial set-up of the high-capacity LPS pump, and Fig. 17 shows the sequential filling of FBIVMs.

High-capacity LPS pumps are installed on all G95-LGIM engines under production and in service. Following the introduction of software that enables sequential methanol filling, the issues experienced during fuel changeover have been solved.

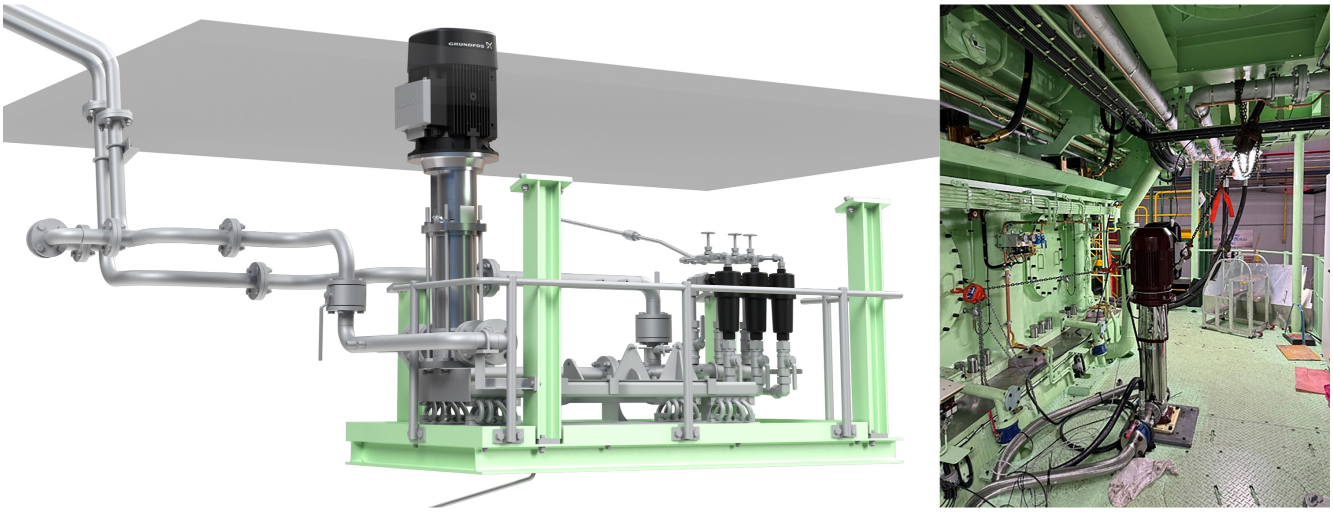


Fig. 16: Initial setup of high-capacity low-pressure methanol filling pump

Fig. 17: Sequential filling of FBIVMs

6.3 Redesigned connection piece with distance piece

Methanol is supplied to the FBIVM via the gas block, through a so-called 'lance' in the cylinder cover, and through the connection piece to the sleeve and ultimately the FBIVM.

It has been observed that the M12 bolts in the connection piece (Fig. 18 and Fig. 19) have broken, leading to methanol leakage and dual-fuel shut-down.

The connection piece has been redesigned to include a distance piece to reduce the dynamic load on the bolts, see Fig. 20.

The introduction of a distance piece has eliminated further bolt breakage cases.

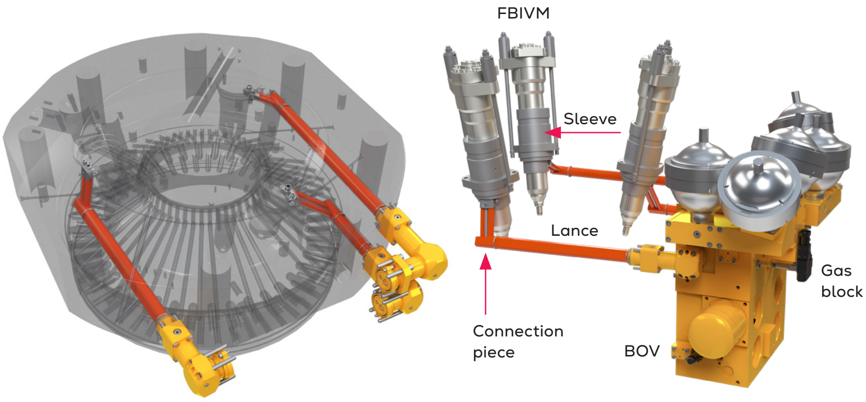


Fig. 18: Methanol supply via gas block, lance, connection piece, sleeve, and FBIVM in the cylinder cover. The location of the blow-off valve (BOV) is also seen

Fig. 19: Breakage of bolts for connection piece (bolts not shown)

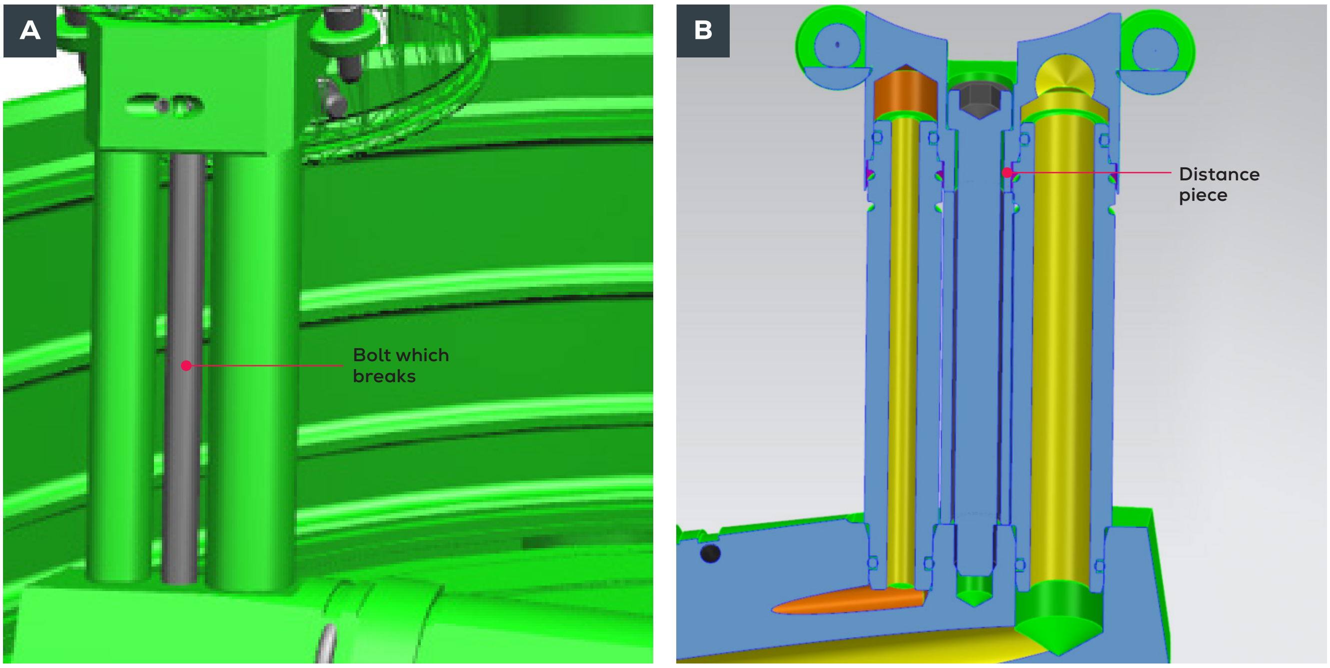


Fig. 20: Connection piece a) original design without distance piece and b) new design with distance piece

6.4 Blow-off valve updated with higher closing pressure

The gas block has a solenoid-controlled hydraulic directional blow-off valve (BOV), see Fig. 18 and Fig. 21. The valve is operated during blow-off operations.

Examples of damage caused by cavitation and erosion have been observed on the BOV spindle on G95ME-C10.5-LGIM engines. This resulted in methanol leaking to the methanol return pipe and excessive purging with nitrogen, eventually triggering an alarm and dual-fuel shutdown. Fig. 22 shows an erosion-damaged BOV valve spindle for a G95ME-C10.5-LGIM engine.

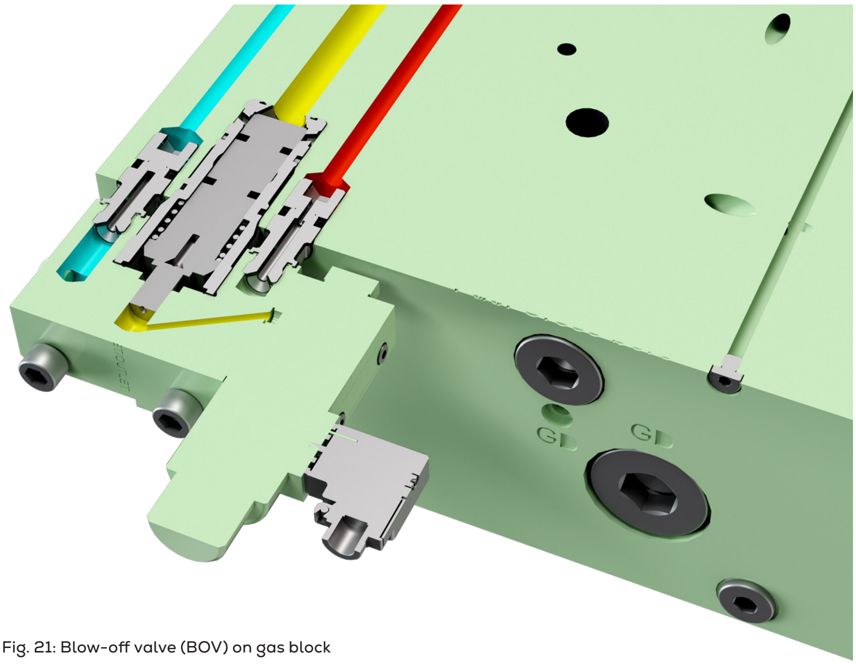


Fig. 21: Blow-off valve (BOV) on gas block

This erosion issue does not affect G50ME-LGIM engines to the same extent, despite the very similar designs.

At the time of writing, further operating hours are needed to be able to make a final conclusion.

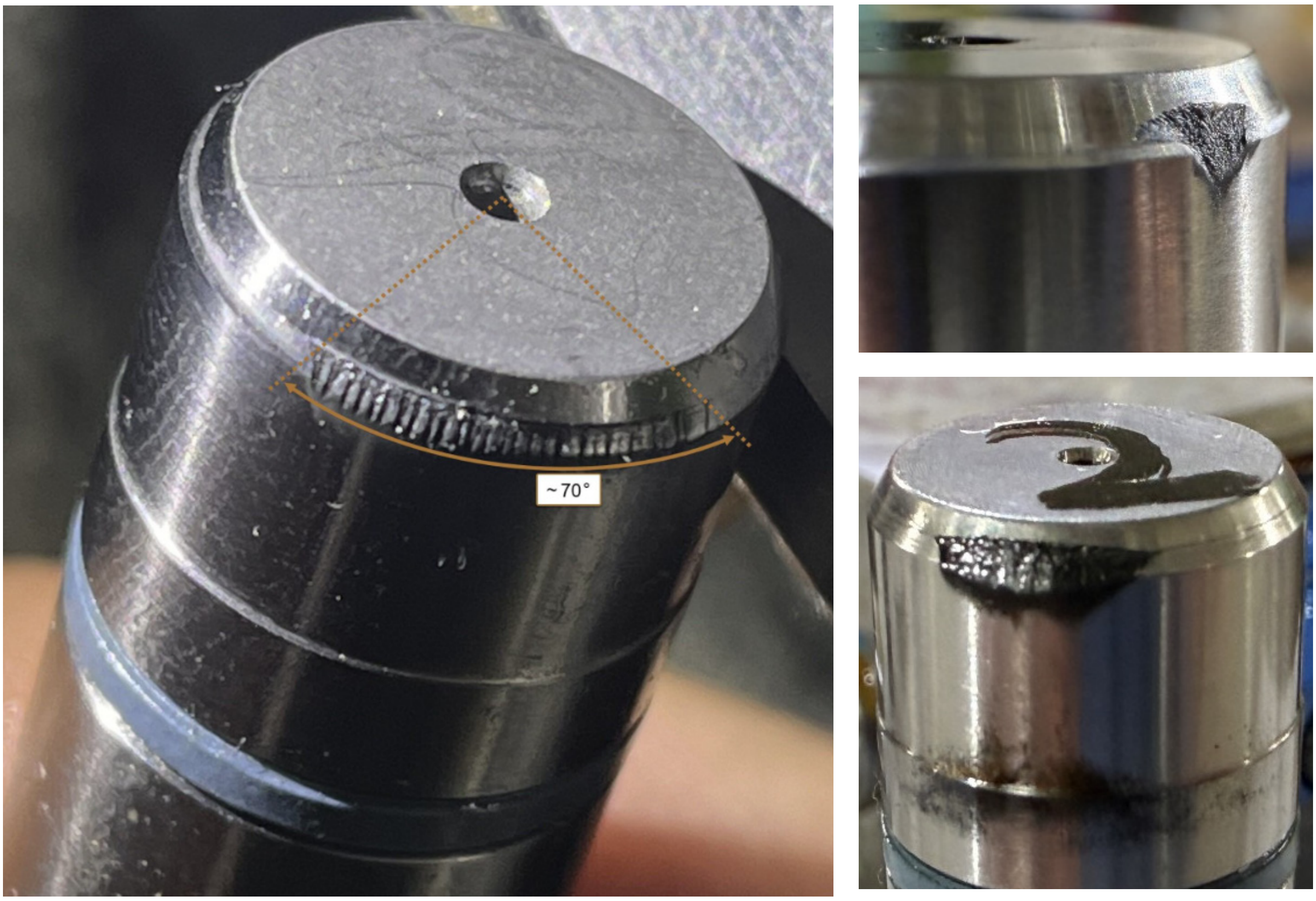


Fig. 22: Erosion damage of blow-off valve spindle for G95ME-C10.5-LGIM

6.5 G95-LGIM nozzle service tests

6.5.1 FBIVM nozzle with heat shield

Because of the increased thermal load on FBIVM nozzles due to the methanol combustion characteristics (extended atomisation time and high heat absorption), a heat shield has been applied to reduce the thermal load. Fig. 23 shows G95-LGIM nozzles with a NiCr alloy heat shield. As concluded in the section for the G50 engine, a heat shield reduces the temperature of the FBIVM nozzle (approx. 100°C).

The heat shield design is now standard on all LGIM engines.

Fig. 23: FBIVM nozzle with heat shield for G95-LGIM engines

6.5.2 New mini-sac nozzle designs

A new nozzle test design has been made to reduce stress at the nozzle holes of the FBIVM nozzle. The test design uses the GI design with separate supply bores to the nozzle holes, which reduces the stress level. Fig. 24 compares a standard slide fuel valve with the mini-sac design.

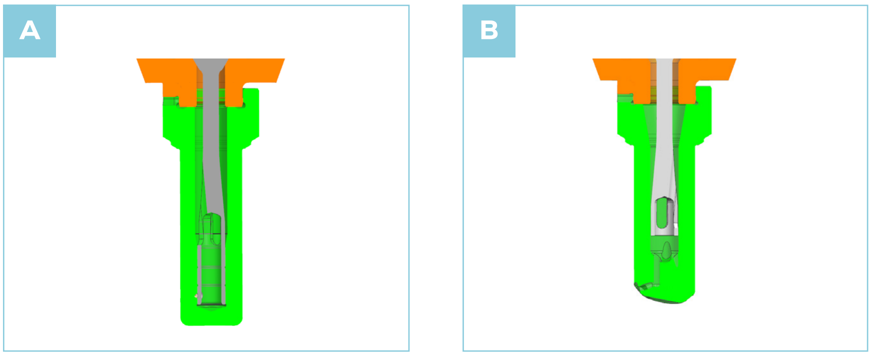


Fig. 24: a) Standard slide fuel valve and b) Mini-sac design

G95-LGIM mini-sac fuel valves are installed on a 13,000 teu container vessel (Fig. 25) for service tests, the first G95-LGIM-powered vessel in a new series.

Fig. 25: 13,000 teu container vessel conducting service tests of mini-sac fuel valve test design (Courtesy of: CMA CGM)

Fig. 26 illustrates details of the mini-sac design being tested.

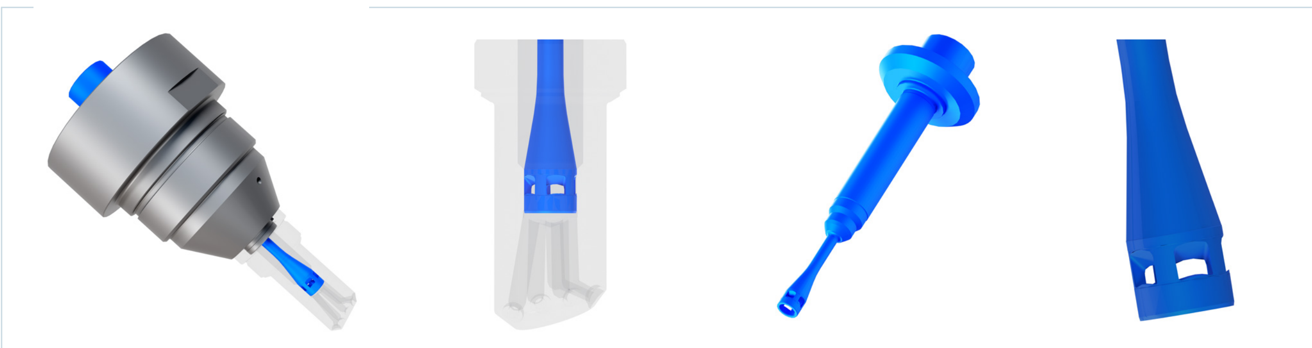


Fig. 26: Details of the mini-sac design

Fig. 27 provides the result of the first inspection of the mini-sac fuel valves. Prior to the inspection, the engine has been operating on diesel fuel.

The first inspection of mini-sac fuel valves after 683 hours of operation on diesel fuel reveals that the nozzle and cut-off shaft are in good condition. Further inspections are needed.

6.5.3 Slide-type nozzle/cut-off shaft with increased sealing length

Erosion has been observed on the tip of the cut-off shaft in the slide version of the methanol nozzle for the G95-LGIM engine, as shown in Fig. 28.

Fig. 27: First inspection of mini-sac fuel valves after 683 running hours on diesel fuel shows that the nozzle and cut-off shaft are in good condition

Fig. 28: Erosion on the tip of the cut-off shaft from the slide-version of the methanol fuel valve for G95 LGIM

The presumed cause of erosion is the intrusion of combustion gases into the slide-type nozzle during diesel operation, as illustrated in Fig. 29.

Fig. 30 illustrates the test design for the slide-type methanol nozzle and cut-off shaft with increased sealing length. A service test is pending for this test design at the time of writing.

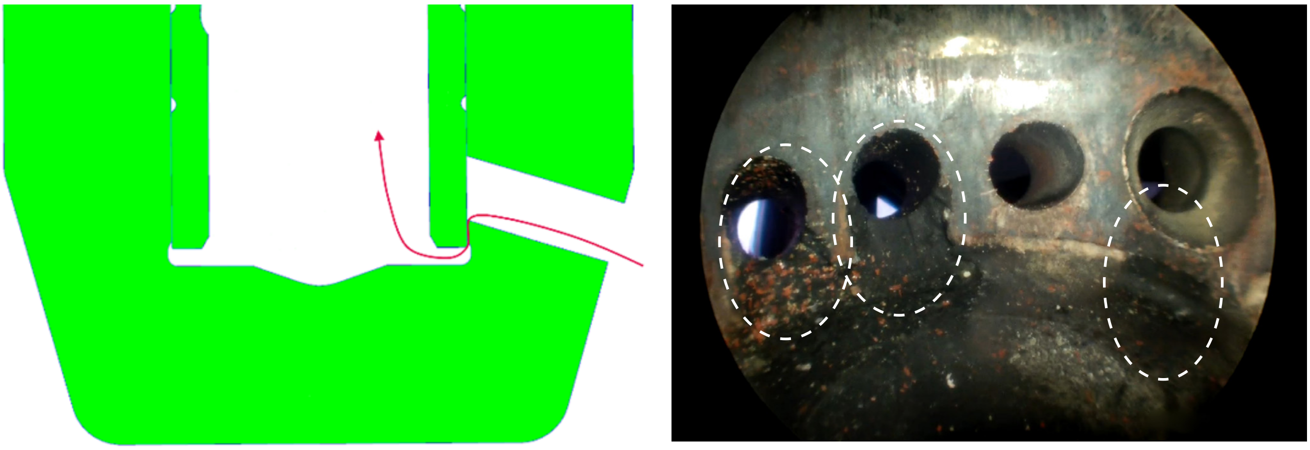


Fig. 29: The presumed cause of erosion is intrusion of combustion gases in the methanol slide-type nozzle during diesel running

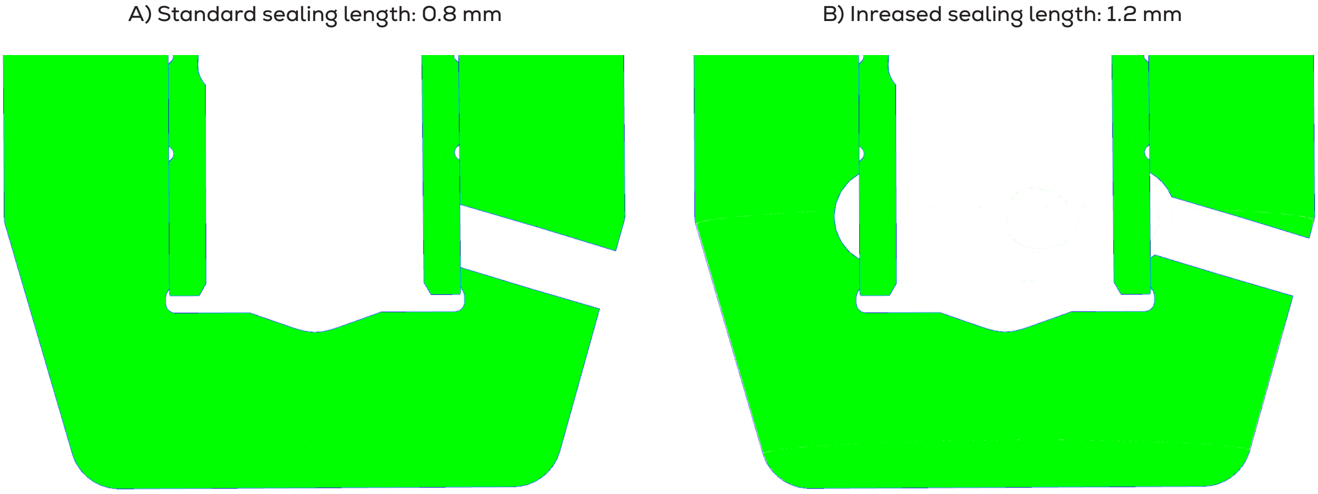


Fig. 30: Methanol slide-type nozzle with standard sealing length: a) 0.8 mm and b) Test design with increased sealing length: 1.2 mm

7. Conclusion

Nearly one decade ago, the LGIM technology was introduced for the propulsion of methanol carriers. In recent years, we have received orders for LGIM engines also for other ship types and engine sizes. This paper has outlined some of the service related issues experienced so far. We will continue to follow up on this in the coming months and years, as further engines and engine types enter service.

8. Acronyms and abbreviations

BOV	blow-off valve
DLC	diamond-like carbon
FBIVM	fuel booster injection valve methanol
FEM	finite element method
GI	gas injection
GIE	gas injection ethane
IMO	International Maritime Organization
LGIM	liquid gas injection methanol
LGIM-W	water as Tier III NO_X compliance measure
LGIP	liquid gas injection propane
LPS	low-pressure supply
PCTC	pure car and truck carrier

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