Everllence B&W
two-stroke
marine engines

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This paper describes the service experience gained from G50-, S60- and G60-LGIP engine types.

Service experience for Everllence B&W ME-LGIP engines

Contents

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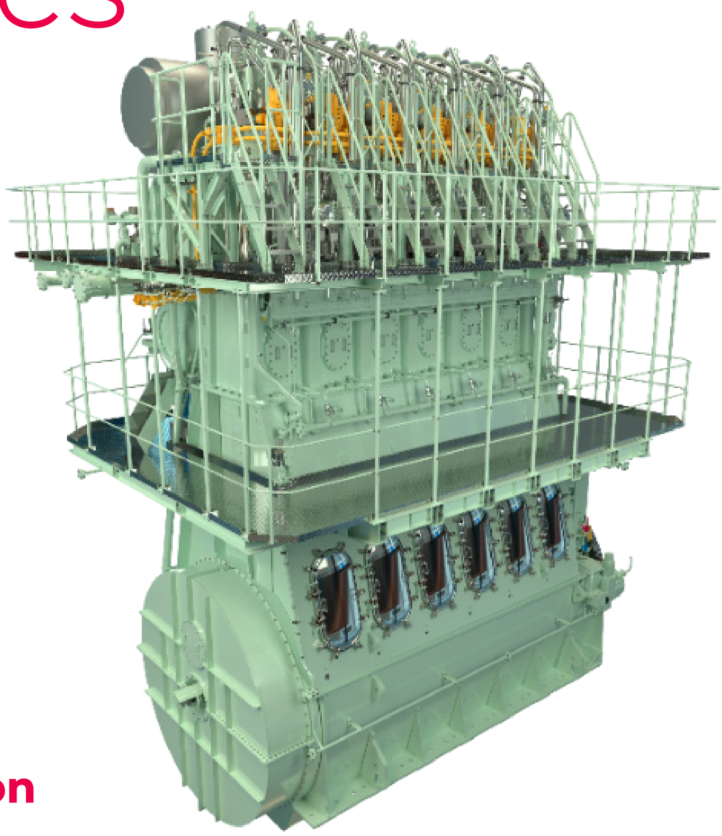

1. Introduction

LGIP engines for liquid gas injection – LPG from Everllence B&W utilise the ME-LGI injection concept, i.e. the diesel combustion principle, which is also applied to alternative fuel engines, such as methanol and ammonia engines.

Everllence B&W LGIP engines have been in service for five to six years. During this period, G50, S60, and G60 engines in various Mark versions were introduced for both newbuilding orders and retrofit projects. To date, all orders for LGIP engines have been for LPG carriers. We expect this to remain the main application for LGIP engines in the future.

The service experiences discussed in this paper derive from G50-, S60-, and G60-LGIP engines. The challenges encountered can be divided into the following categories:

1. Hydraulic pipe integrity
2. Low mean pressure (Pi) alarms, which result in the injection of an insufficient gas amount and gas trip. The low mean pressure can be caused by:
   - air trapped in the fuel system during change-over from diesel to LPG operation
   - clogging nozzles
   - phase shift of LPG (from liquid to gas)
   - cracked spindle guides
3. Short nozzle lifetime due to hot corrosion.

2. Hydraulic pipe integrity

2.1 Improved hydraulic pipe couplings and support brackets

At an early stage, high levels of vibration were observed in hydraulic pipes for activating the electronic window valve (ELWI), and in control oil and sealing oil pipes. The vibration led to loosening of pipe couplings due to insufficient coupling locking force and hydraulic leakage, ultimately resulting in gas shutdown during dual-fuel operation. Fig. 1 depicts the affected pipes (blue and green) and couplings (red).

Therefore, updates were designed for the double-walled pipe couplings. Fig. 2 shows the original and updated designs of ELWI activation pipes, control oil and sealing oil pipes.

The new pipe design enhances the locking force, reducing the risk of hydraulic leakage and pipe breakage. These modified hydraulic pipes are being deployed on both newly built engines and engines already in service.

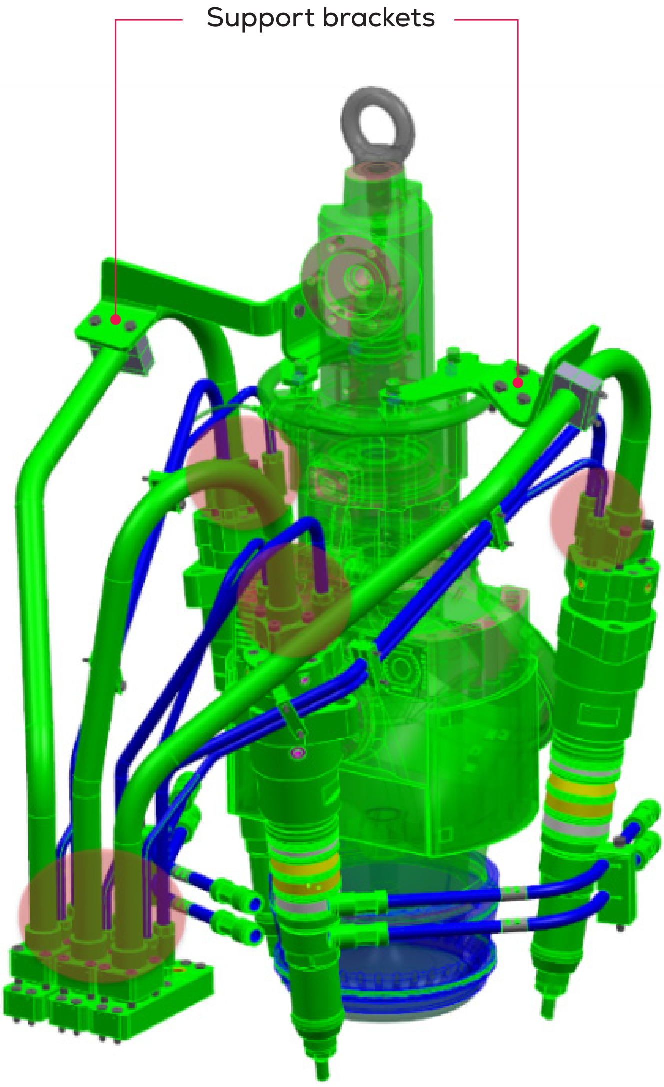

Fig. 1: Hydraulic pipes (blue and green) for activating the ELWI valve, control oil, and sealing oil (couplings marked in red)

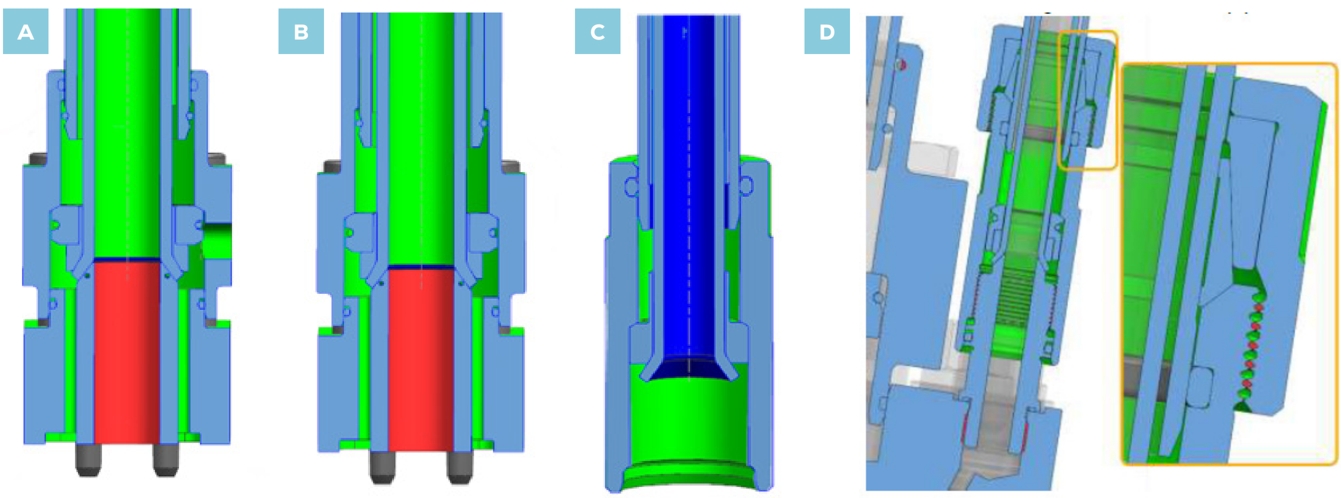

Fig. 2: a) + b) Hydraulic ELWI activation pipes, old and new designs, respectively, and c) + d) Control and sealing oil pipes, old and new designs.

2.2 New cone design in hydraulic high-pressure pipes

Recently, it has been identified that the cone design in hydraulic high-pressure pipes needs updating due to the risk of hydraulic leakage and shutdown during dual-fuel operation. Fig. 3 and Fig. 4 illustrate the original and new designs of the cone, respectively, and Fig. 4 also includes a simulation of the stress distribution of the new cone design.

The new cone design has a 45° cone and a smooth transition to the inner pipe, which has lowered the stress level in the hydraulic pipe connection and also reduced the risk of pipe breakage. Hydraulic pipes with the new design will be supplied to operators of LGIP engines.

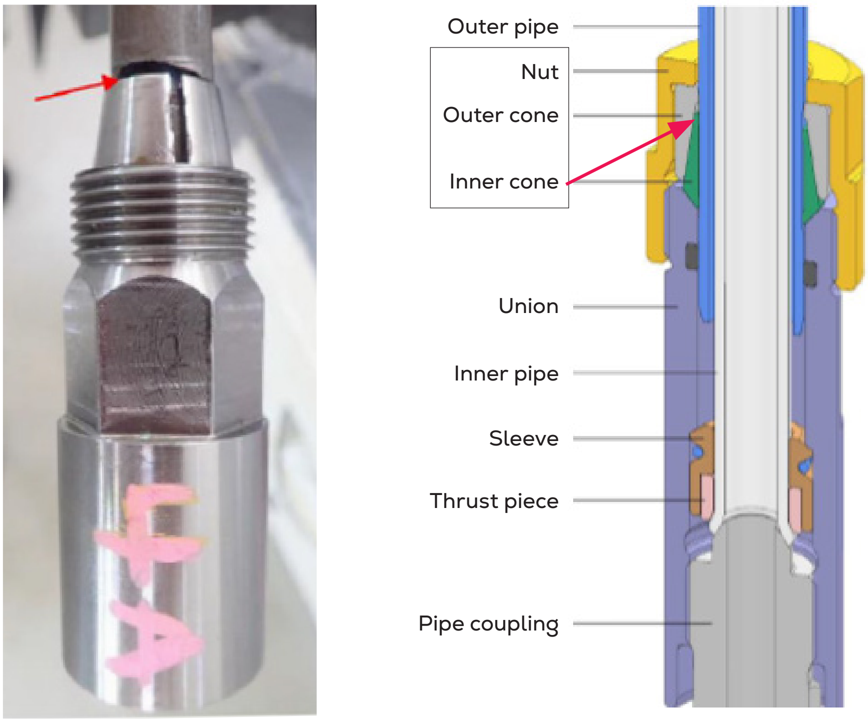

Fig. 3: Original cone design (inner cone indicated by the red arrow)

Fig. 4: New 45° cone design (indicated by the red arrow) with a smooth transition to the inner pipe and b) stress simulation of the new cone design

3. Solutions to low mean pressure alarms

3.1 Sandwich plate with non-return valve

We have found that air can accumulate in hydraulic pipes and bores for the electronic gas injection (ELGI) valve, or within the ELGI valve itself. Fig. 5 illustrates air accumulating in the ELGI hydraulic bore in the top cover of the fuel booster injection valve for LPG (FBIVP), when an orifice connects ELWI and ELGI hydraulic lines during draining.

During changeover from diesel to LGIP operation, the trapped air can result in FBIVP failure and eventually trigger a gas trip. Fig. 6 illustrates a design modification addressing this issue: A sandwich plate with a non-return valve installed in the tank port position (T) of the ELGI valve.

The ELGI valve design with a non-return valve has been successfully implemented in LGIP engines in service.

3.2 Separate venting of ELWI pipe

Fig. 7 shows the second option for avoiding air intrusion in the ELGI hydraulic activation bore, which is to vent the ELWI pipe separately.

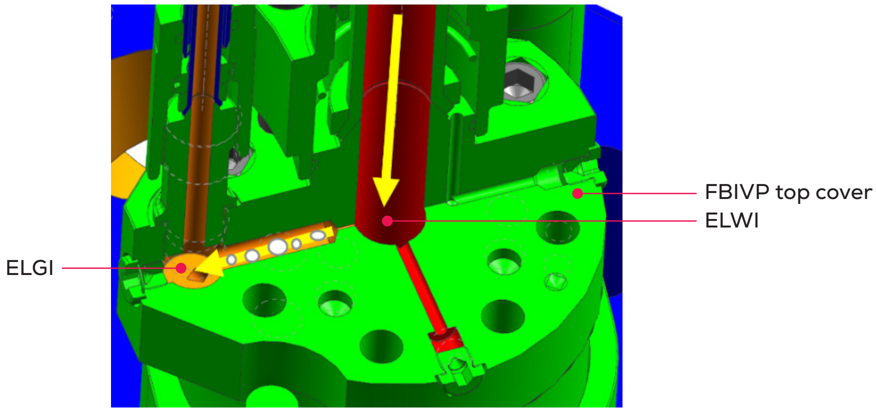

Fig. 5: Air accumulation in the ELGI hydraulic bore in the FBIVP top cover during draining of ELWI and ELGI hydraulic systems

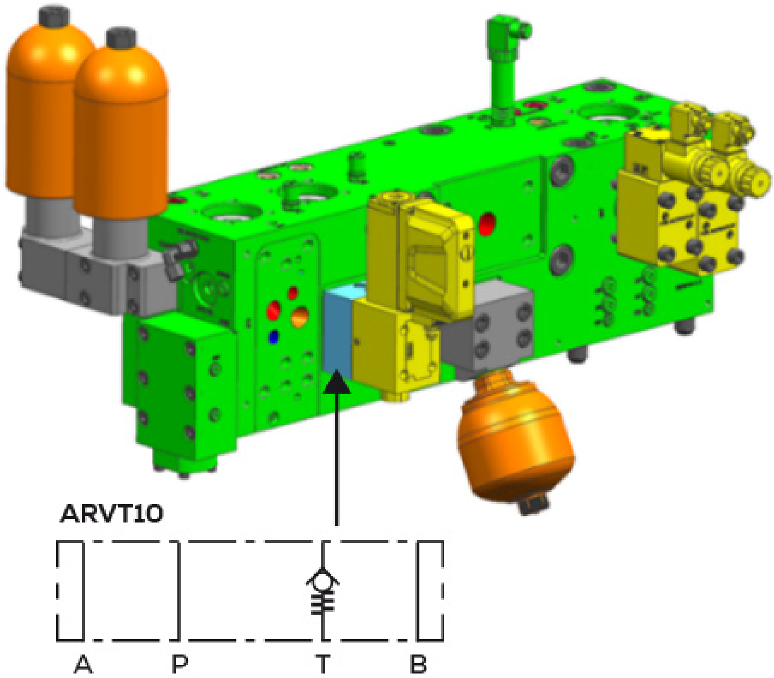

Fig. 6: To prevent air intrusion into the ELGI valve and hydraulic pipe, a sandwich plate with a non-return valve is installed in the tank port (T) of the ELGI valve

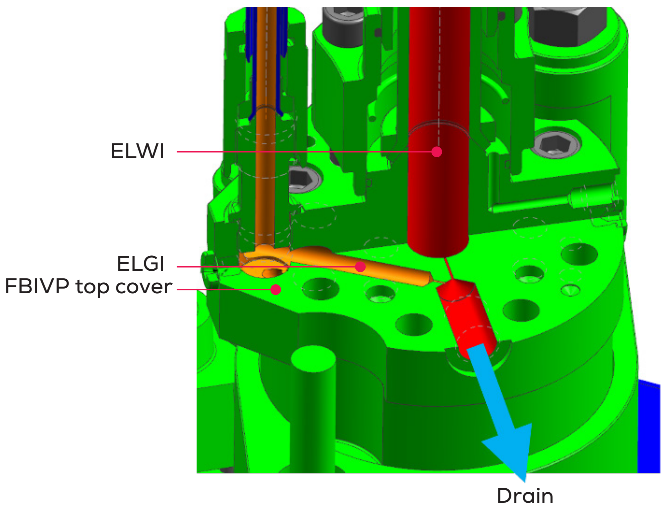

Fig. 7: Redesign of top cover with separate ELWI drain through a non-return valve

This option requires a redesign of the top cover of the FBIVP, modifying the low-pressure supply (LPS) and drain, and introducing a new ELGI adapter block. Fig. 8 illustrates the redesigned and new components necessary for the updated deaeration system.

These design changes have also been successfully introduced on engines in service as an alternative to the ELGI valve with a sandwich plate containing a non-return valve. Both the sandwich plate and the redesigned top cover and drainage solve the air issue. Today, the standard is the sandwich plate design.

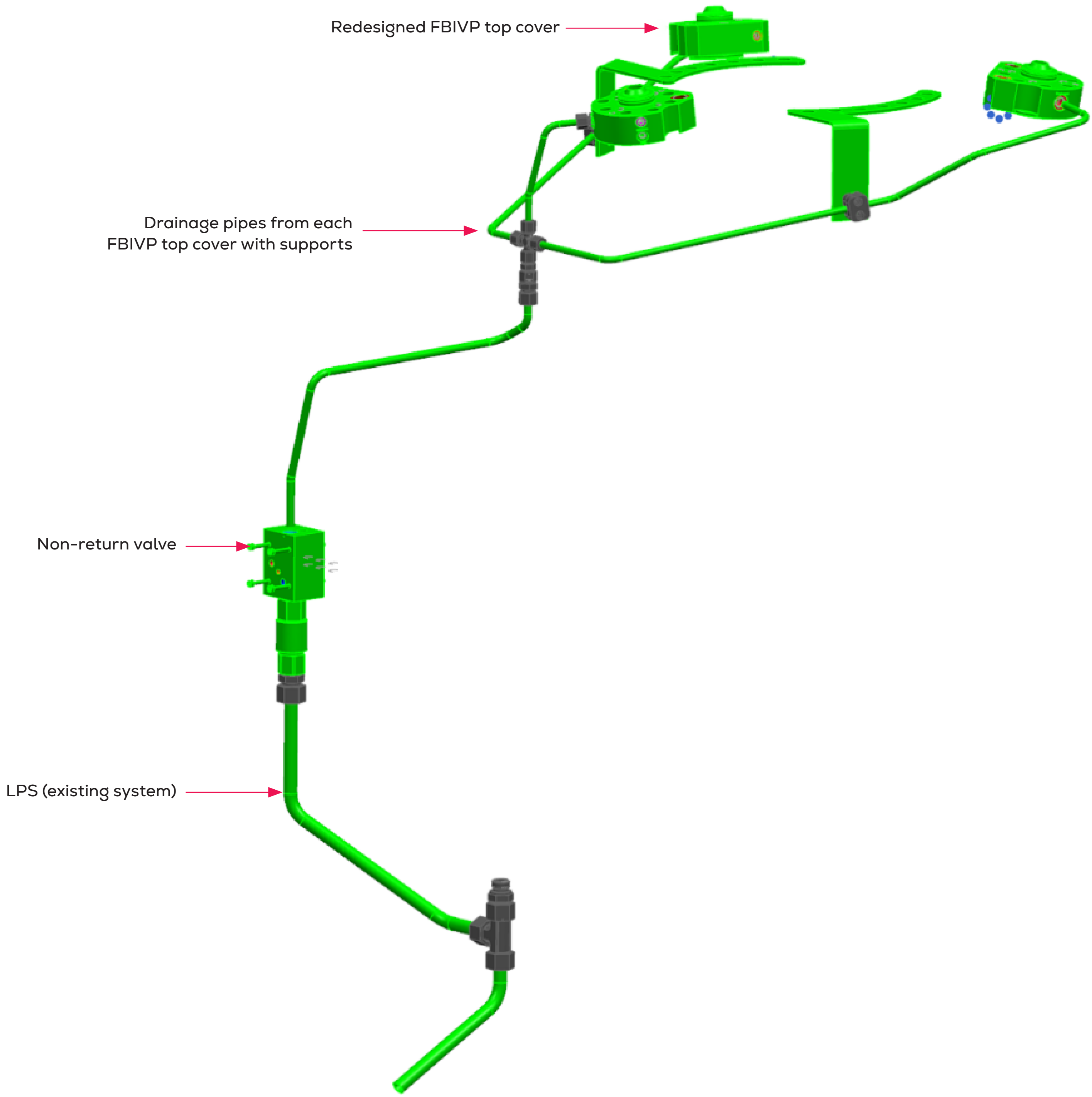

Fig. 8: Overview of all redesigned and new parts required for venting the ELWI pipe separately

3.3 Updated geometry of spindle guide

During an examination of spindle guides, it was found that nearly all of them showed cracks. Fig. 9 shows an example of the cracked area on the spindle guide. The cracked spindle guides are believed to be another cause of low mean pressure alarms.

The cracks were not discovered in the test rig for fuel injection equipment onboard the vessels, since the testing pressure is lower than the pressure in the engine.

Fatigue simulations of the spindle guide geometry were performed using a finite element (FEM) analysis, focusing on the cracked area. The FEM analysis revealed that the wall in the high-pressure booster chamber is too thin, which leads to fatigue and spindle guide material failure. Modifying the geometry of the booster chamber and using a thicker wall (Fig. 10), reduced the fatigue stress.

Besides these changes leak detection holes (Fig. 11) were added to the spindle guide design.

At the time of writing, the supply of more than 2,000 redesigned spindle guides is close to being finalised.

3.4 Gas composition and liquid stability of LPG

In general, LGIP engines are flexible regarding LPG composition and temperature:

- Pressure: 51–53 bar, liquid
- Temperature: 25–45°C
- Injection pressure: 600 bar

The liquid stability of LPG depends on the composition of the gas, as illustrated in Fig. 12.

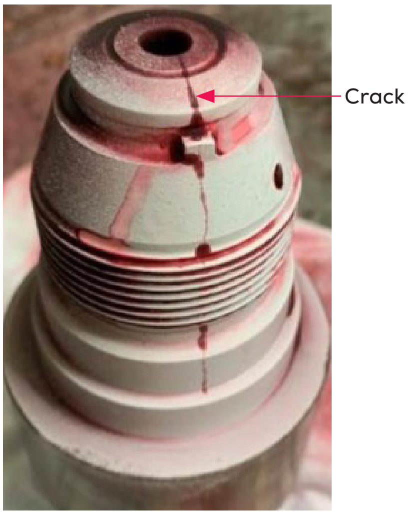

Fig. 9: Cracked spindle guide

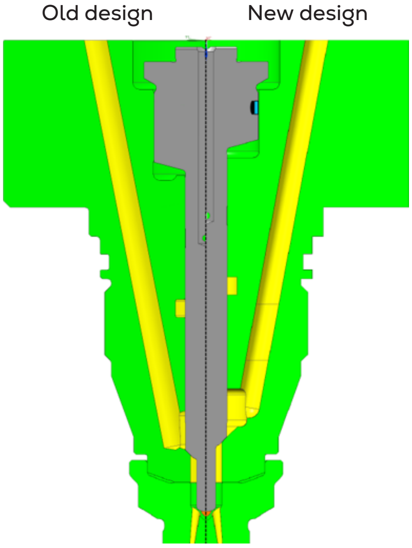

Fig. 10: Comparison of old and new spindle guide designs

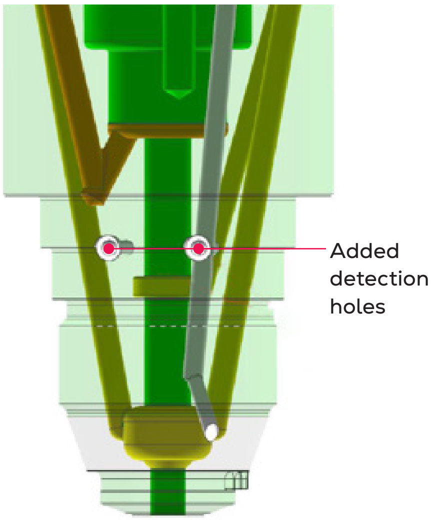

Fig. 11: New spindle guides with leak detection holes

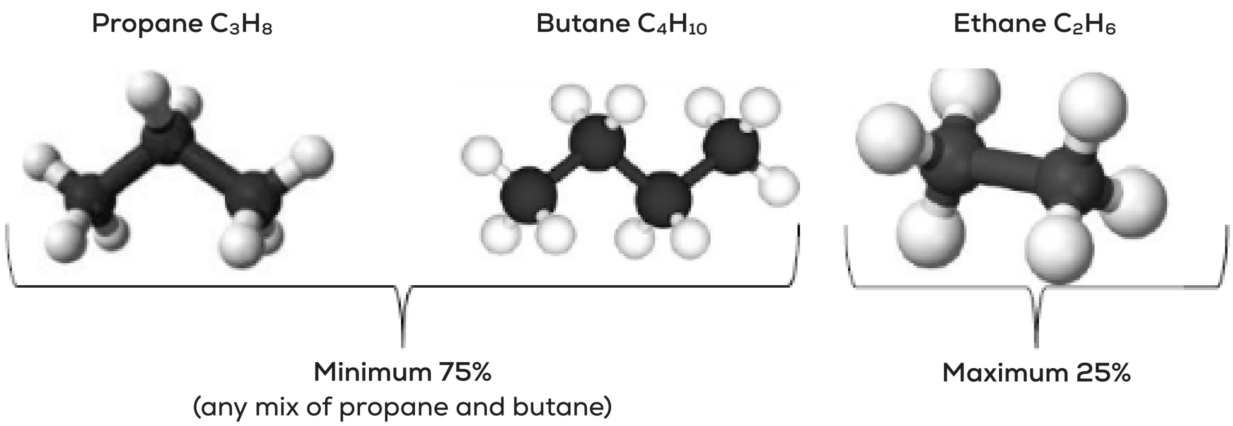

Fig. 12: Allowable range of gas composition: Minimum 75% propane and butane, in any ratio of these, and maximum 25% ethane

If the LPG contains mostly butane (C_4H_{10}) and less propane (C_3H_8), the liquid stability will be high and the LPG will stay liquid at relatively low pressure and high temperature. However, if the LPG contains mostly propane, the liquid stability will be low, and the LPG will become gaseous at relatively high pressure and low temperature. In conclusion, the risk of a phase change (micro boiling) of the fuel in the injection equipment (booster chamber) depends on the gas composition, i.e. the ratio of propane and butane within the allowable range. Furthermore, micro boiling poses a risk of cavitation in the injection equipment.

Fig. 13 and Fig. 14 present the phase diagrams for propane and butane, respectively, illustrating the different conditions under which phase changes occur in propane and butane.

Fig. 13 shows that for the expected LPG conditions in the FBIVP booster chamber, propane is in the micro-boiling state, whereas butane (see Fig. 14) is in a sub-cooled state.

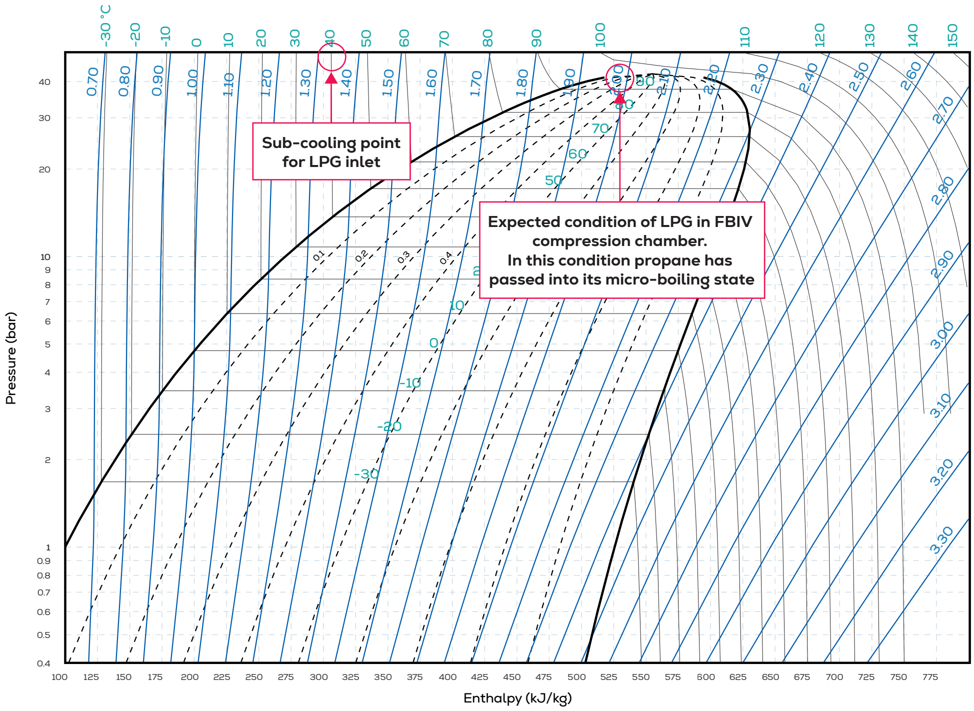

Fig. 13: Phase diagram for propane with LPG conditions indicated for the engine inlet and FBIVP booster chamber

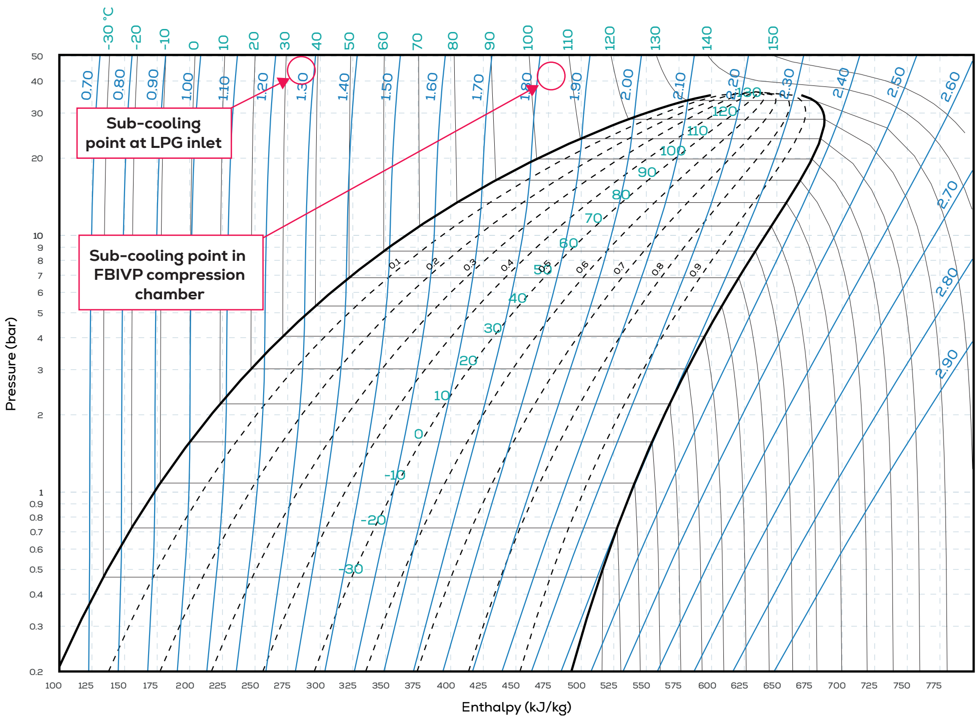

Fig. 14: Phase diagram for butane with LPG conditions indicated for the engine inlet and FBIVP booster chamber

Fig. 15 shows as an example, damaged pressure transmitters caused by a phase change of LPG.

Fig. 15a displays damaged pressure transmitters from an engine operated mainly on gas with a high propane content, whereas Fig. 15b and Fig. 15c show undamaged pressure sensors from an engine operated mainly on gas with a high butane content.

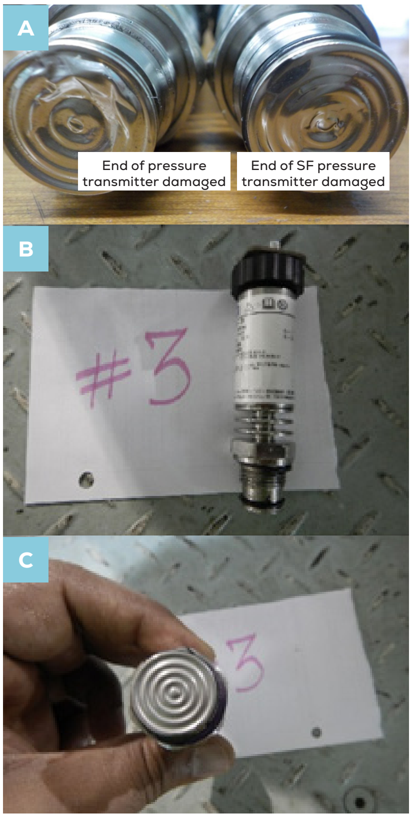

Fig. 15: a) Damaged pressure transmitters from an engine operated mainly on propane and b) + c) undamaged pressure sensors from an engine operated mainly on butane

The following five sections briefly describe possible countermeasures to avoid a phase change.

3.4.1 Orifice plate between return oil valve and gas control block – G60ME-C10.5LGIP

The first countermeasure is to install an orifice plate between the return oil valve (ROV) and gas control block, as shown in Fig. 16.

Throttling of the ELWI valve tank port maintains the LPG pressure inside the FBIVP booster chamber by slowing down the plunger return speed. Without the orifice plate, the booster chamber volume is expected to increase at a higher rate as the plunger returns, and the incoming LPG must compensate for this change. This may result in a pressure drop in the booster chamber, leading to a transition of LPG from the sub-cooled to the micro-boiling state.

3.4.2 Prolonged LPG circulation in FBIVP

An update of the ECS software, which prolongs the LPG circulation at a high flowrate has been introduced. Thereby, the FBIVP is cooled before LPG operation begins, and the LPG in the booster chamber remains in the sub-cooled state.

3.4.3 Reduction of ELWI activations

The temperature of the LPG trapped in the booster chamber increases each time the ELWI valve is activated without opening the spindle guide. This may cause the LPG to shift into the micro-boiling state. An ECS software parameter upgrade has been introduced, which reduces the number of ELWI valve activations before LPG operation begins, thereby avoiding the LPG temperature increase inside the FBIVP.

3.4.4 Increased LPG supply pressure

An increase in the LPG supply pressure has been introduced by upgrading the ECS software parameter. Increasing the LPG supply pressure moves the LPG condition further into the sub-cooled state.

3.4.5 Removal of non-return valve in gas block

The non-return valve in the gas block restricts the circulation rate, which causes a temperature rise of the LPG in the booster chamber. Removing the non-return valve eliminates this flow restriction, allowing the LPG to flow unrestricted between two injections.

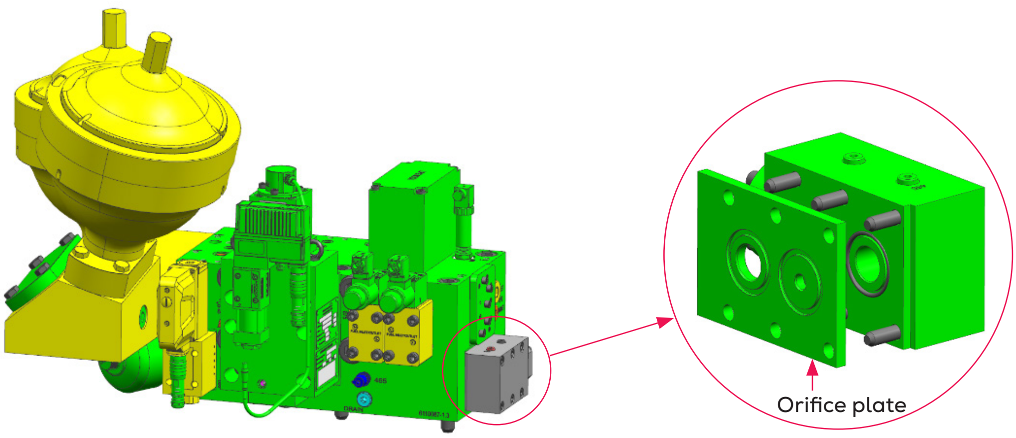

Fig. 16: Gas control block and return oil valve

3.5 FBIVP design changes

3.5.1 Increased clearance and double-sealing

More than 30 vessels have reported cases of seized plungers in FBIVPs, resulting in low mean pressure. The seized plungers (Fig. 17) were found in FBIVPs from different suppliers.

Various factors can cause plunger seizure:

- Particles in the bunker
- Insufficient filtration of the LPG due to an insufficient filtration area or a filter not meeting the specification.
- LPG phase shift can cause the plunger to move fast and potentially cause damage and subsequent seizure.
- Because of the small clearance between plunger and barrel, thermal expansion in the transient condition, and geometrical deviations can lead to seizure (thermal difference between counterparts)
- Geometry of the hole in the barrel.

To eliminate seizures caused by production tolerances, we have introduced slightly increased clearances.

To reduce sealing oil leakage in plunger-barrels, an additional sealing ring was introduced in the test design in Fig. 18. However, tests revealed that this design did not reduce clogging of the atomisers and the extra sealing ring design was therefore abandoned.

3.5.2 Design and material update

FBIVPs have been susceptible to leakage due to weak O-ring materials and a low safety factor for the original two-part thrust piece. This has led to significant sealing oil leakage, thrust piece breakdown, and dual-fuel shutdown.

Fig. 19 illustrates the result of the initiated design and material update of the FBIVP. Furthermore, Fig. 19 illustrates the reduction in sealing oil pressure from 80 bar to 65 bar, and the introduction of a one-part thrust piece.

All FBIVP designs have been updated, and at the time of writing, the implementation is 90% complete.

Fig. 17: Plunger with seizure indicated

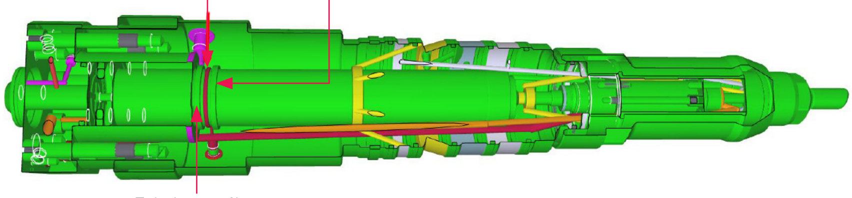

Fig. 18: Double-sealed FBIVP design with increased clearances

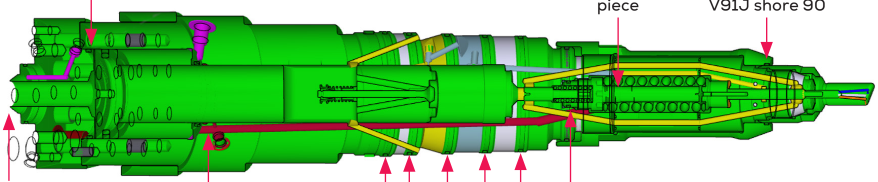

Fig. 19: Design and material update of FBIVP

4. Optimised nozzles

Nozzle clogging and hot corrosion (Fig. 20) have been reported in LGIP engines, resulting in FBIVP failure, reduced mean pressure, and gas shutdown.

Three nozzle materials and two types of nozzles are being investigated to find a solution to clogging and hot corrosion issues. At the time of writing, a slightly longer (5 mm) nozzle made of Inconel has become the standard nozzle based on service test results. Fig. 21 compares the original nozzle design and the present standard nozzle design.

Fig. 22 shows Inconel nozzles, which have been in service in LGIP engines for more than 5,000 running hours.

The test results show that the 5 mm longer nozzle design in Inconel makes a good compromise between clogging and hot corrosion.

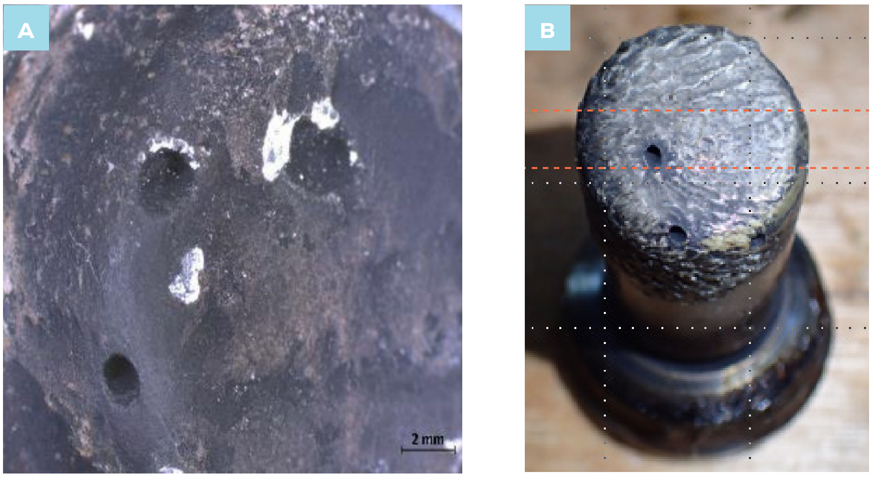

Fig. 20: a) Nozzle clogging and b) hot corrosion

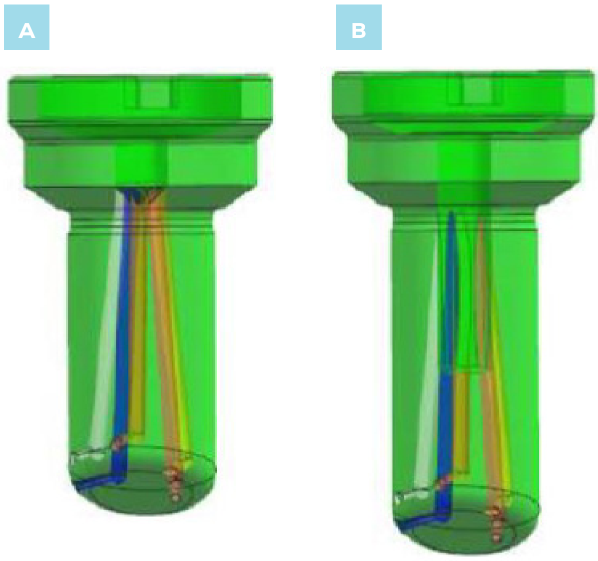

Fig. 21: a) Original nozzle design and b) present standard nozzle design

Fig. 22: Inconel nozzles, which have completed over 5,000 running hours in LGIP engine service tests

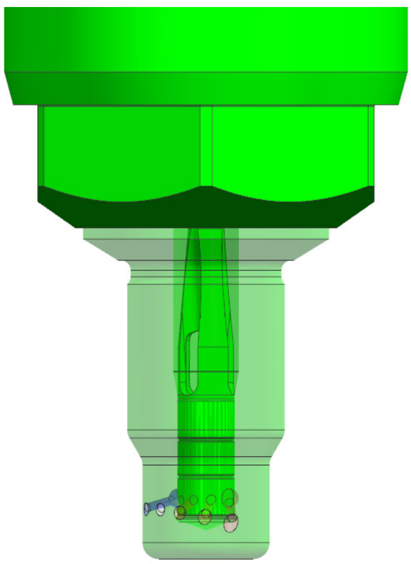

Fig. 23: Nozzle slide valve design – tested with negative results

As an alternative to Inconel, M390 nozzles have been in service for more than 4,000 running hours. However, tests are still ongoing to increase the lifetime of LPG nozzles further. The slide valve design illustrated in Fig. 23 has been tested without positive results.

To reflect the actual running hours, a reduction of the LPG nozzle lifetime from 8,000 to 4,000 running hours has been communicated lately. Furthermore, 'dummy equipment' has been introduced to support longer periods of running in (diesel) fuel mode. The dummy nozzle in Fig. 24b is the first level of rebuilding, and the dummy FBIVP in Fig. 25 as well as blanks for pipes and gas blocks are the next level for extended 'off-LPG' operating periods.

Fig. 24: a) LPG nozzle compared to b) dummy nozzle without nozzle holes

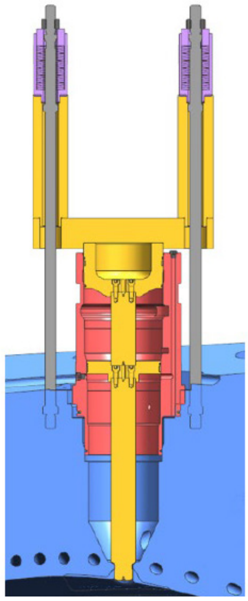

Fig. 25: Dummy FBIVP

5. Conclusion

This paper has demonstrated a rather long list of countermeasures introduced to stabilise LPG running on LGIP engine types. Most of these countermeasures are now implemented, also on engines in service, and gas (LPG) operation has improved significantly with much fewer gas shutdowns. This achievement is naturally also extremely important for new orders of vessels with LGIP engines, such as very large gas carriers (VLGCs) and medium size gas carriers (MGCs).

6. Acronyms

ECS	engine control system
ELGI	electronic gas injection (valve)
ELWI	electronic window (valve)
FBIVP	fuel booster injection valve – LPG
FEM	finite element method
LGI	liquid gas injection
LPG	liquefied petroleum gas
LGIP	liquid gas injection LPG
LPS	low-pressure supply
MGC	medium size gas carrier
ROV	return oil valve
VLGC	very large gas carrier

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