

Service Experience of WinGD's Low-Pressure Dual-Fuel Two-Stroke Engines - The X-DF Engine Generation in the Field

9 - New Engine Developments - Gas & Dual Fuel

Paper 423

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ABSTRACT

The X-DF engine has been developed by WinGD and design details were presented during the CIMAC 2016. The X-DF low pressure gas engine applies the Otto Cycle principle which has never been applied before on large 2-stroke marine engines. After the successful testing and optimisation of the concept on test engines the first commercial engine started service operation in June 2016 powering a 15k Product carrier.

As of August 2018, close to fifty X-DF engines passed factory acceptance tests successfully and about fifteen vessels driven by one (or two) X-DF engines are in operation meanwhile. Most of these engines were built in Korea and China, and some in Japan. The engine fleet has accumulated close to 100'000 operating hours as of August 2018, running mostly on gas.

Teething problems were noted and resolved, with none of them being major. Operational issues on the first commercial engine type, the RT-flex50DF, were resolved in time.

The availability of gas mode on LNG carriers with X62DF and X72DF engines have an impressive level of 97~98% of the total operating time, demonstrating the reliability of the individual systems. On these vessels, diesel mode is only used for berthing respectively engine starting after port call.

For easy and continuous monitoring the 'Data Collecting and Monitoring' (DCM) system was installed on some of the first engines in operation to collect operating parameters and to transmits them to ashore for evaluation.

One focus area in service was the pilot injector design with integrated pre-chamber. The first engines partially suffered from exhaust gas leakages between injector and pre-chamber, followed by corrosion damages on the injector with consequential water ingress to the cylinder liner. By the redesign of the sealing surfaces the operating issues could be solved.

Due to the fact that natural gas contains no sulphur, gas mode operation requires low BN cylinder lubrication oil. The application of BN25 oils has proven to satisfy the demand for lubrication in gas operation. Nevertheless, further improvements for the different requirements during Diesel and Gas operation led to a collaboration with oil suppliers and the definition of new lube oil formulations for X-DF engines. Experience has also shown, that while changing from gas to HFO/MDO operation (or the other way around) attention has to be put on the timely changeover of the cyl lube oil type, to ensure continuous optimum piston running conditions. Therefore, an automatic lube oil changeover device (iCAT) was developed and implemented allowing a faster and more precise changeover.

On X-DF engines, the cylinder pressure sensors are mounted flush to the combustion chamber. This means that the sensors are exposed to high temperatures and combustion deposits may build up over time what may lead to a drift of the pressure signal. A mechanical cleaning is required. For easier maintenance and extended cleaning intervals of the sensors new solutions are under development.

A similar issue is seen on the gas sniffers in the piston underside space which may show clogging orifices of the collecting piping over time. Gas detection on piston underside space is a class requirement. Further design development is needed to increase the cleaning intervals. However, very reliable has proven to be the stroke sensor for the GAV (Gas Admission Valve), which detects if a GAV stays open unexpectedly – in which case the engine trips to Diesel immediately

Gas operation at heavy sea condition brought some challenges associated with fuel gas supply pressure fluctuations (from ship side fuel gas system), leading to increasing engine speed fluctuations, which then resulted in the engine tripping to Diesel. Finetuning of the gas fuel system controls has shown to overcome these occurrences.

To ensure full engine power output availability under any operating conditions the 'Dynamic Combustion Control' (DCC) functionality has been developed. At high engine power, warm and humid ambient conditions and/or low Methane Number (MN), the cylinder pressures might exceed the normal operating range. In this case a small quantity of liquid fuel is being injected into the combustion process through the main fuel injectors, leading to smoother combustion with reduced peak pressures. DCC is included in the engine control system and operation with DCC is certified to be fully IMO Tier III compliant.

1 INTRODUCTION

The X-DF engine concept has been developed by WinGD and design details were presented during the CIMAC conference 2016. The X-DF low pressure gas engine applies the Otto Cycle principle which has never previously been applied on a commercial scale on large 2-stroke marine engines.

The following paper shall give insights into the service experience gained over the last 3 years, since the first DF engine powered ships entered service operation. Subsequent countermeasures have been introduced for resolving reported issues.

2 DUAL FUEL ENGINE SERVICE EXPERIENCE

After the successful testing and optimisation of the concept on lab engines in Italy and Japan, the first commercial engine started service operation in June 2016 powering a 15'000ton Product carrier. In the course of the following months sister vessels, also powered by the RT-flex50DF engine type followed. In July 2017 the first Liquefied Natural Gas Carrier (LNGC) powered by Twin 6X62DF engines entered commercial operation.

As of January 2019, nearly 60 X-DF engines have passed factory acceptance tests successfully and twenty vessels driven by one or two (Twin Skeg) X-DF engines are in operation. Most of these engines were built in Korea and China, with some in Japan. The engine fleet has accumulated totally 180'000 operating hours as of late February 2019 and is running mostly on gas.

The availability of gas mode on LNG carriers with X62DF and X72DF engines have an impressive level of more than 97% of the total operating time, demonstrating the reliability of the individual systems. On these vessels, diesel mode is only used for berthing and engine starting after port call. Note; starting in Diesel mode is a requirement by the classes.

The orderbook indicates today a big number of X-DF engines for powering standard size LNG Carriers with Twin engine configuration. Due to the simplicity of the low-pressure gas system (gas supply pressure requirement is <13bar), along with the engine's IMO Tier 3 compliance in Gas mode it seems to be a preferred propulsion solution in the market.

Despite all efforts some teething problems were reported which are listed hereunder. They were however dealt with in a timely manner so that mostly they are resolved by now.

2.1 Issues observed on RT-flex50DF

The first Dual Fuel engines installed in a ship – the RT-flex50DF engines – faced a variety of issues during the first months in operation which are explained herewith.

The first engine has in the meanwhile accumulated more than 15'000 running hours.

2.1.1 Water leakage pilot injectors

Due to improper sealing of the pilot injectors / pre-chamber (which is water cooled) water leakage into the combustion space was noted, eventually leading to problems with piston running. The sealing method (gaskets, bolts, tightening) had to be improved accordingly. All engines were upgraded.

2.1.2 Tuning optimisations

The premixed flame (Gas mode operation) shows a different pattern of heat release compared to diffusion flame (Diesel mode). On DF engines this means an increase of combustion chamber temperatures – which resulted in an increase of component temperatures, negatively influencing the piston running behaviour (deposit build up on piston). An improved tuning strategy had to be developed to ensure staying within safe levels of cylinder liner wall temperatures.

2.1.3 Load program

Sufficient loading up times are important on these large 2 stroke engines to ensure that heat expansion rate of combustion chamber components is equal. On DF engines operating on gas the correct loading up time is even more important because of the above mentioned higher heat impact. A very quick loading up for example can result in a piston that is growing quicker than the cylinder liner, leading to reduced running clearance and ultimately contact between piston and liner, followed by a mechanical damage (scuffing). Improper load up times were an issue on the pilot project vessels, equipped with Controllable Pitch Propellers (CPP) which lead to a number of failures. Implementing standard loading up times resolved this topic.

2.1.4 Lubrication

The above mentioned higher combustion chamber temperatures lead to a higher cylinder lube oil stress. As consequence, a higher deposit build up rate has been detected. Combined with a fast loading up and consequently the fast component expansion increases the risk for component damages due to higher friction. The research cooperation with one major lube oil supplier on one of the pilot engines helped to

better understand lubricant oil stress in a DF engine. It furthermore supports the further optimisation of the cylinder oils (see CIMAC paper 005, Vancouver 2019).

2.2 Operational issues on X62DF / X72DF

The first X62DF powered vessel, a 174k LNGC built by Samsung Heavy Industries in Korea was delivered in July 2017. The ship has in the meanwhile accumulated more than 11'000 running hours per engine. A few issues became visible on this ship – as well as on other X62DF/X72DF powered vessels - which are explained in the following section.

2.2.1 Cylinder pressure sensor clogging

On X-DF engines, the cylinder pressure sensors are mounted flush to the combustion chamber to ensure a highly accurate pressure signal. By this the sensors are exposed to high temperatures and combustion deposits may build up over time on the sensor surface (see Figure 1) - which can lead to a drift of the pressure signal over time. To ensure the proper functionality of the sensors regular (3~4months intervals) mechanical cleaning is required. A new solution was introduced on the X52DF engine, the most recent addition to the DF family. The sensor is newly mounted inside the cylinder cover relief valves lowest section, which can be 'opened' for air runs, further the sensor dismantling and mounting for mechanical cleaning has been simplified. This solution (once fully validated) will be introduced on the whole portfolio.



Figure 1 – Cylinder pressure sensor with surface deposits

2.2.2 Cylinder liner cooling

The X-62/72DF engines use the same cooling concept as the well-established X-generation Diesel engines, where one part of the Jacket Cooling Water (JCW) is bypassing the shipside mounted cooler – and is led directly to the cylinder liner. The idea is to provide “hot” water to the mid stroke of the liner to avoid issues of cold corrosion. Because of the higher heat impact on combustion chamber components in gas mode

operation the cylinder jacket cooling water flow had to be increased.

Broken holding bolts (which secure the water guide jacket in place) were another issue, leading to a downwards slip of the water guide jacket and an internal bypassing of the liner cooling bores. This led to a reduced water flow over the cooling bores and resulted in an increase of liner wall temperatures (LWT). An improved design of holding bolts resolved this issue.

WinGD released service letters for operators describing a venting method, should a sudden increase of LWT be notified; this mostly helped to stabilize the situation until the root cause was found.

2.2.3 Clogging nozzle tips

During the gas mode operation, the main fuel injectors are inactive but they are still exposed to the heat of the combustion chamber. However, it could be seen that over time the injection bores of nozzle tips start clogging by solid residuals, which ultimately leads to a malfunction of the injector. Due to this deposits in the nozzle bores fuel cannot be injected properly anymore. See Fig. 2.



Figure 2 – Fuel injector nozzle tip with 3 (out of 5) clogged atomizer spray holes

With the current design of fuel injection equipment this issue seems difficult to resolve; on injector inlet side a permanent high pressure is present (to allow immediate tripping to diesel, without it the engine would stall) whereas on combustion chamber side combustion is active.

The remedy introduced was fairly simple: Experience has shown that regular switching to Diesel mode (a few minutes once per week) helps to minimize or even fully resolve this issue. The diesel injections help to free the atomizer bores (acting like ‘cleaning shots’). A service letter with relevant instructions was released October 2018.

2.2.4 Gas detection pipe clogging

As part of the approved safety concept on DF type engines, the piston underside space has an active gas detection monitoring applied. As commonly known, the piston underside is a pressurized space with lots of solid and liquid residues literally “flying” around. It was noted that the gas piping connecting to the central Gas sensor unit was prone to clogging (in particular the pressure reducing orifices). Different executions were tested in the field until a proper solution was found in January 2019.

Despite the clogged gas detection piping the safety of the engine in gas mode was never jeopardized – the active monitoring of the gas admission valves (GAV) allows an immediate detection of a malfunctioning GAV (which basically provides the fuel gas into the liner) – in which case the safety system triggers immediately a trip to diesel.

2.3 General observations in service

2.3.1 Piston running

Piston running on DF engines is very stable. Due to the absence of Sulfur in the fuel when running in Gas mode, piston running seems very robust. The applied cylinder lubricating oil (BN15-25 recommended for Gas mode operation or MGO e.g. during maneuvering) takes over a ‘lubricating and cleaning’ role. See Fig. 3.



Figure 3 – cylinder liner of a X62DF engine in excellent condition (with visible gas nozzles in mid stroke position).

Sulphur impact from pilot fuel is very minor and therefore neutralization neglectable. This also implies that the focus during piston underside sampling is more on the analysis of the ‘iron content’. See Fig 4.

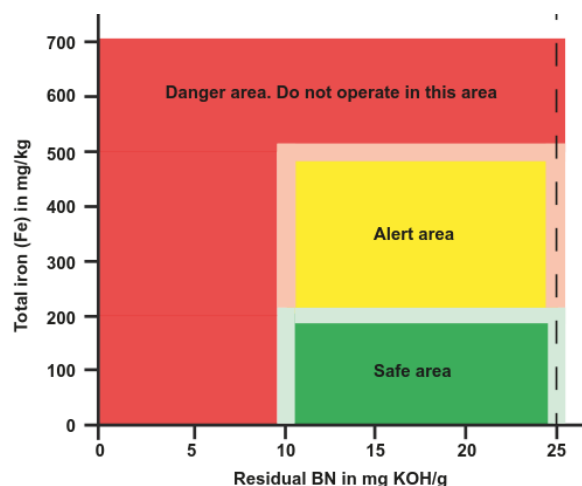


Figure 4 – Piston underside sampling criteria for judging of piston running behavior, BN<25 lubricants

2.3.2 Engine control system

In the initial concept for Gas mode operation an external load signal was needed. This approach was chosen to minimize effects of fuel gas changes (e.g. gas composition linked to calorific heat values) which may occur over time. It turned out however that an instable Shaft Power Meter (SPM) signal would easily lead to a trip to diesel. In a new control logic introduced mid 2018 the external signal is being used now as ‘reference’ signal to align the engine control system internal computed load signal. This allows not only more independency from instable SPM signals, but also helped to cope with quick load changes (e.g. during rudder maneuvers).

2.3.3 Dynamic Combustion Control

Mid 2016 WinGD introduced the Dynamic Combustion Control (DCC) functionality to counteract adverse ambient conditions (hot and humid) for high load Gas mode operation. Through the main fuel injectors, a small amount of liquid fuel is then being injected, allowing the engine to reach full power output e.g. even in the tropic areas. The total energy consumption remains the same however.

It was seen that DCC was rarely active in service on the early installations, and tuning improvements could increase the limits to activation further.

Following field feedback the requirements on design side were adapted; namely:

- Update of scavenge air cooler (SAC) specification to improve cooling capacity
- Low temperature (LT) cooling water circuit temperature set point changed to 25deg to increase cooling flexibility
- Ensure sufficient Light Running Margin (LRM) as per WinGD spec 4~7% for a new ship to avoid overloading.

2.4 Brief technology updates

Following market needs WinGD developed a number of new technologies around the DF engines of which the most relevant are listed here:

2.4.1 Fuel Sharing Mode

LNGC operators were asking for a possibility to develop a mixed operating mode, where in case of a shortage of Gas onboard (e.g. reduced Boil Off Gas amount) the engines could be operated with topping up energy in liquid mode. Mixed operating modes on ships were already known from 4 stroke DFDE (Dual Fuel Diesel Electric) applications where some engines operate on Gas, whereas others may run in liquid mode.

On 2 stroke Otto cycle engines the technology could be introduced using both injection systems: The Gas Admission Valves (GAV) mounted on the mid stroke of the cylinder liner (injecting the fuel gas at relatively low pressures) – combined with liquid mode injection via the main injectors on the cylinder cover. Fuel Sharing Mode (FSM) as a third operating mode is tuned to be IMO Tier 2 compliant and allows any energy share ratio between 5 – 50% in the power range of 50-100% load. See figure 5.

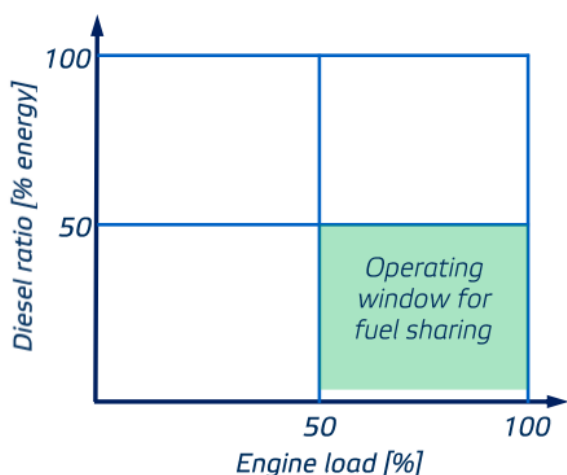


Figure 5 – Operating window for Fuel Sharing Mode on DF engines

As of today a big market demand for Fuel Sharing Mode is seen, particularly for LNGC.

2.4.2 iCAT

The 'iCAT' (integrated Cylinder lubricant Auto Transfer System) was introduced to ensure that the right cylinder oil is being fed to the cylinder liner at the right time. The 'iCAT' system contains two cylinder oil feeding lines (low & high BN) which are mounted inside the rail unit and provide cylinder oil to a 3/2 way valve, which then provides the correct oil to the cylinder lubricating pump. See figure 6.

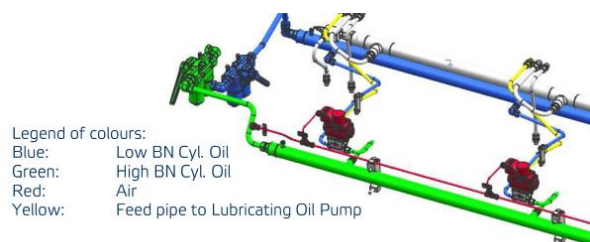


Figure 6 – Visualization of iCAT system inside the rail unit box

The 3/2 way valve is installed very close to the cylinder lubrication oil pump. By this method, the switch over time of the cylinder oil can be minimized, compared to a conventional switch over where a large amount of oil in the pipes from switchover valve (yard side) to engine has to be consumed first, which takes several hours typically until the fresh oil arrives in the cylinder lubricating quills.

iCAT is standard for DF engines today and operators can profit from the quick switch over; e.g. when changing from liquid mode over to Gas mode, a process that takes around 1 minute.

2.5 iGPR

The first generation of WinGD's Dual Fuel engines were utilizing Wärtsilä's Gas Valve Unit (GVU) in the fuel gas supply system. The GVU controls the gas pressure to the engine and provides safety functions (e.g. shut-off valves to cut the gas supply).

In 2017 WinGD started to develop an engine integrated solution to simplify the layout, systems communication and having basically one supplier for the main engine propulsion package. See figure 7.

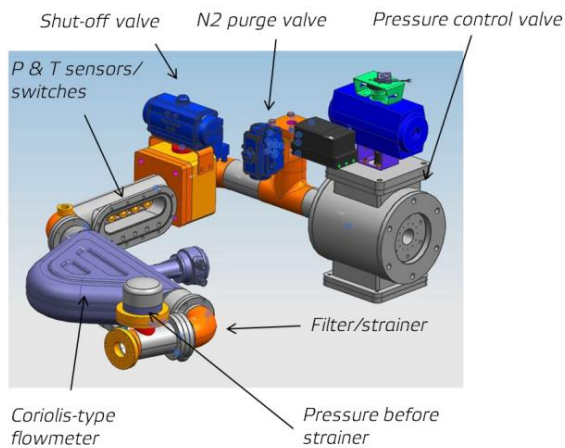


Figure 7 – Concept arrangement of the iGPR

The 'iGPR' (integrated Gas Pressure Regulation) was launched on the X52DF engine in Nov 2018, the first commercial engine, following extensive testing on WinGD's lab engine RTX-5. Swiftly following is the 92DF type, and thereafter the iGPR will be rolled out for the entire DF engine portfolio.

3 CONCLUSIONS

Overall the DF engines show a very good performance in the field, with the fleet having accumulated over 160'000 running hours totally and over 15'000 running hours on the first engines. Some minor teething issues were reported and tackled in time.

On the other side, development never stops and in this respect also WinGD is pursuing continuous improvements on the relatively new DF engine technology to further enhance their performance to satisfy our dear customers.

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