WIN GD
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WinGD 12X92DF, the Development of the Most Powerful Otto Engine Ever

9 - New Engine Developments - Gas & Dual Fuel

Paper 425

Dominik Schneiter, WinGD
Vice President R&D

Stefan Goranov, WinGD
Program Manager Hybridisation

Marcel Ott, WinGD
General Manager Operations

Patrik Printz, WinGD
Project Manager DF

ABSTRACT

For years, the public and regulatory pressure continuously forces shipping to adapt new engine technologies to ensure a cleaner environmental footprint. Additionally, to guarantee green transportation to their customers, shippers are challenged by major cargo owners and logistic companies to go even further beyond the thresholds set by regulators .

In such business environment, the pressure on WinGD increased to make the most powerful engines applied in very large container vessels available also with X-DF technology. The X-DF burns LNG in a lean cycle, which practically omits particulate matter (PM), sulphur oxide (SOx) emissions and drastically reduces Nitrogen Oxides (NOx) to below IMO Tier III level. Additionally, the carbon oxide (CO2) and CO2 equivalent are also reduced to below diesel combustion levels. Those were strong arguments for the 1st customer to commit into a project with the new engine and propulsion technology for container vessel designs with the size of 22’000TEU.

In this paper, WinGD experts will elaborate how the experience and knowledge gained with X-DF engines in the mid bore range (i.e.: X62-DF/ X-72DF) were up-scaled and adapted to the current biggest bore size of the X-92DF. In particular, it will address the challenges with achieving a homogenous gas air mixture, igniting the combustion and the thermal loading of the components. It will also address the particulars of the lean burning cycle and the effect it has on the engine structure with related design upgrades. Additionally, the paper will show the complexity associated with controlling such an engine. It also gives some insights on the development of the next generation WinGD control system, which took place in parallel with the base engine development.

Among the different development tasks, the unique X-DF technology and its potential for the shipping industry will be discussed. The technology is still at the beginning of it’s lifecycle, and major development steps are still expected. The paper will highlight some of them. Upon the Vancouver congress, test results from the very 1st 12X92DF will likely be available and can briefly be summarized in the presentation.

With the 12X92DF, WinGD has now undertaken the task to proof that also largest engines can operate in a lean burning cycle, and is therefore offering completely new propulsion options to the industry, which can be adapted and optimized according requirements of cargo owners, shippers and public views.

1 INTRODUCTION

With the 12X92DF, Winterthur Gas & Diesel (WinGD) undertook to develop the most powerful lean burning, pre-mixed Otto cycle reciprocating combustion engine ever.

The key technology driver for development of a lean burning engine running on liquified natural gas (LNG) as fuel, were the unprecedented environmental benefit with the clean fuel, combined with a combustion cycle that allows to control the Nitrogen Dioxides (NOx) well below current emission limit levels.

Key gaseous local pollutions normally present with the standard diesel cycle engines running on residual fuels, like Sulphur Dioxides (SOx), NOx and particulate matters (PM) are mostly eliminated. In addition, and considering all currently known and IPCC (Intergovernmental Panel on Climate Change) declared green house gases, the green house gas emission footprint of a LNG burning ship with a lean burning cycle main engine has been reduced up to 20% compared with a standard diesel or heavy fuel oil (HFO) application.

Making available a considerable cleaner solution compared to todays gaseous emission references in merchant shipping has been recognized and awarded by well-known shipping industry organizations. The WinGD X-DF concept earned amongst other below recognitions:

- The 2018 Marine Propulsion Emission Reduction Award
- The 2017 Marine engineering of the Year award issued by the Japan Institute of Marine engineering
- Shortlisted 2018 Safety4 Sea Sustainability Award
- Shortlisted 2018 The Motorship emission reduction Award.

However, it is obvious that an engine powered by fossil fuel like the X-DF with liquified natural gas (LNG) in gas mode will by itself not be enough to meet the ambitious International Maritime Organization (IMO) declared green house gas (GHG) reduction targets of the shipping industry. We at WinGD see the lean burning cycle applied on a slow speed 2-stroke as one feasible way to accommodate a higher variety of future Carbon Dioxide (CO_2) neutral fuel, hence enabling the Industry to seek and develop indeed sustainable solutions.

To make a platform available, eventually meeting current and future emission targets, WinGD from the beginning was preparing to roll out the lean burning technology to the entire engine portfolio.

Initially, the lean burning 2-stroke slow speed technology was developed with inheriting knowledge from medium speed applications, particularly profiting from the experience and expertise of Wärtsilä developed solutions [1].

In this paper the technical challenges of a big bore, big volume combustion chamber in combination with a lean burning cycle are addressed. The experience and observations of smaller sized engines are reflected. The paper gives insights how WinGD further developed the technology with the lessons learned and how we ensure a working system without having the possibility of a prototype test.

Additionally, the specific demands to the advanced control system, which is not only controlling 2 complete different combustion cycles, but newly also provides for a high data throughput and effective data analysis in spite of “digitalization” and predicted maintenance capabilities.

A short section in the paper will also address the application and fuel logistic challenges the 1st ship operator had to address with the innovative approach.

Despite the technical challenges and the ambitious schedule, the project has progressed well. It is expected that the 1st engine will start in Q1-2019, and some 1st operational results can be shared during the CIMAC 2019 Vancouver congress.

2 ENGINE DESIGN DETAILS

2.1 General

The herein discussed 12X92DF engine will be installed on a series of 9 x 22’000TEU container vessel trading between Asia and Europe. The ships and the engines are being produced by WinGD’s partner companies within the China State Shipbuilding Cooperation CSSC.

The FAT of the first engine is planed in early June 2019, just at the time of the Vancouver congress. The 1st vessel delivery to the customer will be mid 2020.

The engine selected is rated at its maximum power output and develops 63'840kW at 80 rpms in both, diesel and gas mode operations.

Table 1: Engine particulars

12X92DF	
Bore	920 mm
Stroke	3468 mm
Speed	80 rpm
Power	63840 kW
Mass	2140t
Length	22.87m
Total Height	15.92m

2.2 Combustion System Development

2.2.1 Emission footprint

The NOx emissions in diesel mode comply with IMO Marpol VI Tier II NOx regulations. In gas mode, the NOx emissions are well below the IMO Tier III NOx limits without exhaust gas after treatment.

Fundamentally, based on the gas composition, LNG fueled engines reduce CO2 output by approx. 20% caused by the reduced C content in the fuel. For pre-mixed, lean burning engines however, a certain fuel slip is a reality and need to be addressed. This fuel slip with LNG operated contains CH4 or methane, which is also a IPCC defined green house gas. Consequently, the methane slip needs to be reviewed when defining a total emission footprint of this engine. See figure 2 showing the effective emissions of an X-DF engines compared to the Industry benchmark.

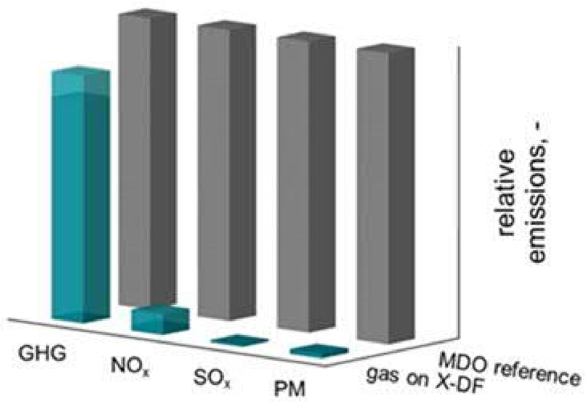

Figure 1: overview pollutants including CO_2e

Due to the larger combustion space in comparison to the former, smaller DF engines, and consequent favorable combustion volume to wall surface ratio, a further reduction of the specific THC/methane emissions is expected. Please find an extended analysis of green house gas relevant emissions of X-DF engines in CIMAC paper 426/ 2019.

2.2.2 Gas admission and pilot injection

In many aspects, the design of the X92DF is a scaled-up version of smaller DF engines [1].

Two gas admission valves (GAVs) are mounted on each cylinder liner. The GAVs are connected to two gas manifolds that run along the engine on both sides.

Pneumatic shut-off and vent valves are arranged at both ends of the gas manifolds for a fast release of the gas pressure providing for the required double block and bleed system.

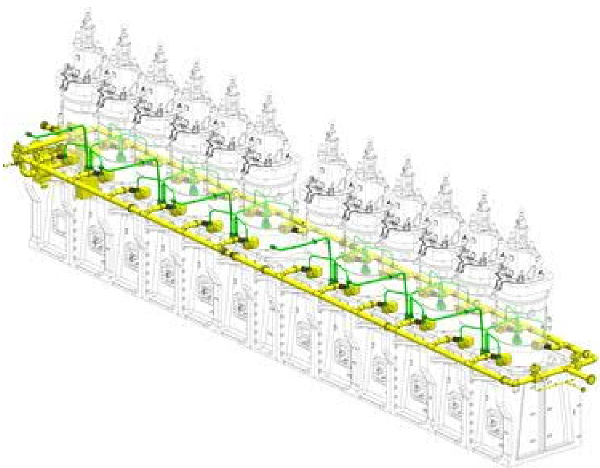

Figure 2: Overview of gas admission

Two pilot injectors with their pre-chambers are arranged in each cylinder cover.

Additionally, the three main injectors for the diesel operation are arranged in the same way as with the standard X92 diesel application in each cylinder cover.

The scaling-up approach not only reduces the risk of new initial design flaws, but also allows to keep the effort for the initial manufacturing of the new, larger components lower. The X92DF is more a technology evaluation, not a revolution.

2.2.3 Higher number of cylinders

However, the higher number of cylinders required adaptations of the design and several design iterations during the development.

For instance, to avoid disturbing pressure oscillations in the long gas manifolds, the system layout was investigated and optimized by simulating the fluid dynamics in detail.

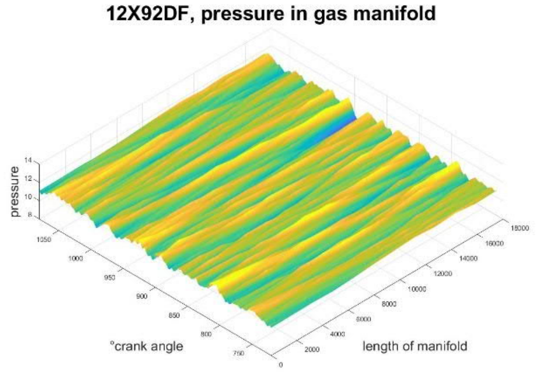

Figure 3 simulation of pressure in gas manifold

Furthermore, and based on the mechanical FEM analysis of the gas pipes, additional elastic bellows are applied in the gas manifolds to reduce the stress triggered by thermal expansion.

The fast release and venting of the gas pressure from the manifolds is an important safety function, which could be realized with the same fast shut-off and vent valves as on smaller X-DF engines, despite the higher number of cylinders.

2.2.4 Integrated gas pressure regulation

So far, the DF engines were combined with an external gas pressure regulating unit called “gas valve unit (GVU)”, a separate module that was installed in the engine room. The GVU was designed and delivered from a third-party supplier.

As a replacement for the GVU, WinGD developed an integrated gas pressure regulation (iGPR). Due to its compact design, the iGPR can be arranged on the platform of the engine. The function of the iGPR is controlled directly by the engine control system.

The iGPR consists of several elements:

- Control valve for the accurate adjustment of the gas pressure for the gas admission.
- Gas filter and gas flow meter.
- Automatic valves for the venting and inverting of the gas manifolds.
- Electric control unit with local panel.

All elements are of double wall design, like the gas manifolds and fulfil the requirements of marine classification societies and meet IMO SOLAS (International Convention for the Safety of Life at Sea) standards.

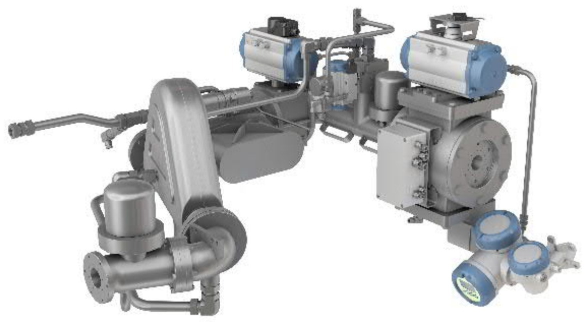

Figure 4: integrated gas pressure regulation iGPR

2.2.5 Pre-chamber and pilot injection

For ensuring a stable ignition at very low engine loads in gas mode also, the volume of the pre-chamber is scaled up. The nozzle geometry of the pilot injector and the related spray pattern is optimized based on a CFD analysis. The temperature distribution of the pre-chamber and of the nozzle tip in particular, is optimised based on a thermal FEM analysis. For simplifying the maintenance, a sleeve between the pre-chamber and the cooling water is added to the design.

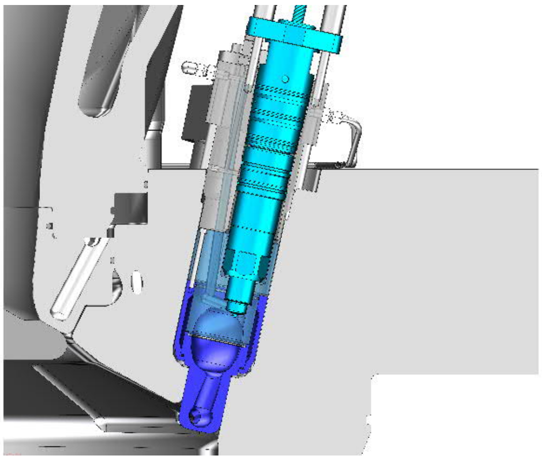

Figure 5: pre-chamber and pilot injector

2.2.6 Main injection system and nozzles

The liquid fuel injection system from the diesel engine was taken over for the DF engine. It consists of three mechanical injectors per cylinder that are controlled by a common injection control unit ICU. One ICU per cylinder is located on the fuel rail.

So far, nozzles with a similar layout/geometry were applied for diesel and DF engines. For the X92DF, atomizers with a more specific bore geometry were developed. The new nozzles aim to further improve the temperature distribution in the combustion space, leading to lower thermal loads for the components and to lower NOx emissions. A new CFD based tool was used to develop a model of the spray pattern, including the distribution of the jets, the evaporation of the liquid and the estimation of the combustion process and the related emissions.

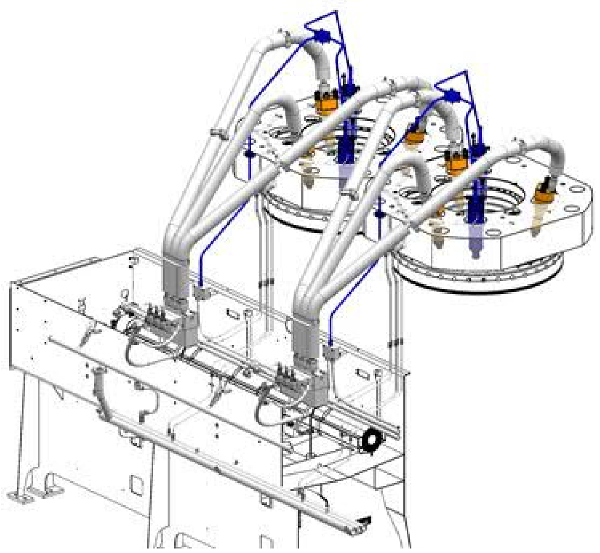

Figure 3: ICU based main injection system

2.2.7 Turbo charger characteristics?

Based on the experience with the smaller bore X-DF engines, a new turbocharger matching strategy for pre-mixed lean burning engines was established together with the major turbocharger manufacturers.

The target is to reach the highest possible turbocharger overall efficiency at high loads. This is considerably changing the characteristics of turbochargers applied on 2-stroke slow speed engines (see figure 5).

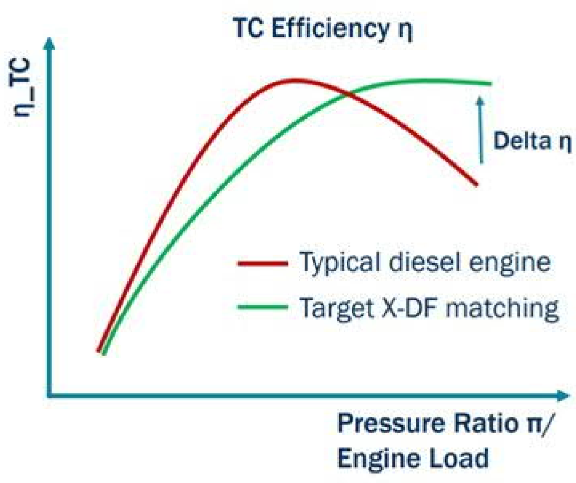

Figure 4: X-DF TC matching strategy

For typical diesel engines, an accurate adjustment of the scavenge pressure by an accurate turbocharger matching with an evaluated pressure curve at part load is normal, while with X-DF engines, a larger variation of scavenge pressure is tolerated but high efficiency at highest engine loads is desired.

The scavenge pressure on an X-DF engine is fine-tuned by an exhaust waste gate that by-passes exhaust gas around the turbine as part of the performance control concept. With this system, lambda of the combustion can precisely be adjusted according current operation and ambient conditions.

2.2.8 Electric blowers with variable speed

Conventional auxiliary blowers on diesel 2-stroke engines are just switched on and off when the scavenge pressure is passing a pre-defined trigger level. Such blower control is simple, but towards very low engine loads in gas mode, the combustion gets slow due to the lean and cool mixture. By reducing the air flow in a variable way, a smoother running of the engine can be achieved towards very low loads. Consequently, frequency controlled auxiliary blowers are introduced as standard for the X-DF engines.

2.2.9 Temperature dependent scavenge pressure.

The speed of the pre-mixed combustion depends not only on the air to fuel ratio, but also on the temperature of the scavenge air. It is possible, within reasonable limits, to compensate the accelerating effect of a higher temperature with the decelerating effect of a higher air to fuel ratio and vice versa. The engine control system adjusts the scavenge pressure based on the measured temperature of the scavenge air and keeps the combustion therefore more stable. The function simplifies the tuning of new engines by the licensees, in particular for cold conditions.

2.2.10 Combustion process

The scaling-up of the gas combustion was carried out by considering two main criteria:

Air/fuel ratio:

The turbo chargers were carefully selected for achieving a high total efficiency as well as a high air flow. In addition, slightly higher scavenge ports were applied for increasing the duration of the scavenging.

Gas mixing:

A primary mixing of the fuel gas into the air is made by two gas jets. Despite that primary mixing takes place in the relative low pressure of the scavenging (before start of compression), the jets require a significant momentum to achieve the anticipated penetration lengths. The required momentum is created by injecting the gas with approximately sonic speed. The gas jets for the primary mixing were scaled-up from the smaller reference X-DF engine by applying fluid dynamic calculations for subsonic and supersonic flow.

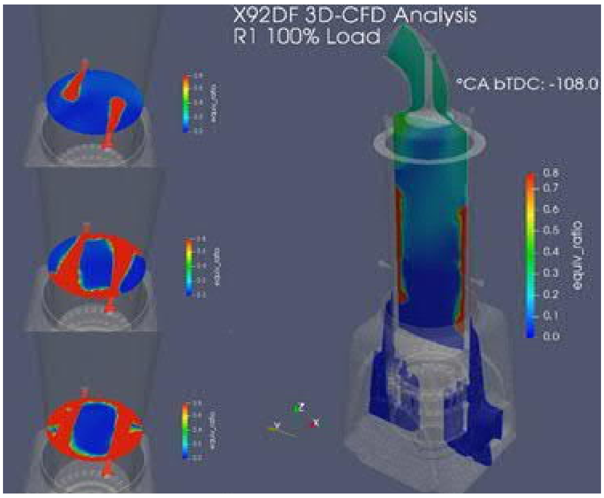

Figure 5: gas air mixing in cylinder

A secondary gas mixing takes place during the compression phase, driven by the air swirl in the cylinder. For a more efficient, but also accurate analysis of the scavenging and the gas mixing, a new CFD tool was used. The new tool was validated and models calibrated based on the results from the smaller DF engines. The layout for the secondary mixing of the X92DF is to a large extent a scaled-up version of the X72DF engines.

The goal was to get a characteristic distribution of the gas. That distribution is not fully homogenous, but shows a certain stratification in the combustion volume. For example, the zone below the exhaust valve is only partially flushed with fresh air and contains a significant amount of hot air from the former cycle. Therefore, a mixing of gas into that zone is not desired.

2.2.11 Fuel sharing

The fuel sharing mode allows to burn gas and liquid fuel simultaneously. The operator can choose a share of up to 50% liquid fuel. So far, the additional flexibility is particularly applied for LNG carriers. It allows such LNG carriers to achieve the desired vessel speed even with limited amount of natural boil-off gas, eliminating the need to apply a forced boil off.

But also for merchant vessel the fuel sharing mode can be utterly attractive. For instance, when experiencing gas aging or when the next LNG bunker station is too far away to just run on gas. See chapter 3 “engine application” for more details.

Because a considerable part of the fuel is burned in a diffusive regime, the fuel sharing mode is tuned to be IMO Tier II compliant [1].

2.2.12 Cylinder Oils for DF engines

Because of the zero-sulphur content of LNG and only low volume of pilot fuel, WinGD recommends using a cylinder oil in the range from BN 15 to 40 to lubricate the X92DF engines.

The thermal stress of the piston running components including the cylinder oil on a DF engine can be higher than known from the diesel engine. The premixed flame leads to higher temperatures closer to the cylinder liner running surface compared to the diffusion flame known from the Diesel engines. From experience it’s known that this higher thermal stress on the cylinder oil can increase the risk of deposit accumulation on piston top land, piston ring grooves and on the backside of the piston rings. These deposits can lead to reduced component clearances and, engine operation mode dependent, to piston running issues. Therefore, WinGD recommends using cylinder oils which have a high oxidation stability and a high detergency level.

WinGD has a comprehensive oil validation program which includes an extensive laboratory analysis followed by an extended field test. Every oil which is mentioned on the WinGD list of validated oils has passed this validation program. The list consists of a wide range of cylinder oils from BN 15 to BN 140 to cover LNG, distillate fuels and as well HFO up to 3.5 % sulphur. The portfolio is ready for every fuel available which a WinGD DF engine can burn.

The DF engines are still new on the market and a further optimization of the cylinder oil portfolio and the oil formulations is required to enhance the piston running performance. Upcoming engines with further increased efficiency will be even more demanding for the cylinder oils. WinGD is in close contact with all relevant oil and additive companies to address the challenges and to support the development of new generation cylinder oils.

2.2.13 iCAT

WinGD introduced the iCAT (**I**ntegrated **C**ylinder Lubricant **A**uto **T**ransfer system) to have the correct cylinder oil always and immediately available at the cylinder lubricating pump. Typically, a low and a high BN cylinder oil are selected to comply with LNG and a wide range of liquid fuels.

iCAT eliminates the risk of feeding a wrong cylinder oil for hours into the cylinder, what could lead to severe piston running issues. In the past, the entire oil amount in the piping system had to be used up first because the switch-over valve has been located in the tank area far away from the engine.

iCAT allows a very fast switch-over between the cylinder oils. A separate piping system for each cylinder oil type is supplying the cylinder oil from the tank to a switch-over valve. The 3/2-way switch-over valve is located very close to the cylinder lubricating pump. See figure 7.

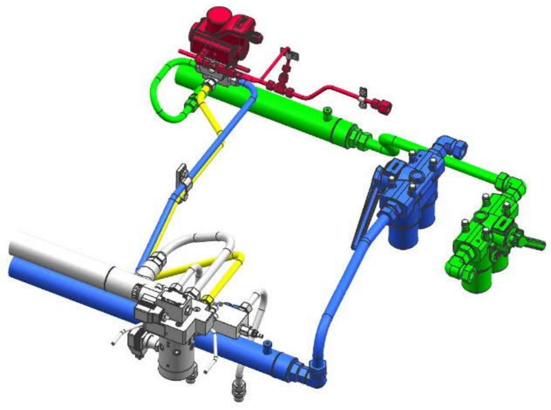

Figure 6: iCAT system for an efficient lubricant switch

Table 2: Colour-code iCAT illustration

Colours	System
Blue	High BN cylinder oil
Green	Low BN cylinder oil
Red	Air
Yellow	Feed pipe to lubrication pump

Today, iCAT is a standard for DF engines and it significantly simplifies and accelerates the cylinder oil switch over procedure. The operator does not have to calculate anymore the ideal switch over moment by considering the current cylinder oil consumption and piping volume. iCAT is designed and programmed to switch over automatically to the correct cylinder oil based on the current fuel properties after a fuel switch.

Nevertheless, it is still highly recommended to frequently analysis the piston underside drain oil. This is essential to monitor the cylinder condition and to set the optimal feed rate.

2.3 Engine structure and powertrain

2.3.1 General

To comply with the increased maximum firing pressure of the X92DF as well as the next generation X92-B (Diesel) engine, the engine structure and powertrain had to be partly modified and reinforced. The design modifications made on some of the key components are briefly described below.

2.3.2 Main Bearing Girder

In general, due to increased firing pressure, the hydrodynamic pressure on the main bearings is increased. Accordingly, the main bearings as well as the main bearing girder design and loading was analysed in detail. Finally, a new main bearing girder design was developed, reducing the bearing loading significantly, and at the same time reducing the girder weight and consequently manufacturing cost.

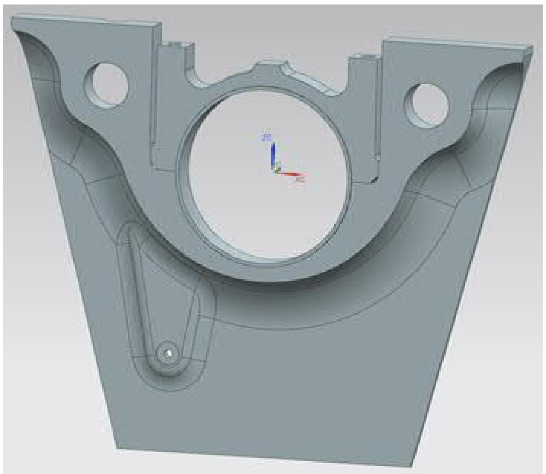

Figure 7: new main bearing girder

2.3.3 Crosshead

Additionally, also based on the increased maximum cylinder pressure, the loading of the crosshead is increased. The X92DF as well as the X92-B will incorporate a new crosshead design. The main difference is the increased crosshead pin diameter. The new design was introduced without impacting the column design.

Furthermore, crosshead lubrication pumps are introduced as standard on all X-DF engines. These pumps are installed cascading to the normal bearing lubrication system and increase the oil pressure specific for the crosshead bearing. This enhances the hydrodynamic behaviour of the bearing and considerably increases reliability with the new boundary conditions.

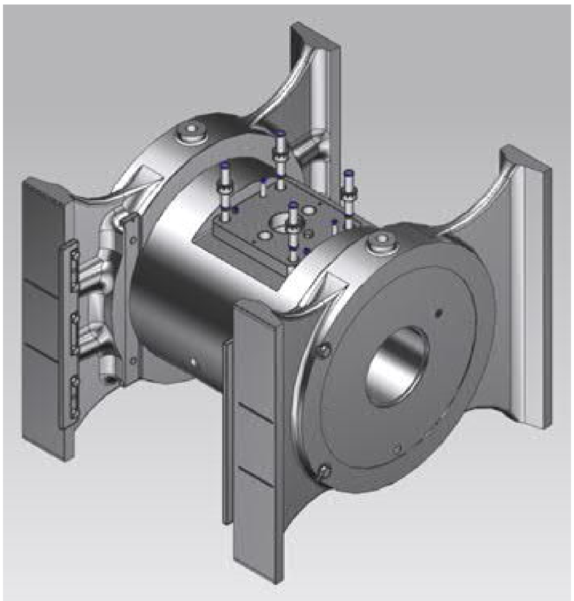

Figure 8: Crosshead VCR ready

The mentioned changes mean that the VCR (Variable Compression Ratio) technology under development by WinGD (ref. to CIMAC paper number 424) can be implemented without change to the main cross head dimensions. The VCR will bring improvements to engine performance mainly in part load operation in diesel and gas mode, and as an example, allow for higher tolerance to use lower methane number (MN) gas qualities as fuel.

2.3.4 Cylinder Liners, -Covers & Cylinder Jacket

Generally, the X-DF engines utilize a lower compression ratio than the X-series (Diesel) engines. Accordingly, the X92DF cylinder liner and cover dimensions were adapted to achieve the desired compression ratio. In addition, due to the higher maximum firing pressure, the design was generally reinforced.

Therefore, the X92DF and the derived X92-B engines will build 82mm higher than the previous X92 pure diesel design.

2.3.5 Cylinder Liner Cooling

As the ideal cylinder liner wall temperature (LWT) in Gas and in Diesel operation are quite different, a new cylinder liner cooling concept was developed. The new concept features active LWT monitoring and control, based on an on-engine cooling water recirculation pump and a cooling water flow control valve.

In Diesel mode, by active cooling water recirculation, the LWT can be increased to avoid

Sulphuric acid condensation and cold corrosion, while in Gas mode a lower LWT is applied.

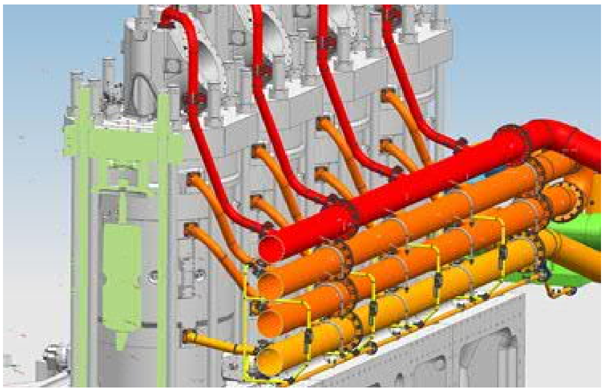

Figure 9: cylinder cooling water pipe arrangements

2.3.6 Rail Unit

As the X92DF rail unit incorporates additional piping and systems required for X-DF operation, such as the iCAT, the unit is slightly wider than the one of the previous X92. As on other X-DF engines, the Rail Unit feet are re-arranged to allow easy access to the Gas Admission Valves, mounted on the Cylinder Liners.

2.3.7 Scavenge Air Receiver & Exhaust Manifold

As required by classification societies for all X-DF engines, the Scavenge Air Receiver and Exhaust Manifold are designed to withstand a potential gas explosion. The applied calculated pressure is 10bar. The necessary reinforcements were made to comply with this requirement accordingly.

2.3.8 Harmonized with latest X92-B generation

During the design of X92DF, also the requirements for the next X92-B generation engines were considered and harmonized. Therefore, these engines share the same engine structure, powertrain and most of the components.

2.4 Engine control system

With the 12X92DF engine series, WinGD introduces the next generation engine control system (ECS) - WinGD integrated Control Electronics (WiCE).

WiCE is a scalable platform for machinery control, consisting of several types of modular devices (units), which can be put together to build differently sized arrangements. In case of main engine control, a distributed system is built and introduces variety of new concepts and standards, compared to the current systems. Few examples:

- State-of-the-art software and hardware architectures, allowing easy scalability and lifecycle management.
- Ethernet ring for data communication and Crank angle signal distribution; enabling faster data transmission.
- New bus system topology internally, and to external systems, contributing to efficient and lean installation.
- Hardware hierarchy with redundant main controllers, gateway units and one control unit per cylinder, clustering signals and functions.
- A firewall, separating essential engine control functionality from peripheral systems, minimizing the risk of system breach
- New HW design with powerful logic components and flexible I/O types; fulfilling the demands for the years to come.
- New Development environment and module interface for software development and configuration.
- New commissioning and monitoring tools; making the system intuitive for the operator

2.4.1 Motivation

In a fast-paced world, one must provide modular and scalable solutions to fulfil constantly increasing demands for new features and functionalities whilst keeping conformity with the rules set by the classification societies. These are mostly related to changes in regulations for environmental protection. Additionally, in a digital age, more and more requirements emerge for digital integration of the main engine to various systems and platforms on-board and/ or ashore. The connectivity per se is not the main challenge but transmitting securely and efficiently good quality operational data without jeopardising the integrity of the essential (core) engine control functionality is demanding.

Figure 12 below displays the ECS in the context of conventional propulsion system logical integration:

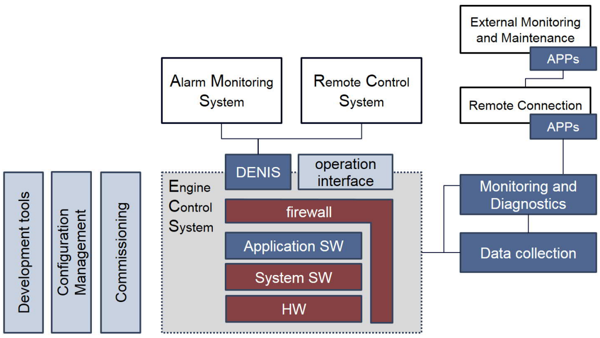

Figure 10: Propulsion system logical integration

An integral part of WiCE is a hardware unit, called a Gateway Unit (indicated as "firewall"), that provides universal secured connectivity. Moreover, it has sufficient computing power and resources to acquire, buffer and pre-process, and push further fast sampled signals from the control system.

Given the rather long in-service timespan of the main engine, WiCE was developed as a future-proof system with extended lifecycle and capacity to fulfil future requirements. The CPU applied has power that is believed to be sufficient for the years to come. The state-of-the-art hardware and software architectures, and interfaces enable relatively straight-forward scalability and testability.

2.4.2 General system architecture

WiCE as an ECS is a distributed system for machinery control, built on a platform composed by various modules:

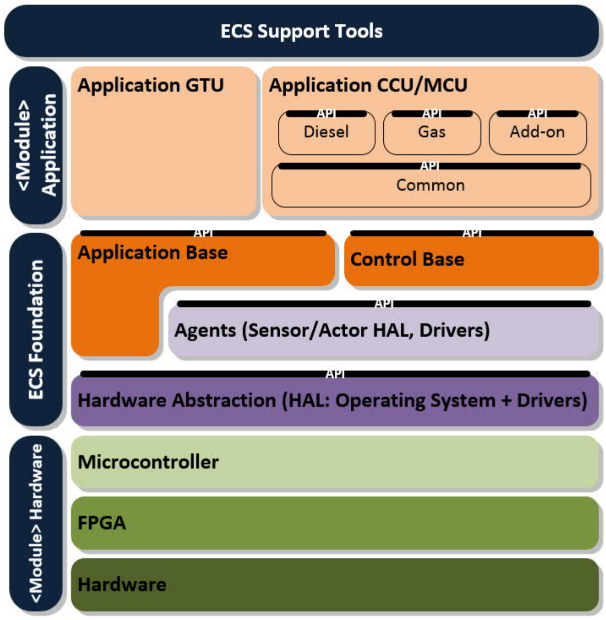

Figure 11: WiCE modules and layers

- Hardware, providing specific (configurable) inputs, outputs and communication ports, as well as processing power by means of CPU and FPGA. This subsystem is module specific. Three hardware types are introduced: Gateway Unit (GTU), Main Control Unit (MCU) and Cylinder Control Unit (CCU) and each uses a different hardware variation.

- The ECS Foundation abstracts and interfaces the underlying hardware and supports different hardware-and application types. This subsystem is common to all modules. It can be reused, itis developed and maintained centrally, and provides basic system services and functions that are required for each domain-specific control application to run.

- The ECS Application implements the control functionality (application) software and provides product specific services and software distribution management. This subsystem is module specific. GTUs, MCUs and CCUs run different applications in a given setup. The same module type can use different software applications for the various system use cases. (ECS, add-on systems, etc.).

- Several software tools are also provided for system support. They fulfill the following tasks: system configuration, monitoring, and troubleshooting, software download/update and Software parameter synchronization (from tool to system, and vice-versa).

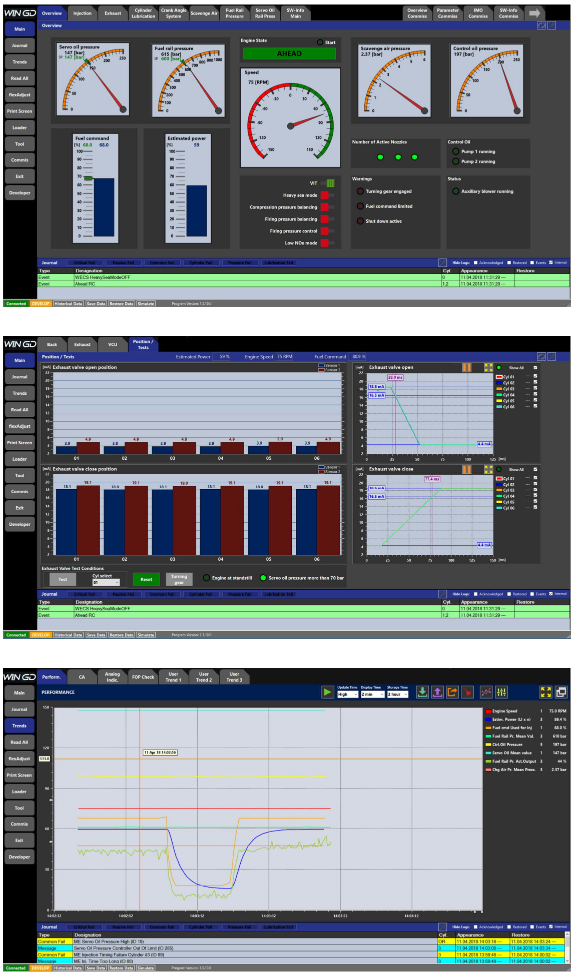

Figure 12: WiCE commissioning tool

2.4.3 WiCE as an ECS

The figure below displays the interaction system – operator.

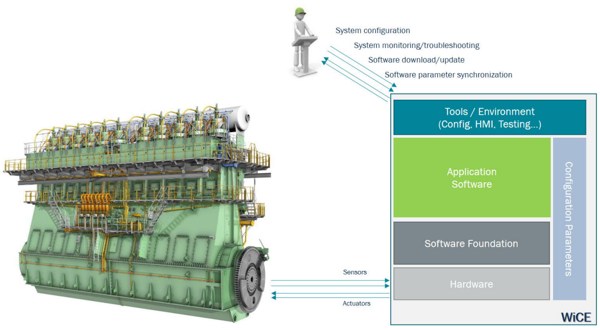

Figure 13: WiCE system interaction

Figure 4 below indicates WiCE physical layer when applied for an ECS setup:

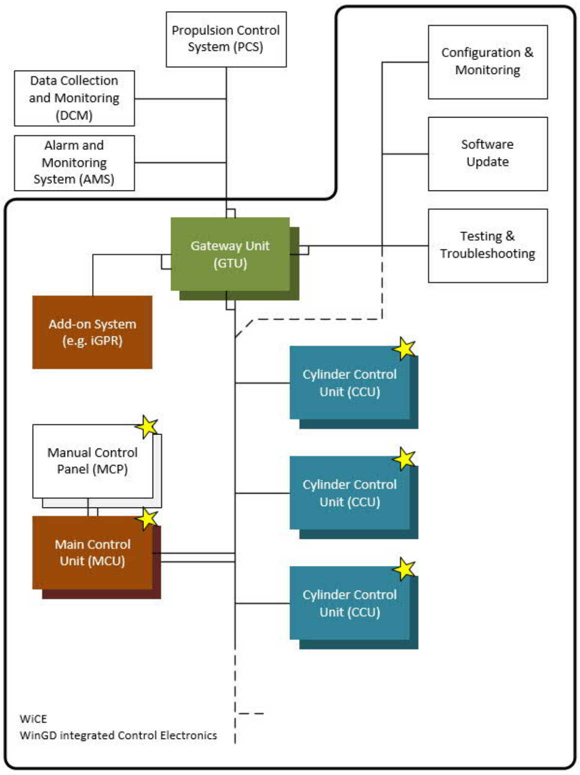

Figure 14: WiCE topology as an ECS

The system is composed by the following WiCE module types, physically installed on the engine:

- The Cylinder Control Unit (CCU) drives the actuators installed on each cylinder of an engine. One CCU is mounted per cylinder. The CCU is running the fast-local cylinder control loop to avoid latencies potentially introduced by a communication network. It drives all the hardware outputs and processes sensor inputs present on the module. The CCU is connected to the communication network to provide data to other modules and use data which, in turn, is provided by them.

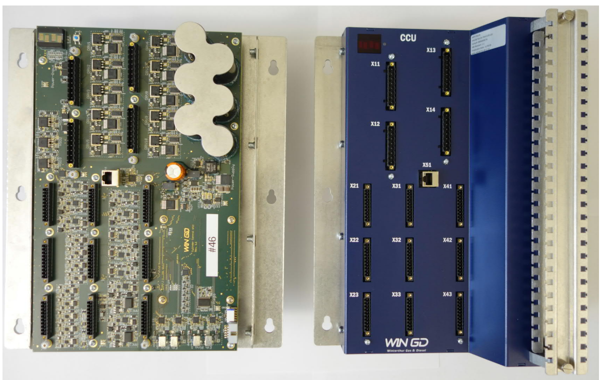

Figure 15: WiCE cylinder control unit

- The Main Control Unit (MCU) is a central device in the ECS. It is responsible for carrying out tasks that are not required locally on a cylinder but for the engine as a whole. For this reason, it regularly collects data from CCUs and provides them with data on the state of the engine.

- The Gateway Unit (GTU) is a module that allows the ECS to communicate with external systems. These can be other onboard systems (e.g. on the bridge) or systems in a remote location. The GTU is the only way for the external systems to interact with the ECS. It also fulfils security tasks (access control, firewall, etc.) and converts different communication protocols to/from a form that the ECS can process. The GTU also provides configurable inputs and outputs, such as analogue current input measurement, analogue current output, digital input and digital output.

- The Manual Control Panel (MCP), is the human-machine-interface (HMI) to the operator, enabling her to perform basic engine operation (start/stop, normal running).

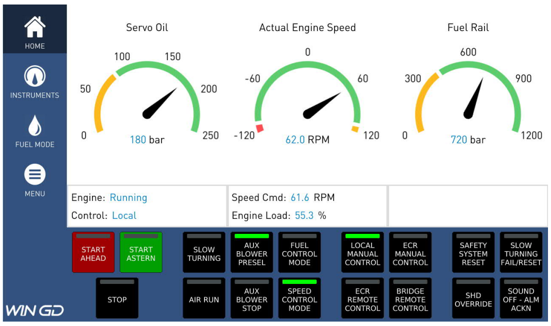

Figure 16: MCP: Main-, Instruments-, and SW info screenshots

All modules (excluding the redundant MCP's, which are connected to two MCU's via dedicated CAN buses) are connected to a single communication network called the System Bus. The System Bus is not necessarily a bus in the strict sense, but a communication network in a wider sense.

The System Bus provides enough bandwidth to transport the arising traffic:

- Periodic traffic used for the exchange of control data

- Occasional traffic for tasks like software updates, monitoring of ECS state or testing

- Reliable low-jitter / low-latency distribution of the engine crank angle signal

To fulfill performance and reliability requirements the system bus is foreseen with the following structure/use:

- The bus is realized in terms of a ring topology interconnecting all ECS modules

- The ring topology is realized with two separated physical rings

- One physical ring is exclusively used for transmission of all essential control data that needs to be sent redundantly between all modules, including distribution of the absolute crank angle signal.

- The other ring transmits non-essential data which has no redundancy requirements. Examples are: Diagnostic data from CCUs and MCUs to monitoring systems (via GTU), system software services (download, parameter synchronization), etc.

- In case Ethernet ring #1 completely fails, ring #2 can take over the function of transmitting control data (and stop sending non-essential data if necessary).

The system bus is intended to interconnect the electronic hardware units only. Any peripherical system (indicated as “Ad-on System” on Figure 3) must not be connected to the system bus, but to the GTU.

2.4.4 WiCE application on 12X92DF

The following amount of electronic hardware units are installed on the 12X92DF engines

- 12 x CCU for mainly cylinder-related functionality when operating in Gas or Diesel
- 3 x MCU as central devices in redundant form
- 2 x GTU as interface to external systems
- 2 x MCP as HMI

3 ENGINE APPLICATION

Beside the task given with developing the main engine, several vessel operational issues need to be solved as well.

3.1 On board LNG handling

One major concern of ship owner is bunkering and handling LNG on board in general. Discussions circle around safety standards, required tank volumes and a well integrated fuel tank and supply system.

In the first application of the X92DF, this was recognized in an early project phase. Operating on LNG fuel requires close integration between the engines, the fuel tanks, and the fuel supply and control system [2].

To address this effectively, WinGD teamed up with major industry equipment supplier Wärtsilä for the fuel gas supply system and GTT for the LNG fuel tanks in order to provide the most effective solution to ship owners.

Eventually the tank selected for the 22000TEU application was a membrane type tank, sized at 18’600m3 which supplies sufficient fuel for one full round-trip Europe to Asia and back.

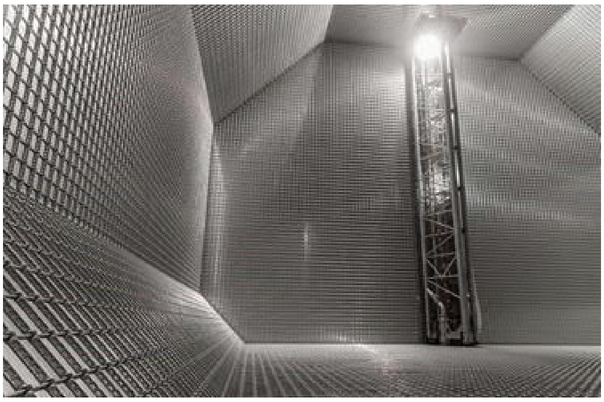

Figure 17: cryogenic membrane tank used for LNG

In early project phases, the slushing of the LNG inside the tanks was a concern. This challenge was addressed using a membrane containment system. Class Bureau Veritas (BV) has been instrumental from the beginning ensuring the requirements for safe use of LNG are fulfilled.

3.2 LNG aging

Due to the long voyage, another concern of the ship owner was the “aging” of the LNG fuel. Aging refers to the gradual change in the initial LNG composition over a period of time. Aging describes the process triggered by the evaporation of boil of gas. The consequence is a reduction of the methane number while the heating value of the LNG remaining in the tanks is increased.

With the 22’000TEU application, an oil free boil off compressor will circulate the light gas fractions into the engine supply system. An additional evaporator unit heating up the LNG will ensure sufficient gas supply for the engine. The process is called forced boil off.

In order to not phase issues with gas supply to the engine, the system is over-sized and supplies gas pressures higher than required.

With the 1st installations coming into service and experience building up, such margin can likely be reduced and the total system becomes even more integrated.

Showing the aging process in a very simplified calculation, starting with a given gas with MN76 according to MWM and considering the previous mentioned tank size and boil-off rate, and a constant gas consumption of according specification. The gas tank would be empty on day 33. In this case the methane number would drop from about 76 to 69 within the given 33 days.

On the engine side, aging of LNG can become an issue when methane numbers drop bellow 65. At full engine output and in adverse ambient condition, the engine might tend to develop knocking or experience early ignition of the pre-mixture.

To avoid such effects, WinGD has integrated several counter measures into the combustion concept. At one hand, the engine automation system will automatically increase the liquid fuel share a fraction when knocking is detected and thus avoid high temperature and mechanical loading of the reciprocating components.

On the other hand, the fuel share mode can be applied manually to counter act deteriorating gas qualities. In that case, HFO is mixed to the LNG gas combustion. Fuel share mode is also an option in case LNG quantities bunkered would not be sufficient for an entire round trip. Fuel share mode is explained briefly in chapter 2.2.11 and has been reflected in detail at the CIMAC 2016 conference [1].

4 CONCLUSION

In this paper we reviewed the development process and methodology WinGD applied to make the largest lean burning pre-mixed Otto cycle combustion engine ever possible.

With the scaling up approach of components and simulation models, a conservative approach was selected. This is mainly due to the nature of the product. It is impossible to have prototype engines of this size and a conversion of an existing field engine is also not feasible.

Hence, WinGD was forced to build on the experience it gathered from smaller engines. The X-DF technology was initially developed on a 500mm piston diameter, then scaled to a 720mm diameter and now to a 920mm piston diameter.

The scale up from 500mm to 720mm with a factor 3.12 related to swept volume was successful. The X72DF is in the meantime an established product with more than 100 engines in service or on order.

Now to scale further from 720mm to 920mm bore diameter, hence applying a factor 1.83 related to swept volume, seems compared to the earlier scaling a rather small step, with considerable low risk.

Nonetheless, due to the mere size of the engines, from lessons learned on the smaller bore engines and as result of improved simulation methodologies, several new features like e.g.: a new bearing girder, a new gas pressure regulating unit (iGPR) or an improved pilot pre-chamber were introduced.

This mentioned X-DF technology at this engine size and the related vessel types effectively reduce the gaseous emission footprint of global container trade. With successfully launching the technology also at this scale, a major step towards more sustainable and environmental friendly shipping is made.

The technology platform as such, particularly the availability of a lean burning “Otto” process and a diffusion “Diesel” process at the very same engine, will enable an unprecedented technical opportunity for future green house gas friendly fuel mixes applied to 2-stroke slow speed engines, thus the merchant shipping fleet.

The completion of the X92DF development is framing the WinGD DF portfolio at the top power end. With the X40DF and an upgraded X82DF being developed and launched just now, the portfolio is complete and offers solution with the same before mentioned advantages for most common ship segments.

With the new control system applied first time on the X92DF, WinGD is not only undertaking to get more grip in the digitalization of shipping, but furthermore builds a platform that allows for a considerable more intelligent energy management platform.

With such a platform in place, in fact controlling engine loads and condition in all situation based on idealised combustion models running in parallel directly on the control modules, we create a huge opportunity to further optimize integration of subsystems of any electrical load or producer.

Hence, if for instance Power Take Off (PTO) or Power Take In (PTI) are arranged, the new control system can help to optimize to run the engine constantly at its sweet spot with the best trade between fuel consumption and emission rate, while fluctuations are absorbed by the PTI/ PTO arrangement and an energy storage.

Such functions which development is at full swing, will allow for an effective peak shaving, vessel accelerating and wave loading once applied on a vessel. It will help to further reduce the fuel oil consumption and therefore improve the vessels total economy.

Regarding the availability of LNG as fuel for global merchant shipping, some challenges are still existing. The owner selecting the 12X92DF for its

Asia to Europe trade had to carefully plan its fuel availability, size the tank and fuel gas supply system for an entire round trip and made a long-term supply agreement with the LNG supplier.

However, this very benchmark order for the 9 container vessel triggered investments at several major container ports around the globe to make LNG locally available. Such investments include storage capacities and bunker vessel.

It seems a question of time until LNG is widely available for global merchant shipping and again an infrastructure is establishing it self that in future can be utilized for even more environmental friendly and sustainable fuels, giving the industry a fair chance to meet the ambitious IMO declared green house targets.

5 ACKNOWLEDGEMENTS

The authors are grateful for the work and dedication of the various expert teams at WinGD and Wärtsilä who made not only the paper, but fundamentally the project possible.

Additionally, we are greatly respecting and honoring the decision of the future ship owner to select such novel technology for their ship without having relevant track records available. It shows the attitude needed to turn current established market patterns into the direction of sustainability and environmental protection. Without this bold move of the financing party, such a benchmark project would not be possible.

Finally, we would also thank Bureau Veritas for their support throughout the project constantly reviewing proposals and ideas to make sure no issues related to safety on board arise. It was and always is a pleasure to work on such professional levels.

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7 CONTACT

This paper was written by:

- Dominik Schneiter, Winterthur Gas & Diesel, Switzerland
- Ingemar Nylund, Winterthur Gas & Diesel, Switzerland/Finland
- Roland Alder, Winterthur Gas & Diesel, Switzerland
- Patrik Printz, Winterthur Gas & Diesel, Switzerland
- Stefan Goranov, Winterthur Gas & Diesel, Switzerland
- Marcel Ott, Winterthur Gas & Diesel, China

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