X-DF: latest references, service experience – plus future outlook

WinGD Japan Technical Seminar – 07/11/2019

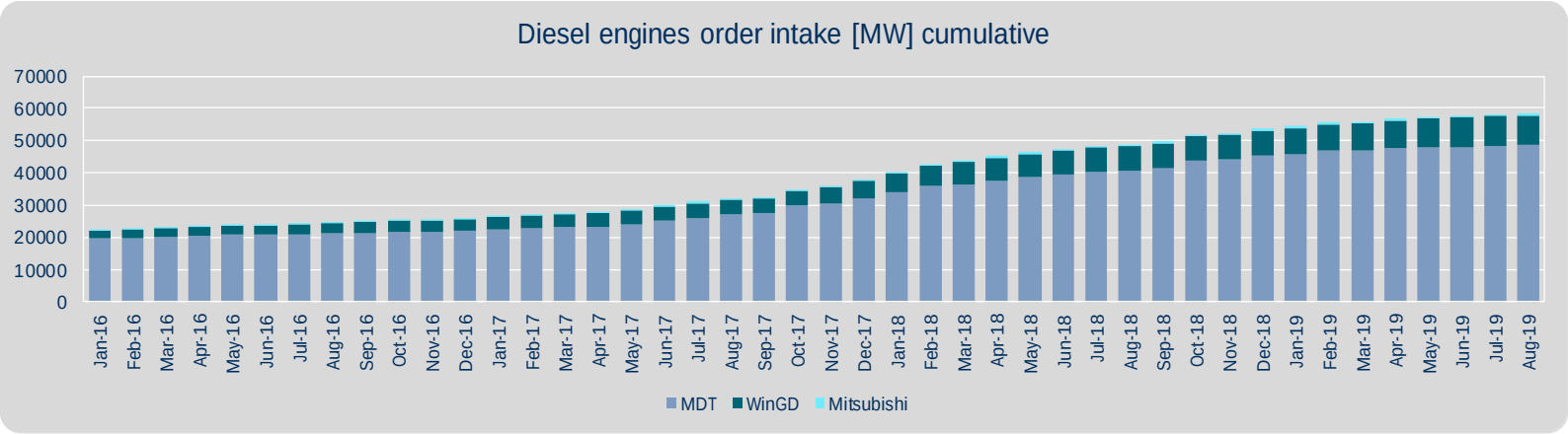
Adrian Siegfried – Product Manager X62DF/72DF

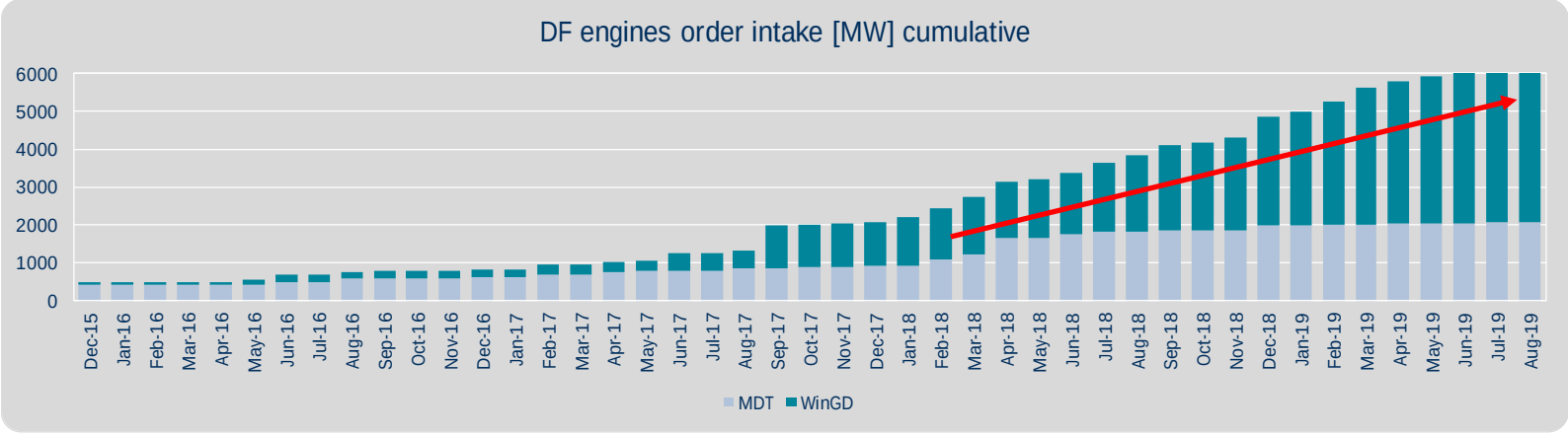
Market & references

Development of LNGC propulsion

Source: Clarksons Research Services, WinGD internal data

X-DF capturing the market





- LNG is becoming one of the primary fuels for shipping.... gaining market share..
- Diesel fuel orders steady

X-engines (diesel) reference list

X engine type	Vessel type		Orders
X35 X40	8K Multi-Purpose Vessels 10-44K dwt Bulk Carriers 11-22K dwt Chemical Tankers 23K dwt Shuttle Tankers 1-2K TEU Feeder CVs 2'000 vehicles PCC		83 engines 10 engines
X52	38-70K dwt Bulk Carrier 50K dwt Product Tankers		35 engines
X62	56–108K dwt Bulk Carriers 60K dwt Chemical Tankers 115K dwt Crude/Product Tankers 2-3K TEU Feeder CVs 80K cu.m. LPGC		80 engines
X72	150-210K dwt Bulk Carriers 158K dwt Crude Oil Tankers 3-8K TEU Intermediate CVs		86 engines
X82	250-400K dwt Bulk Carriers 280-310K dwt Crude Oil Tankers 8-12K TEU Neo-Panamax CVs 12-15K TEU Neo-Panamax CVs		103 engines
X92	8-12K TEU Neo-Panamax CVs 12-15K TEU Neo-Panamax CVs 15K+ TEU Post-Panamax CVs		55 engines
TOTAL	452 X engines (ca. 11.0 GW)		

X-DF engines reference list

X-DF engine type	Vessel type		Orders
X40DF	9'500 cu.m. LNGC		1 engine
RT-flex50DF	15K dwt Product Tankers 1-2K TEU Feeder CVs 14-20K cu.m. LNG Carriers 3'600 vehicles PCC 5'800 lane m Ro-Ro	 	33 engines
X52DF	125K dwt Shuttle Tanker 7'000 vehicles PCC	 	6 engines
X62DF	115K dwt Crude Oil Tankers 180K cu.m. LNGC/twin screw 174K cu.m. LNGC/twin screw	 	35 engines
X72DF	174k cu.m. LNGC/twin screw 180K dwt Bulk Carriers	 	186 engines
X92DF	22K TEU Post-Panamax CVs 15K TEU Neo-Panamax CVs	 	14 engines
TOTAL	275 DF engines (ca. 4.8 GW)		

69 LNG Fuelled Vessels with X-DF

X40DF (6 cyl)
- 9 kdwt Oil & Gastanker

RT-flex50DF (5,6,7 cyl)
- 4 x 15 kdwt Chemical Tanker, Sweden
- 6 x 1400 TEU Container Vessel, Finland
- 4 x 15 kdwt Asphalt Carrier, Canada
- 2 x 3600 unit PCTC, Norway
- 4 x 25 kdwt Tanker, US
- 2 x twin-screw RORO, Sweden

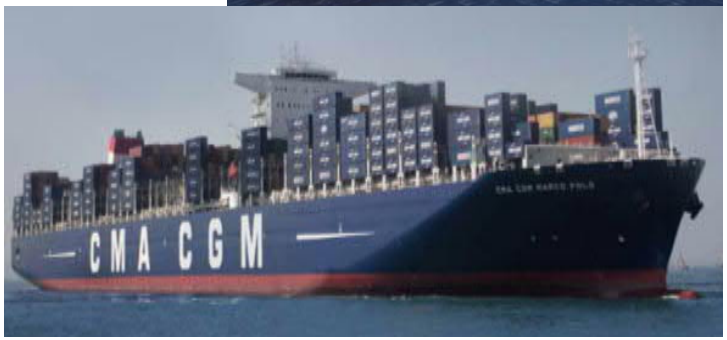
X52DF (7,8 cyl)
- 2 x 125 kdwt twin-screw Shuttle Tanker, Singapore / Norway
- 1 x 7000 unit PCTC, Japan

X62DF (6,7 cyl)
- 25 x 114 kdwt Aframax Tanker, Russia/Singapore/Korea

X72DF (6 cyl)
- 4 x 180 kdwt Bulker, Korea

X92DF (10,12 cyl)
- 9 x 22'000 TEU Container Vessels, France
- 5 x 15'000 TEU Container Vessels, France

73 engines on order, 20 delivered, 15 in operation



100 LNG Carriers with X-DF

- 5RT-flex50DF
  1x14k + 2x20k m³ Coastal LNGC
- 5X52DF
  1 x 30k m³ LNGC
- 6X62DF
  5 x 180k m³ LNGC
- 5X72DF
  86 x 174k/180k m³ LNGC
- 6X72DF
  6 x 180k m³ LNGC

Shipbuilders: SHI, HHI, DSME, Hudong

190 engines on order for LNGC,
41 delivered, 21 in operation
TOTAL 275 engines + options (30.9.2019)

An order that is challenging the market

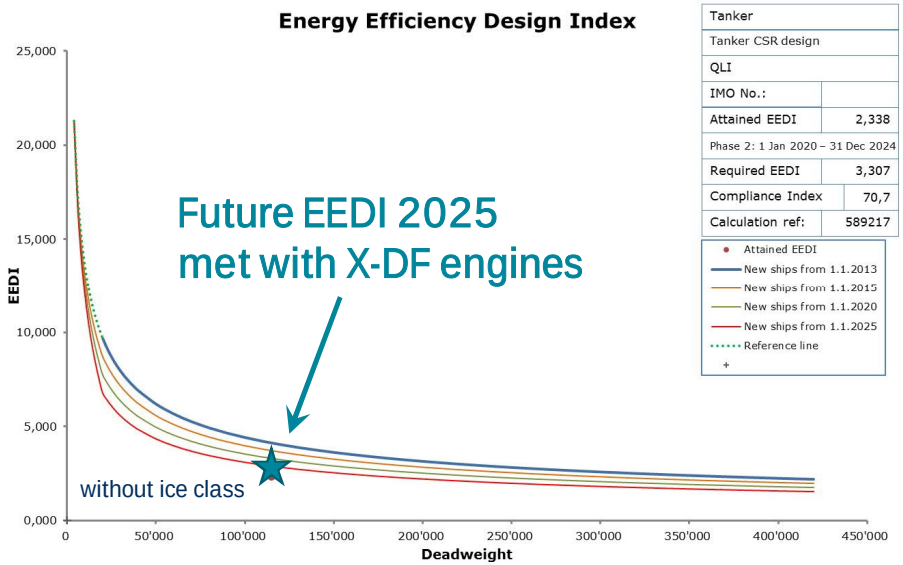
9 x 22’000 TEU + 5 x 15’000 TEU container vessels with LNG as fuel

Press Release of Nov. 7, 2017
http://www.cma-cgm.com/news/1811/world-innovation-cma-cgm-is-the-first-shipping-company-to-choose-liquefied-natural-gas-for-its-biggest-ships
Announced during COP 23 (UN Climate Change Conference) in Bonn, Nov 6 - 17, 2017

22’000TEU CV

Main engine	**12X92DF**
Power	63 840 kW / 80 rpm
Bore	920 mm
Stroke	3 468 mm
Length	23 000 mm
Weight	2 140 tons
Gensets	
Wärtsilä	6 x L34DF
Fuel Gas Supply System	
Wärtsilä	
Fuel gas tank	
GTT	18 600 m3

First LNG-fuelled Aframax Tankers



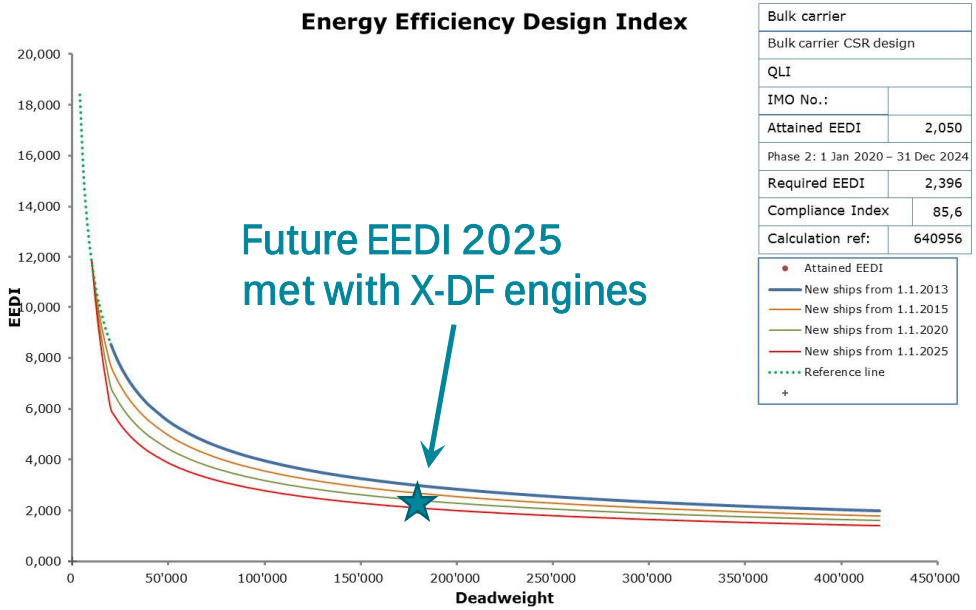
	7X62DF	6X62DF
• **Main engine**		
Power	13 800 kW / 86 rpm	11 200 kW / 81 rpm
Bore	620 mm	=
Stroke	2 658 mm	=
Length	9 215 mm	8 110 mm
Weight	435 tons	380 tons
• **Fuel gas tank**	Type C: 2 x 850 m3	Type C: 2 x 850 m3 → approx 6000 nm
• **Vessel**	Ice 1A	no ice class
• **Seatrials**	July 2018	Oct 2018

First LNG Fuelled Capesize Bulker

H-Line orders largest LNG-powered bulk carriers

Mon 15 Oct 2018 by Mike Corkhill LNGWorldShipping

Main engine	**6X72DF**
Power	16 180 kW / 76.5 rpm
Bore	720 mm
Stroke	3 068 mm
Length	9 400 mm
Weight	560 tons
Fuel gas tank	
C-type	2 x 3 000 m3
	→ approx 15'000nm

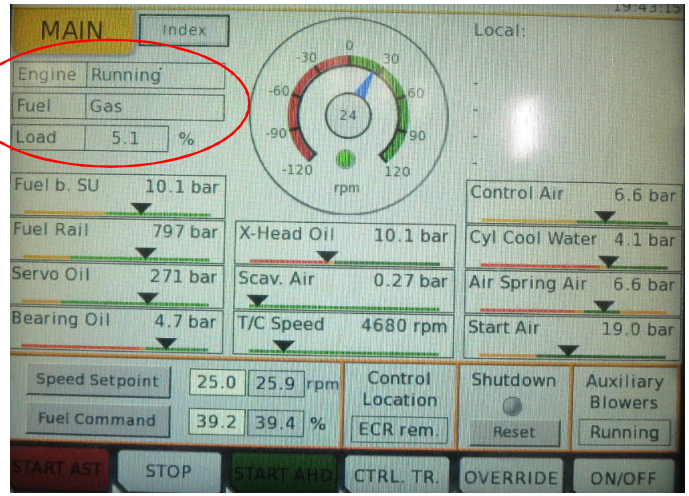


Service experience update

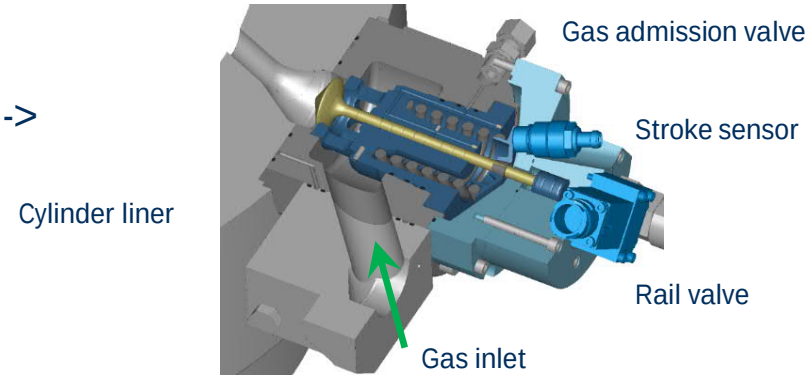
Findings on low pressure concept

Experience from DF engines in operation

- **Low-pressure gas concept works well**
  - Stable combustion process
  - Stable engine loading in rough sea
  - Very low load operation on LNG gas down to 5% proven



- **Gas admission system excellent operation**
  - No malfunction or gas leakage experienced
  - Single cases of sticking GAV during testbed commissioning encountered (particle contamination rail valve), resulting in GT -> safety system worked as designed.
  - Design update (adding lube oil filter) implemented, issue resolved.

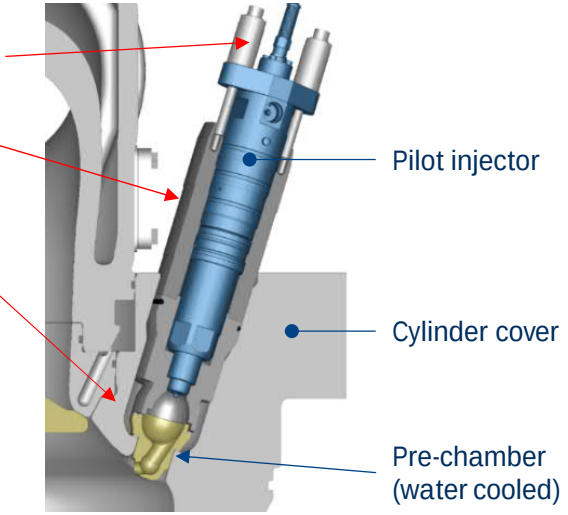


RT-flex50DF pilot injection system

First experience and issues notified - and corrected

Leaking pilot fuel injectors found on first installation; solutions:

- Injector Holding bolts: design changed
- Relief bore (venting): implemented
- Seals on pilot injector: design modified



Some non-DF related items resolved:

- Cylinder lubricating quills malfunction due to quality issues
  -> supplier changed and assembly instruction updated
- Lubricating oil leakage
  -> piping tightening instruction updated
- Fuel oil leakage
  -> piping tightening instructions updated

The X62/72DF engines could profit from the RT-flex50DF experience and design improvements (including instructions) were implemented from the start.

X-DF Shop test list (backup page)

95 engines passed FAT and are partly delivered to ship yards

- 13 sets RT-flex50DF (in China & Japan)
- 4 sets X52DF (in Korea)
- 19 sets X62DF (in Korea)
- 59 sets X72DF (in Korea & China)

Engine type	Project	Number engines FAT's
Flex 50DF's	various	13
X62DF	SK2080/81	4
X62DF	MBK2148s	6
X62DF	AET2197s	2
X62DF	SH919s	6
X62DF	ROS131010s	1
		13 + 19

Engine type	Project	Number engines
X72DF	Gaslog2800/01	4
X72DF	GASL2130/31	4
X72DF	MOL DW2462	2
X72DF	GASL2212/13	4
X72DF	SK2937/38	4
X72DF	MOL1810s	4+4
X72DF	GASL2274/62	4
X72DF	Cardiff3020/3037s	7
X72DF	SH8006s	4
X72DF	NYK SH970s	2
X72DF	Cardiff SN2271s	6
X72DF	Frontline SH8010s	4
X72DF	CELS2297s	2
X72DF	Thenamaris 3096s	2
X72DF	GASL2300/2301	1
X72DF	NYK SH8029s	1
		59

Engine type	Project	Number engines FAT's
X52DF	SN2236/37	4

X-DF shop trials being a routine

95 engines passed FAT and are partly delivered to ship yards

A number of engine manufacturers have gained significant experience and routine in production and testing of X-DF engines:

- 13 sets RT-flex50DF (in China & Japan)
- 4 sets X52DF (in Korea)
- 19 sets X62DF (in Korea)
- 59 sets X72DF (in Korea & China)
- Type approval testing (TAT) completed on RT-flex50DF, X62DF, X72DF and coming up for X52DF (November 2019) and X92DF (Dec 2019)
- 1st and 2nd X92DF engine passed FAT, 3rd engine under post-optimization testing (China)

X-DF Seatrial list (backup page)

35 DF powered vessels passed seatrials / 32 delivered

- 12 vessels with RT-flex50DF (China & Turkey)
- 13 vessels with X62DF (Korea)
- 10 vessels with X72DF (Korea / China)

Engine type	Project	Number of del. vessels
Flex 50DF's	Terntank (4)	4
Flex50DF	LNG Coastal carrier	0 (pending gas trial)
Flex 50DF	Transport Desgagnes (4)	4
Flex 50DF	Nordic (4)	4
X62DF	SK2080/81 (2)	2
X62DF	MBK2148s (3)	3
X62DF	AET2197s (2)	2
X62DF	SH919s (6)	6

Engine type	Project	Number of del. vessels
X72DF	Gaslog2800/01	2
X72DF	GASL2130/31	2
X72DF	MOL DW2462	1
X72DF	GASL2212/13	1
X72DF	SK2937/38	2
X72DF	MOL1810s (4)	2

X-DF sea trials and vessels in service

35 X-DF-powered vessels successfully completed sea trails

- Locations: China, Turkey and Korea
- Ship types:
  - 14,000 m^3 Coastal LNGC (gas trial pend.)
  - 15,000 dwt Chemical Tanker
  - 14,000 dwt Asphalt Carrier
  - 180,000 m^3 LNGC with 2 x 6X62DF
  - 174’000 m^3 LNGC with 2 x 5X72DF
  - 115k Ice class (crude) Tankers with 7X62DF
  - 115k Crude oil Tanker with 6X62DF
- Engine types: RT-flex50DF, X62DF, X72DF
- 33 vessels in service (October 2019)

Picture: 5RT-flex50DF powered chemical tanker

Picture: Twin 5X72DF powered LNGC (source Gaslog LNG)

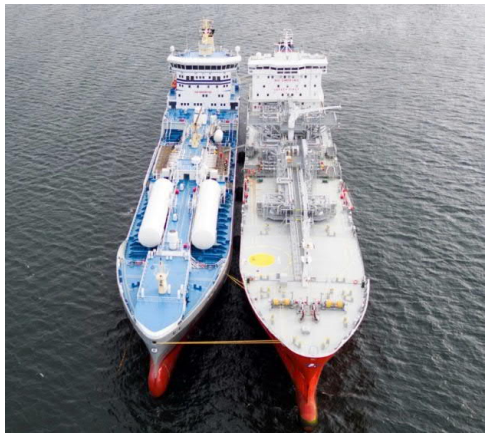
Picture: 7X62DF powered Aframax (Ice class) tanker

First RT-flex50DF on LNG-fuelled vessels

The early movers

First engines in service:

- **“M/T Terntank” series** in regular service in the Baltic / North Sea since August ’16
- **“M/T Desgagnes” series** in service on Great Lakes since August ‘17
- First engine accumulated > 18’000 running hours, running more than 90% of time on gas (only port operation in diesel mode)
- Accumulated running hours of RT-flex50DF fleet: **> 85’000h**
- Some teething issues experienced and rectified in the mean time (e.g. piston running issues caused by pilot injector water leakages)



Picture: Port of Gothenburg

Container Feeder Vessels:

- First 7RT-flex50DF vessel (Owner Nordic), delivered mid Dec 2018.
- 2 sister vessels delivered, last one coming up.

Picture: Containerships Nord

Picture: Besiktas Shipyard

LNGC & X-DF: Close to 100% running on LNG

Operation according to class: Start / Stop / Manoeuvring in liquid mode – the rest in Gas mode

- 14 x LNGCs with twin-X62DF or X72DF in service
  First vessel delivered in July 2017
- First X-DF vessel accumulated: 16’000 running hours
- Total X-DF LNGC fleet accumulated running hours: >**200’000h**
- Excellent operational experience, only minor operational issues, majority solved in the meantime
- Excellent gas mode availability:
  Typically >**97%** of voyage time running on gas

- Meanwhile also 8 LNG fuelled Tankers (with LNG tanks on deck) in operation

LNGC & X-DF: Rapidly accumulating running hours

Vessel list – selected (longest running in their class) projects

Engine / vessels type	Vessel Delivery	R/H After ship delivery	Gas mode R/H after 1st gas loading
Product Tanker 5RT-flex50DF	August 2016	18’200	14’100
LNGC Twin 6X62DF	July 2017	16’000	13’800
LNGC Twin 5X72DF	Jan 2018	11’400	9500
Ice class Tanker 7X62DF	July 2018	6300	4000
Aframax Tanker 6X62DF	Nov 2018	3200	1900
Container feeder 7RT-flex50DF	Dec 2018	3700	2200
Total running hours DF fleet		>330’000	-

Cylinder pressure sensor clogging

Redesign under validation

SL-0003-1_Cleaning_cyl_press_sensor_DF-eng_July2019.pdf

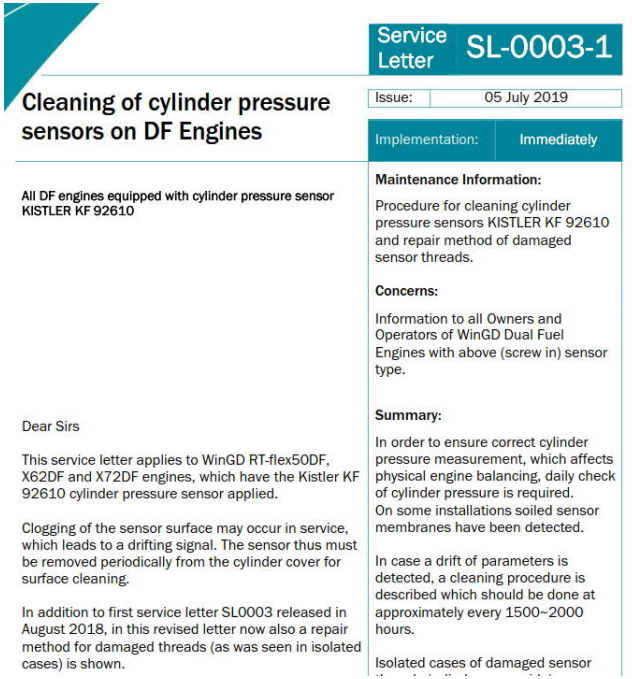
The flush-mounted cylinder pressure sensors show over time a build-up of surface deposits, which has resulted in sensor signal drift in a few cases.

Recommended interval for cleaning of the cylinder pressure sensor is 1500~2000 rhrs or 3~4 months based on experience. First Service letter released in Aug 2018.

- Alternative design for Newbuildings introduced late 2018 (X52DF / X92DF)
- Solution to be validated, thereafter rollout portfolio
- Same solution for X62DF / X72DF introduced June 2019
- Updated Service letter released July 2019

Investigations 'faulty sensors' by maker (general):

- Water / oil contamination leading to sensor failure -> with sealing plugs applied issue resolved.
- Signal drifting (seen in isolated cases after long time in service) under investigation



Service Letter SL-0003-1

Issue: 05 July 2019

Cleaning of cylinder pressure sensors on DF Engines

Implementation: Immediately

All DF engines equipped with cylinder pressure sensor KISTLER KF 92610

Maintenance Information:

Procedure for cleaning cylinder pressure sensors KISTLER KF 92610 and repair method of damaged sensor threads.

Concerns:

Information to all Owners and Operators of WinGD Dual Fuel Engines with above (screw in) sensor type.

Summary:

In order to ensure correct cylinder pressure measurement, which affects physical engine balancing, daily check of cylinder pressure is required. On some installations soiled sensor membranes have been detected.

In case a drift of parameters is detected, a cleaning procedure is described which should be done at approximately every 1500~2000 hours.

Isolated cases of damaged sensor

Dear Sirs

This service letter applies to WinGD RT-flex50DF, X62DF and X72DF engines, which have the Kistler KF 92610 cylinder pressure sensor applied.

Clogging of the sensor surface may occur in service, which leads to a drifting signal. The sensor thus must be removed periodically from the cylinder cover for surface cleaning.

In addition to first service letter SL0003 released in August 2018, in this revised letter now also a repair method for damaged threads (as was seen in isolated cases) is shown.

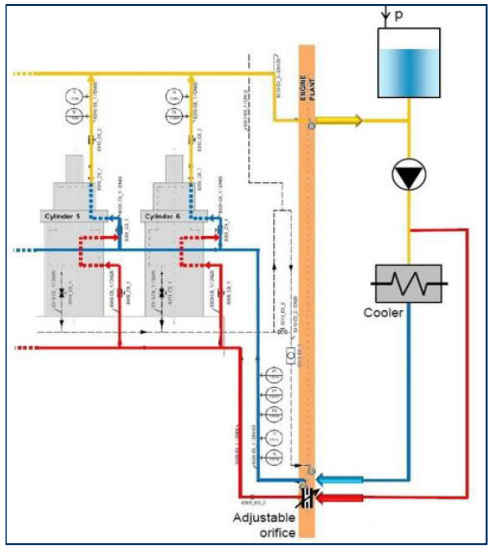
Liner Wall Temperature / JCW

Internal cooling water leakage leading to increased cylinder liner wall temperatures

Jacket cooling water system issues

X62/X72 bypass cooling system with “hot” cooling water along cylinder liners via cooling bores, entering cylinder covers, both on Diesel and X-DF engines.

Lower water guide jacket (WGJ) fixed with bolts, which broke on some engines in field, hence jacket slipped downwards, creating an internal bypass of the liner cooling bores, resulting in locally increased Liner wall temperatures (LWT’s). Solutions:



- 1st Service letter (venting instr.) released Sept. 2018, with update in Jan 2019, highlighting correct **WGJ alignment**.
- **Air separators** introduced as new standard on X62DF / X72DF NB engines as per updated drawings Nov 2018 -> removal air bubbles in cooling circuit.
- Improved fixation of the water guide jacket -> New holder “**C-clamp**” and Service letter SL-0011 released for implementing solution onboard in April 2019.
- Following latest findings **pre-chamber fixation** design upgrade, Service Letter SL-0015 released in Oct 2019.
- Future NB solution – “Uniflow” cooling system (moving away from bypass system – like new X62B and X72B).


Service Letter SL-0004-1

Cooling water system venting instruction for engines with by-pass cooling system

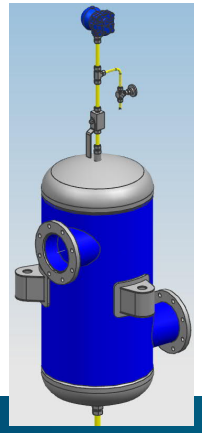
For WinGD X62 / X62DF / X72 / X72DF and X92 engines

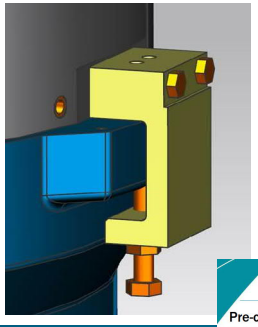
Issue: 22 January 2019

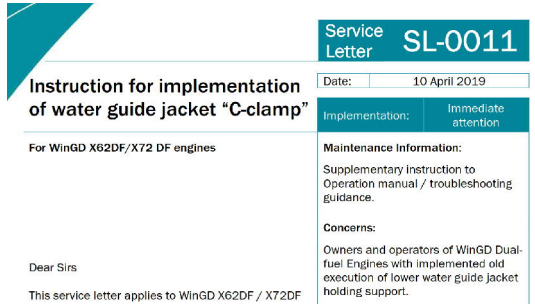
Action: Immediate attention

Maintenance Information:

Supplementary instruction to Operation manual / troubleshooting guidance.






Service Letter SL-0011

Instruction for implementation of water guide jacket “C-clamp”

Date: 10 April 2019

Implementation: Immediate attention

For WinGD X62DF/X72 DF engines

Maintenance Information:

Supplementary instruction to Operation manual / troubleshooting guidance.

Concerns:

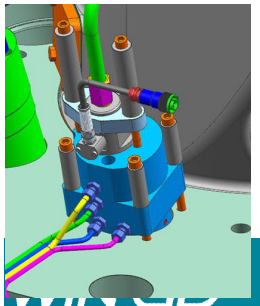
Owners and operators of WinGD Dual-fuel Engines with implemented old execution of lower water guide jacket holding support.

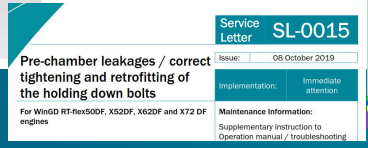
Dear Sirs

This service letter applies to WinGD X62DF / X72DF

Service letter SL-0011 (above), with new WGJ holder “C-clamp” (left)

New pre-chamber bolts (right)




Service Letter SL-0015

Pre-chamber leakages / correct tightening and retrofitting of the holding down bolts

Issue: 08 October 2019

Implementation: Immediate attention

For WinGD RT-flex50DF, X52DF, X62DF and X72 DF engines

Maintenance Information:

Supplementary instruction to Operation manual / troubleshooting

Clogging nozzle tips

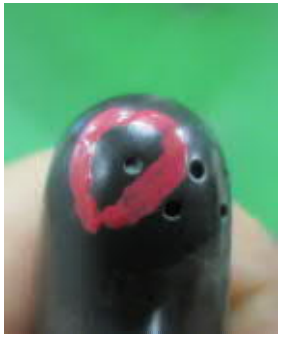
Issue on LNGC's running primarily in Gas mode

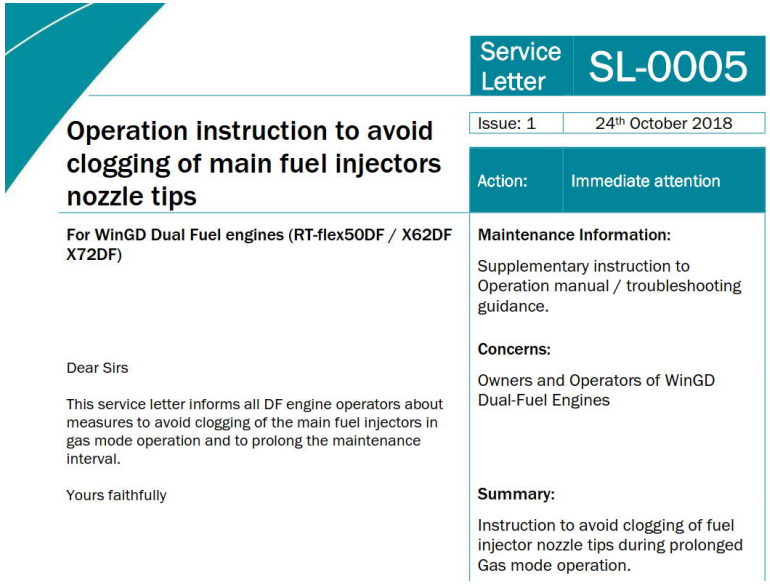
Atomizers / nozzle tip clogging

During Gas mode operation the main fuel injectors are inactive. It could be seen that over time deposits in the nozzle tip bores build up, eventually leading to clogged atomizer tips.

Some cases found during routine inspections, some cases notified due to reduced exhaust gas temperature on respective unit (triggering exhaust gas deviation alarm). Deposits consist of: Oxygen, Calcium, Carbon, Sulphur -> Cylinder oil & Fuel oil mixture.

- Service letter SL-0005 released, introducing (weekly) cleaning "shots" (clearing bores).
- Since service letter release issue seems resolved.
- First injectors reached 10'000rhrs (above initial TBO interval).





Service Letter SL-0005

Issue: 1 | 24th October 2018

Operation instruction to avoid clogging of main fuel injectors nozzle tips

Action: Immediate attention

For WinGD Dual Fuel engines (RT-flex50DF / X62DF X72DF)

Dear Sirs

This service letter informs all DF engine operators about measures to avoid clogging of the main fuel injectors in gas mode operation and to prolong the maintenance interval.

Yours faithfully

Maintenance Information:

Supplementary instruction to Operation manual / troubleshooting guidance.

Concerns:

Owners and Operators of WinGD Dual-Fuel Engines

Summary:

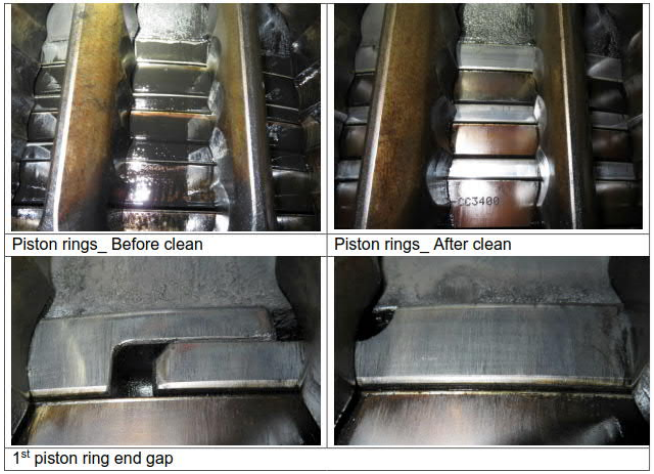
Instruction to avoid clogging of fuel injector nozzle tips during prolonged Gas mode operation.

Piston running behaviour on DF engines

Good running behaviour

In general X-DF LNGC's & LNG fuelled ships

- Running behaviour good
- Cylinder oil used for "lubrication & cleaning" not neutralization of Sulphur
- Regular piston underside sampling recommended (iron content, BN), refer to WinGD instructions



Experienced challenges in field

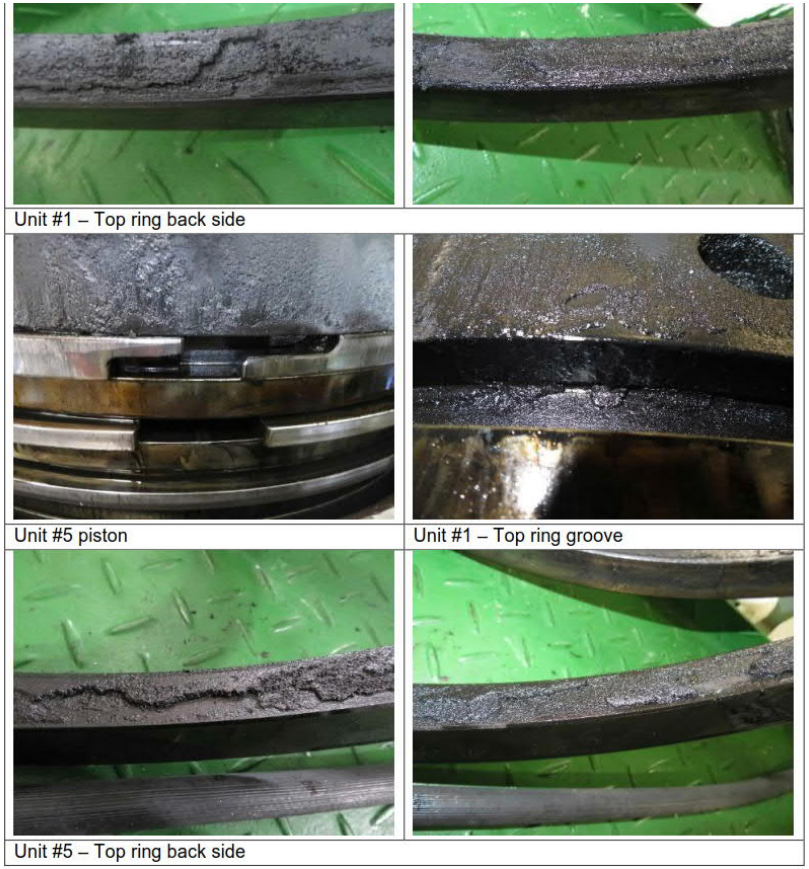
- ➢ One case on a X62DF with piston running issue shortly after overhauling unit (and a lifting incident) mid 2018– confirmed normal operation since replacement.
- ➢ One X72DF case (cracked cylinder liner) related to a pre-damage during R&D testing notified June 2019 - replaced.
- ➢ Some recent further issues (water ingress) due to loss of pre-tensioning on pre-chamber holding bolts.

Piston running

Ring groove & piston ring deposits – vessel feedback

- Massive deposits seen on piston ring grooves and piston rings backside. These deposits will hinder the free movement of the rings in engine running condition.
- Piston ring gap exposed to higher contact pressure -> leading to macrocracks network, and eventually later to CC spalling.
- Damaged piston rings may damage cylinder liners as consequence.
- Cylinder oil feedrate adjustment (surplus feed adding up on deposit formation)

➢ A higher detergency ('cleaning ring pack) of a low BN (minimize carbon deposits on piston crown) oil is needed -> address to oil supplier.



Piston running – Cylinder oils

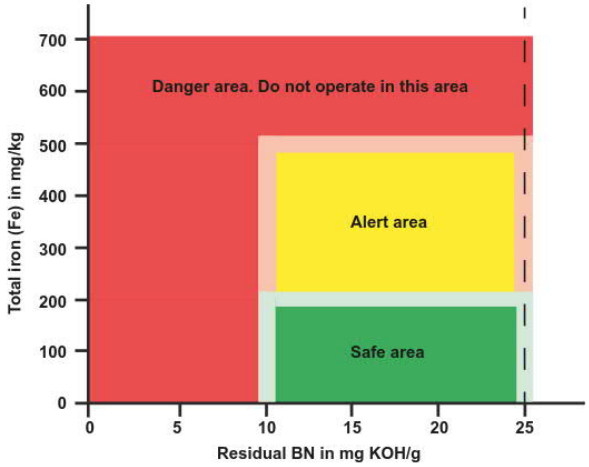
The right cylinder oil – balance between BN and detergency

The cylinder oil makers must be addressed – to find suitable cylinder oils which fulfil both

- Low BN (15~25) cylinder oil for Gas mode operation recommended, high BN (100) for HFO operation.
- Various field tests with oil majors ongoing
- Some with fairly promising results, with feed rates down to 0.6g/kWh
- WinGD Lubricants guideline will reflect latest findings in next release
- Ship operators dialogue with oil suppliers highly recommended.

WinGD-Lubricants-Issue-3-March-2019.pdf

Example of extensive piston ring deposits (above)
From PU sampling guideline – in gas mode focus is on iron content (right)



Other issues

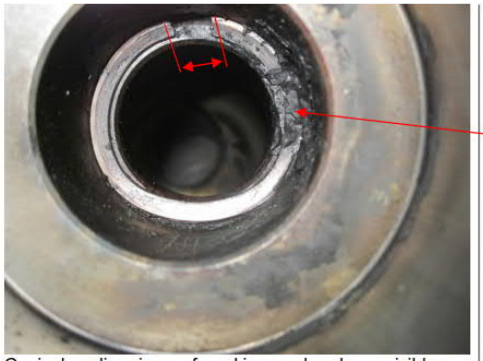
Pilot fuel injector

Pilot injector gas leakage

- Isolated cases of gas leakages on pilot injectors noted, related to a damaged sealing, allowing combustion gas from the pre-chamber to flow backwards. Lower part of pilot injector burnt.
- Reason identified as insufficient tightening of the pilot injector holding bolts (resulting in reduced sealing pressure).

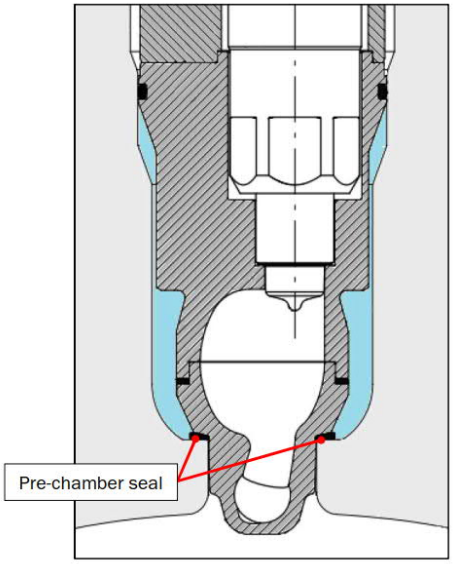
Water leakage pre-chamber

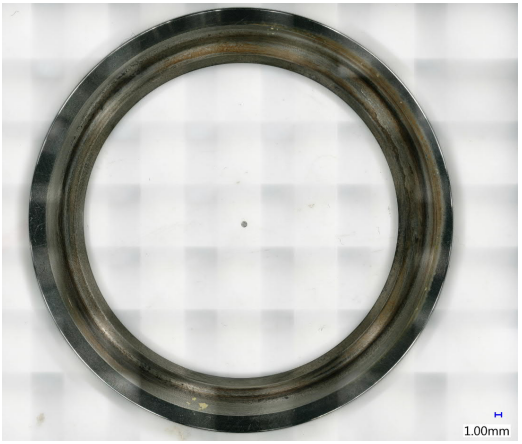
- Water leakage into the cylinder liner, due to broken seal of pre-chamber (water cooled lower part) in Dec 18. Root cause incorrect tightening of pre-chamber fixing bolts.
- Recently some further cases from X72DF reported (visible in form or red discoloration on liners).
- Reason found in loss of pretension holding bolts -> solution developed and rollout started.
- Dedicated Service letter SL-0015 released (Oct 2019).



Conical sealing ring as found in pre-chamber – visible crack of conical sealing ring and damage caused by exhaust gas blow-by.

Pilot fuel injector valve with heavy damage due to long term exhaust gas blow-by.



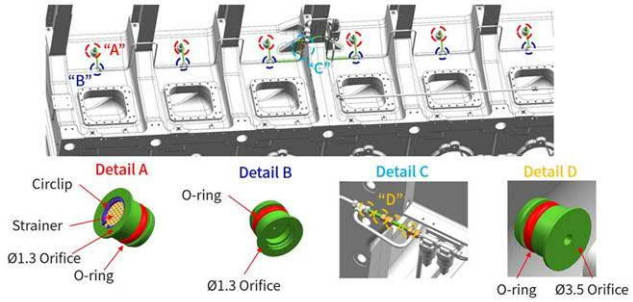


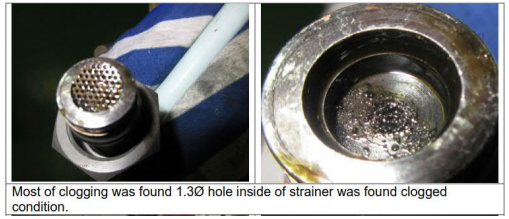
Pre-chamber sealing X72DF

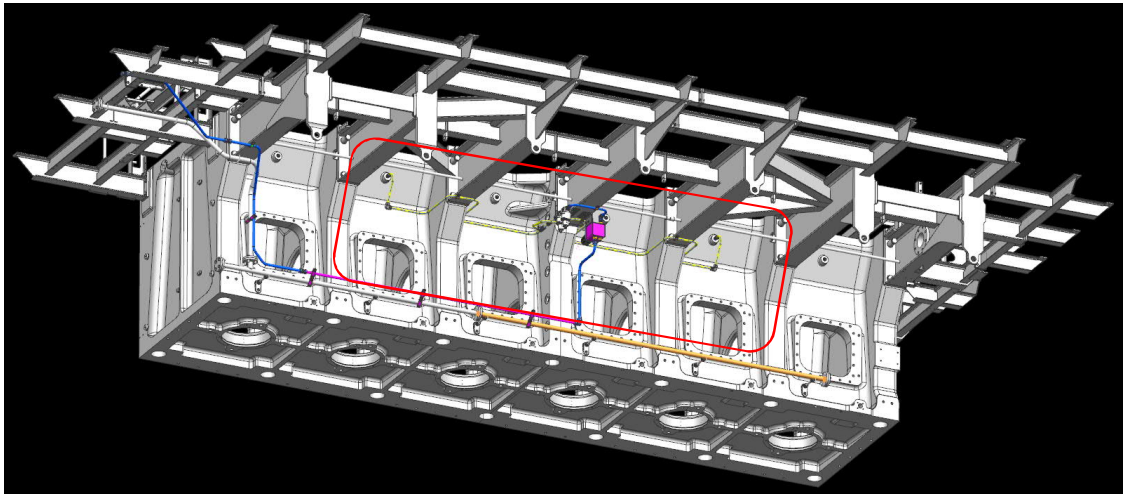
Clogged Piston Underside Gas Detection System

Design upgrade under rollout

- Clogged gas detection system orifices were noted on some installations.
- Initial design: 1mm orifices in piston underside - prone to be clogged with oil mist/soot
- New design: Reduce number of branch pipes, bigger orifices, easy access points (T-unions).
- Field test new design started in Q4 2018. Inspection follow up showed good condition after 6 month in operation..
- New solution design released late June 2019 for affected DF engines, rollout started.
- Important: Safety in Gas mode operation is not affected; the GAV stroke sensor on GAV's react immediately in gas of non-closing GAV (triggering GT).




Most of clogging was found 1.3Ø hole inside of strainer was found clogged condition.

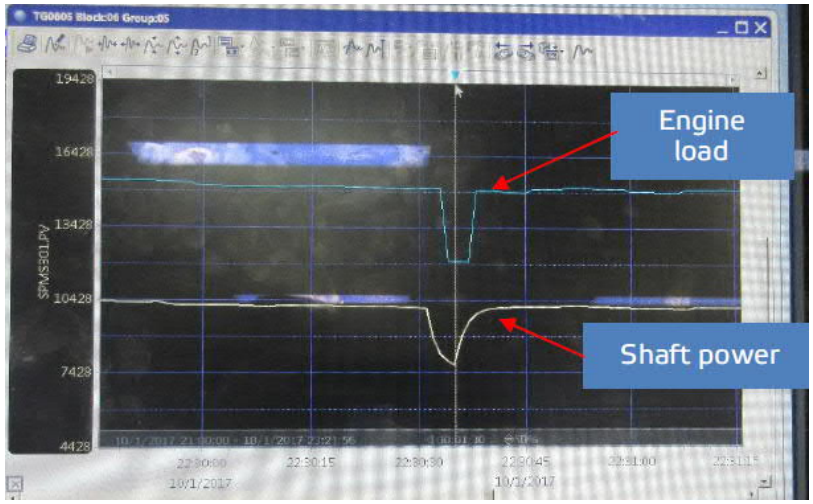


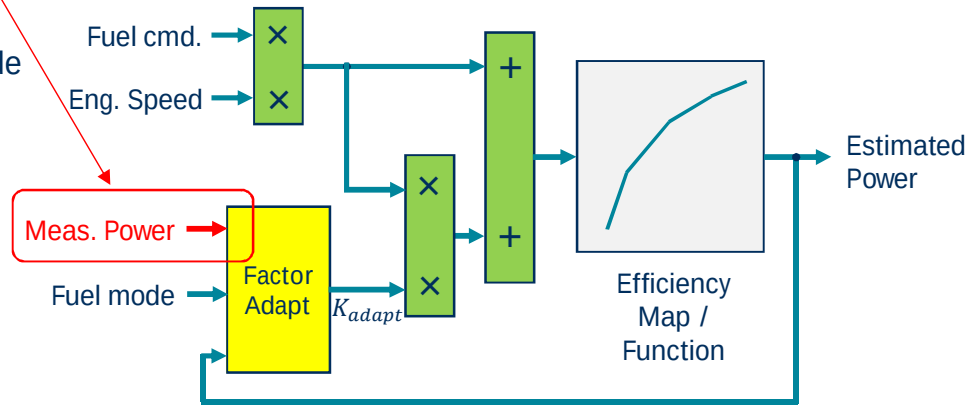
New design pipe routing (1 branch pipe per 3 cylinders) – see red box

Determination of engine power

Issue experienced in service

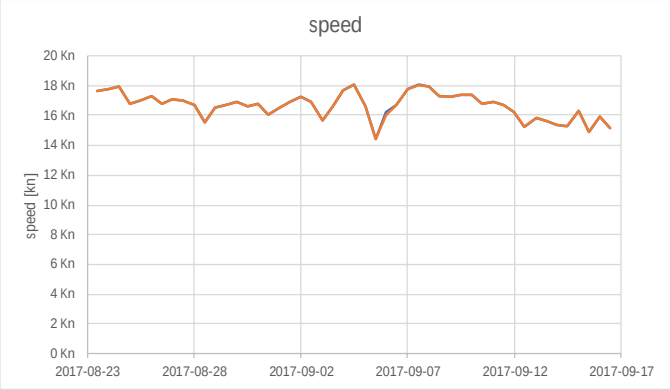
- For engine control purposes, the control system needs to know the actual engine power, e.g. for compensation of changes in calorific value of gas fuel
- An external power signal from a shaft power meter was used on X-DF engines as direct input. However, several installations in service have experienced issues with the quality of the signal, resulting in gas trips
- A new function for internal estimation of the engine power was introduced in the engine control system, where the external power signal is used for correction only
- Various further **control system improvements ongoing** as part of regular product care (based on changing requirements and / or service feedback). Major upgrade **SW 2.0** under release preparation. Key features of SW 2.0:
  - New speed controller & improved Heavy Sea mode operation
  - Power estimator improvements (GAV physical formula)
  - Ambient temperature correction
  - Crank Angle detection improvement
  - Improved cylinder lubrication functionality

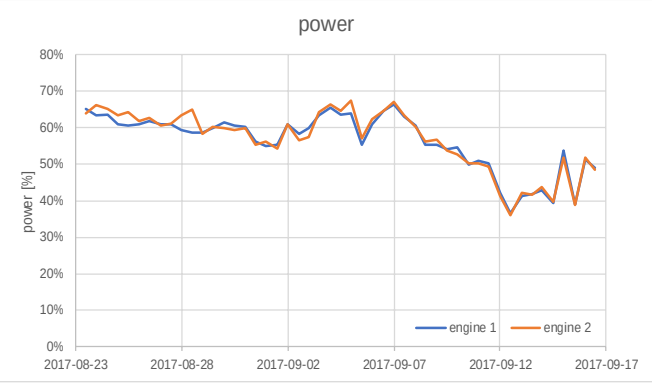


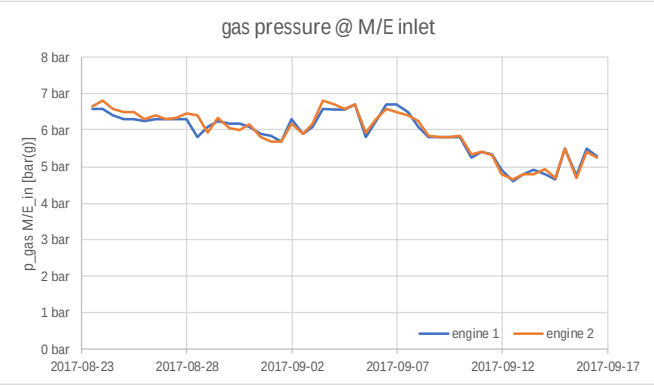


Stable operation on low gas pressure

Lower inlet pressure leading to reduced CAPEX







Engine power: Up to 70 % load with Natural boil of gas (NBOG)

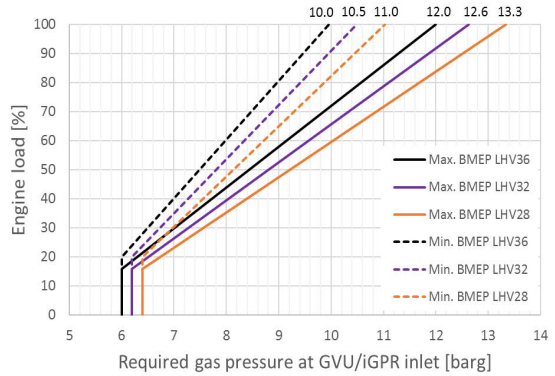
Vessel speed: Between 16kts - 18kts

Gas pressure: Engine inlet (after Gas Valve Unit) at about 7 barg at 65% power

Prove that inlet pressure of < 9 bar at GVU is sufficient for service speed

Reduction from 6 stage to 4 stage compressor possible -> CAPEX reduction

Documentation for revised gas feed pressure was updated



Summary: Operational experience

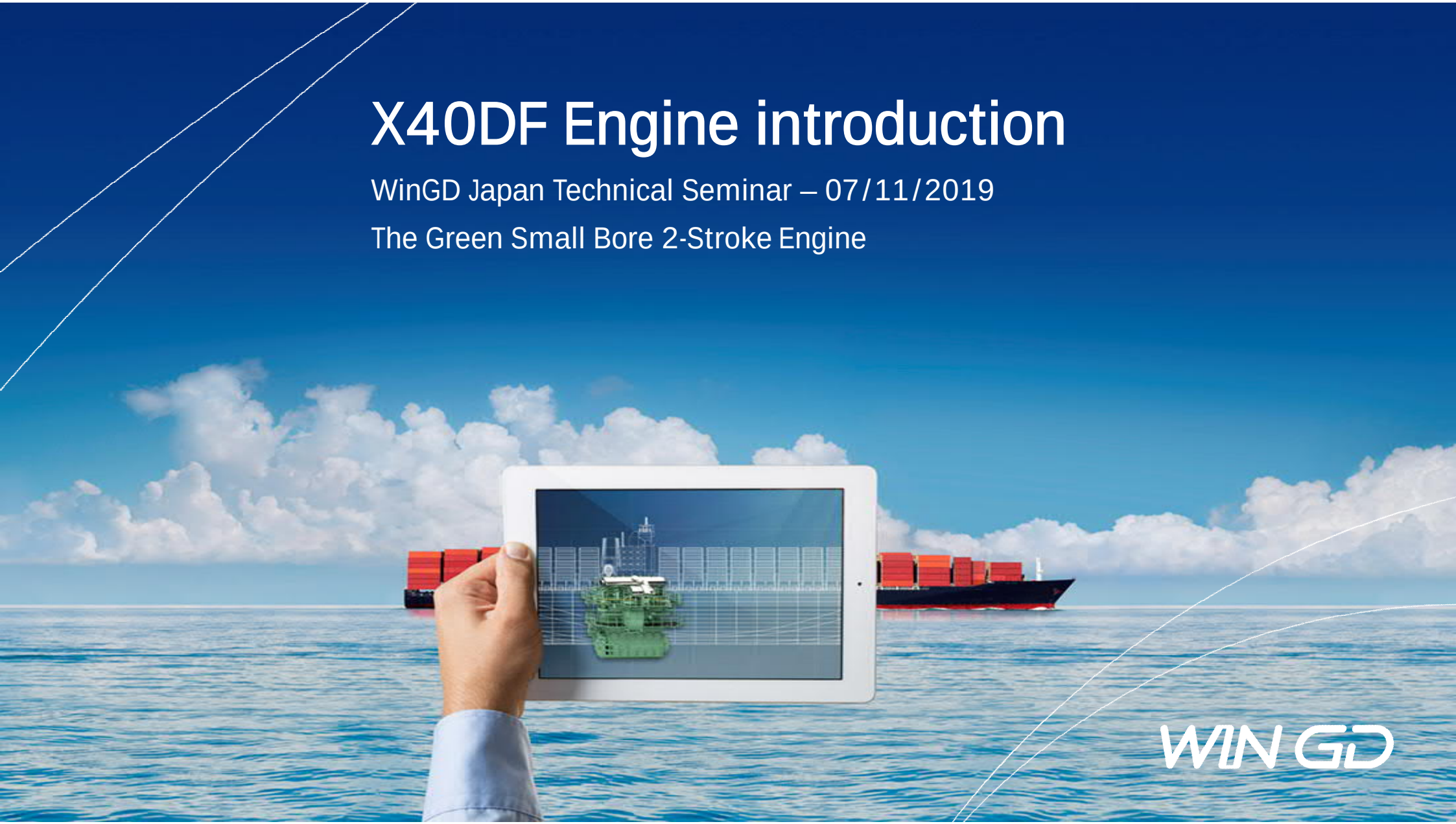
After >330’000 operating hours on WinGD low pressure DF engines

- X-DF engines are running very well.
- Teething problems noted and resolved, none of which being major.
- Operational issues on the first commercial engine RT-flex50DF, resolved in time
- Today, engines type RT-flex50DF are showing good operational behaviour
- X62DF and X72DF engines gained from experience gathered on RT-flex50DF, but brought up some unexpected new challenges.
- Engine availability running in Gas mode on LNGC’s on BOG impressive >97% !
- WinGD following up closely on DF fleet to further enhance customers satisfaction on this unique propulsion concept.

X40DF Engine introduction

WinGD Japan Technical Seminar – 07/11/2019

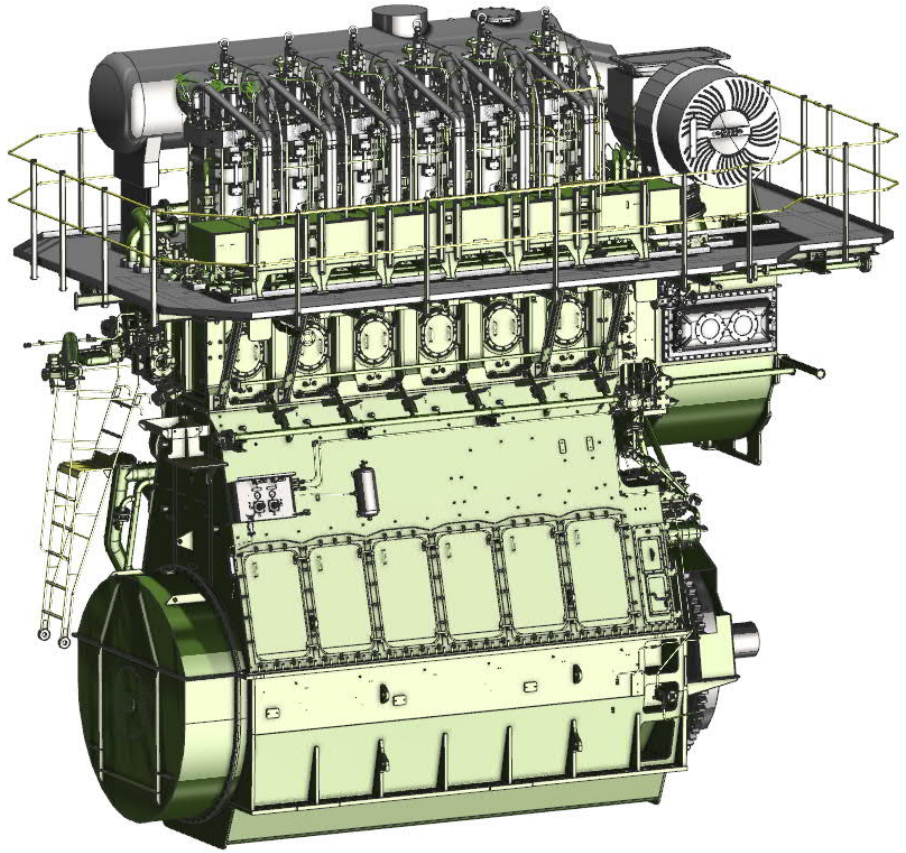
The Green Small Bore 2-Stroke Engine



X40DF

Main Engine Parameters

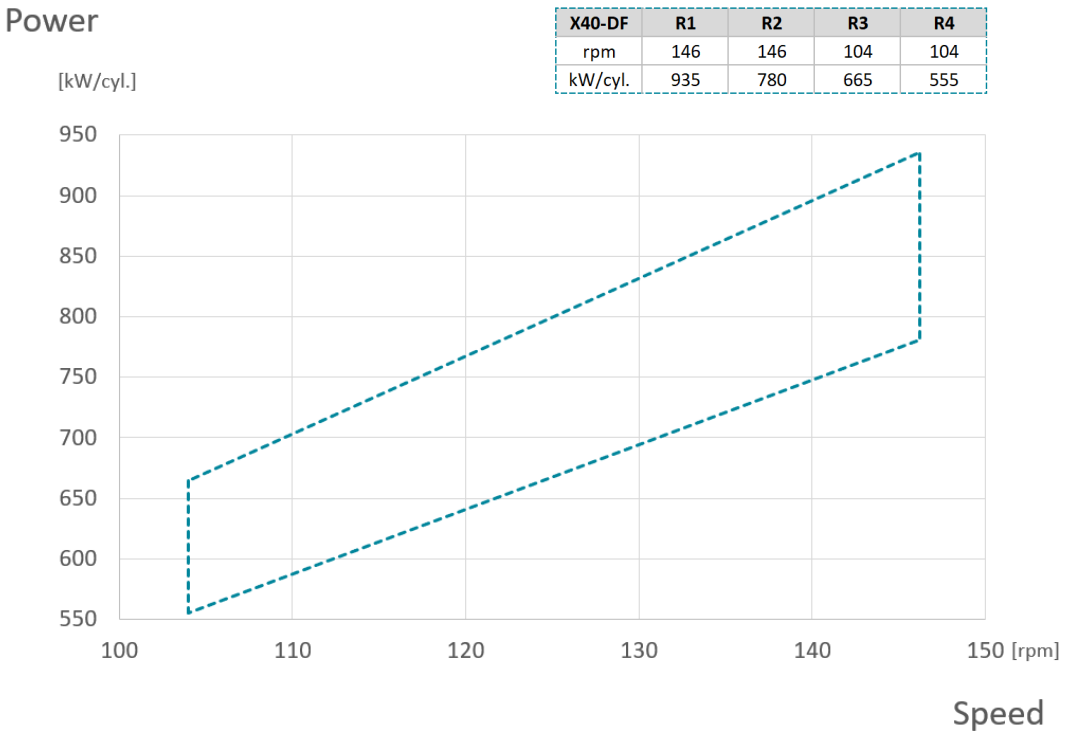
	X40DF
Bore [mm]	400
Stroke [mm]	1770
Stroke / bore	4.43
Cylinder number	5 - 8
Cylinder output [kW] @ R1	935
Engine speed [1/min] @ R1	146
Engine speed [1/min] @ R3	104
BMEP [bar] @ R1	17.3
Mean piston speed [m/s] @ R1	8.6
Max. cylinder pressure [bar]	200
BSFC @ R1 [g/kWh]	189.9
BSGC – BSPC @ R1 [g/kWh]	145.0 - 1.4
BSEC @ R1 [KJ/kWh]	7310
Cylinder distance [mm]	700

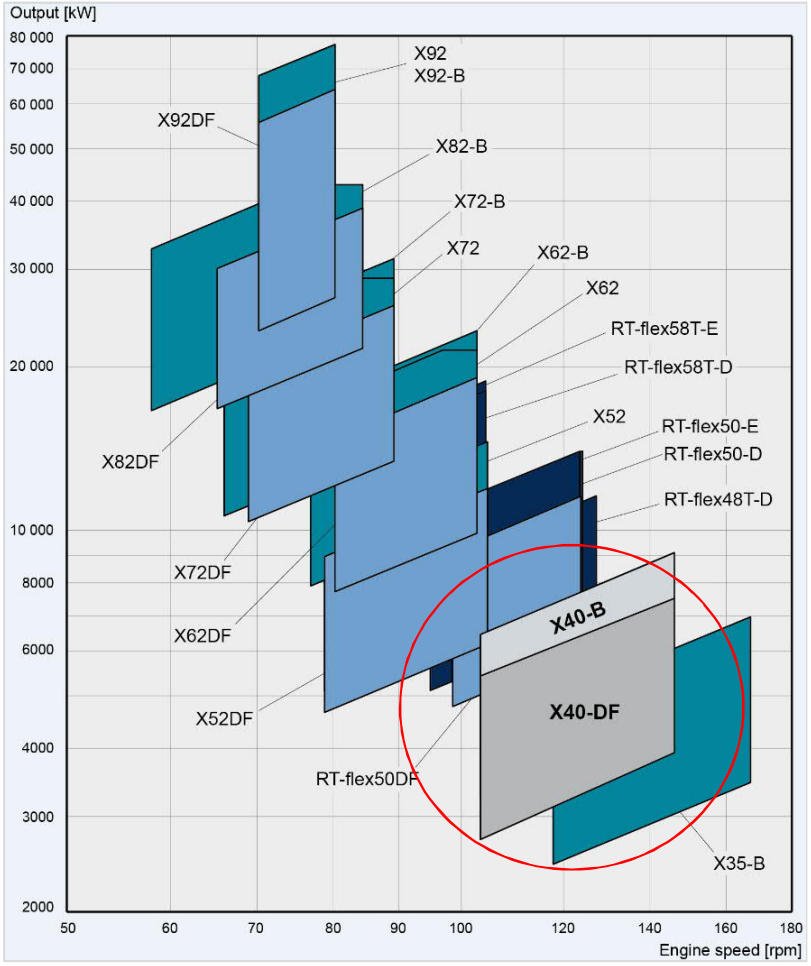


X40DF

Rating field X40DF

X40-DF	R1	R2	R3	R4
rpm	146	146	104	104
kW/cyl.	935	780	665	555



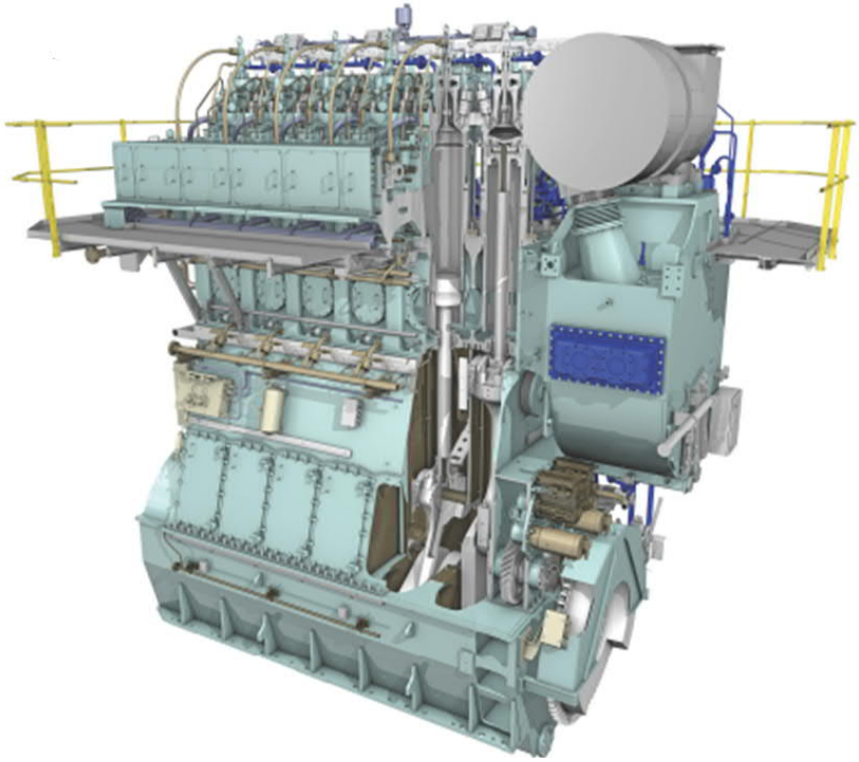


X40DF

Engine Concept - Overview

The X40DF has been designed using the X40-B platform:

- The benefits of our market-leading, proven low-pressure dual-fuel technology introduced to the small bore engine range
- Idea is an MGO based design (clean fuel for Tier II operation), with the option to add HFO-capability per customer wish (validation on lab engine starting Nov 2019)
- WiCE Control System: State-of-the-art hardware and software architecture. Easy to understand commissioning and monitoring tools



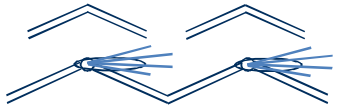
WinGD 6X40-B engine

X40-DF

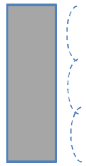
Combustion Chamber design

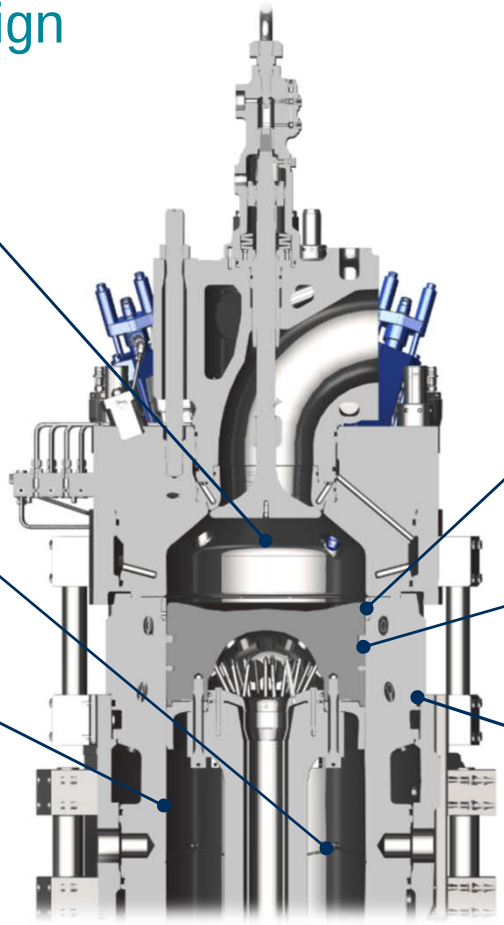
200bar peak pressure

Pulse Lubricating System + grooves

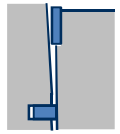


Liner plateau honed

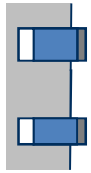




Anti-polishing ring



2 piston rings
- *Top ring gas-tight*
- *Cr-ceramic coated*
- *Pre-profiled*



Piston ring grooves with thick chromium layer

Liner wall temperature sensors

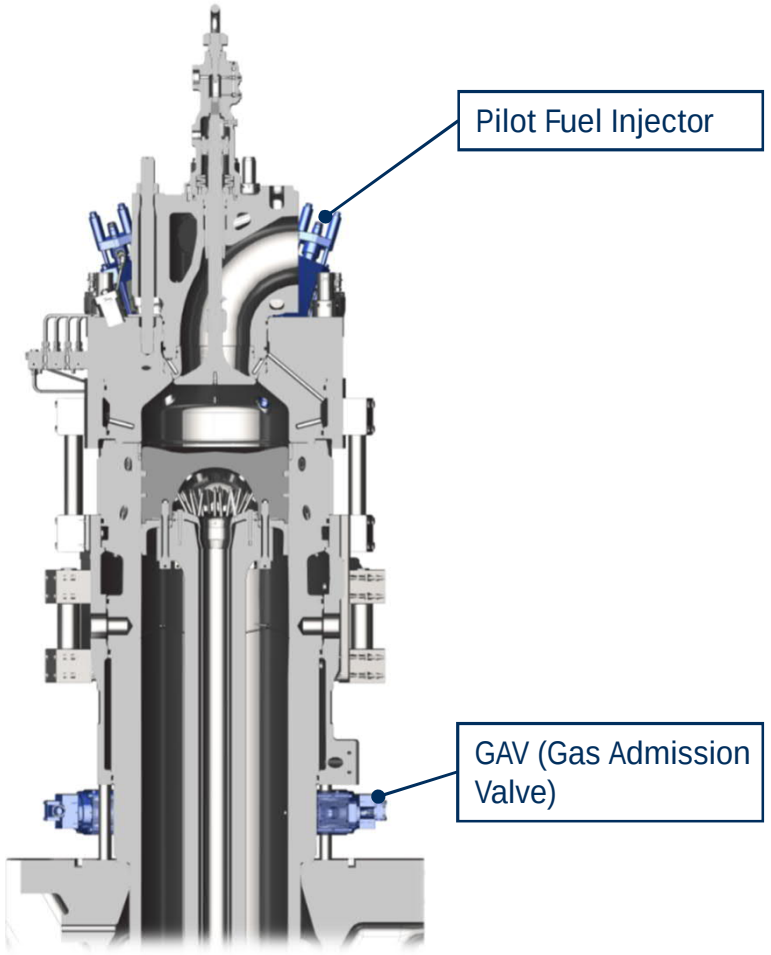
X40DF

Cylinder Liner / Cover and pilot injection system

- The cylinder liner compared to the X40-B engine has been increased by 179mm height to achieve the lower compression ratio required for the X40DF engine, thus increasing the piston dismantling height.
- DF specific components are shown in blue on the right (GAV's and pilot injectors)

Pre-chamber technology

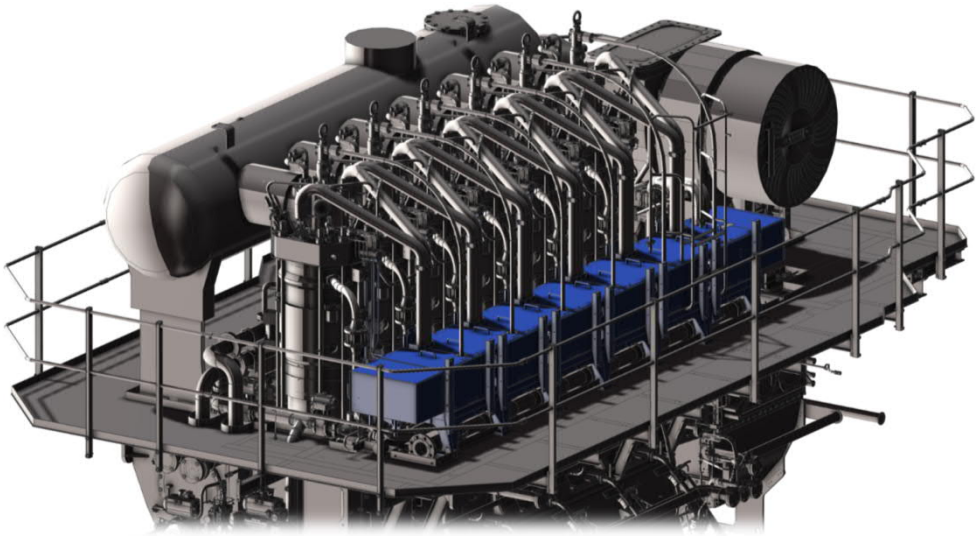
- Basic design – first time without separate Pilot Fuel Pump (subject to validation test results)
- Proven Pre-chamber Pilot Fuel Injection



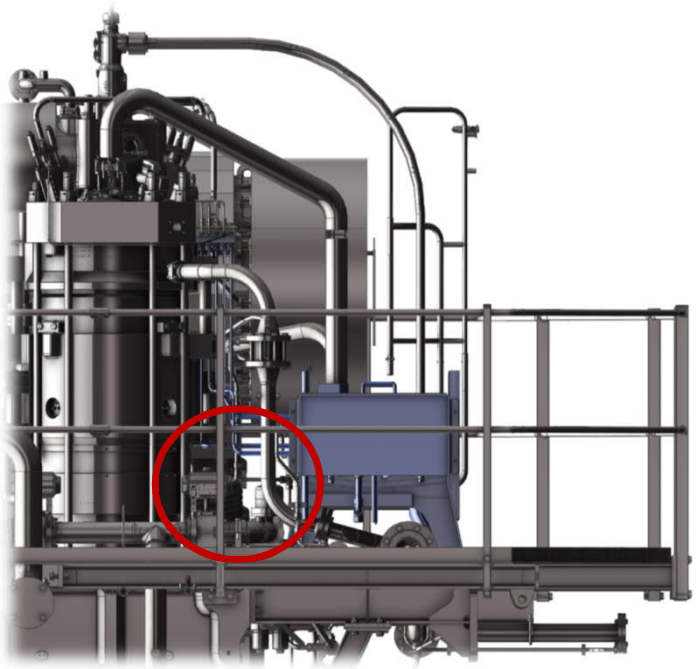
X40DF Combustion Chamber

X40DF

Compact Rail Unit design



- The X40-B Rail Unit was optimized for the X40DF. The more compact design allows for better access to GAV and Gas Piping, which increases operation and maintenance friendliness of the engine

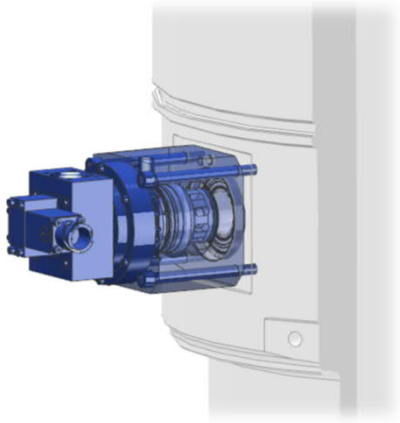


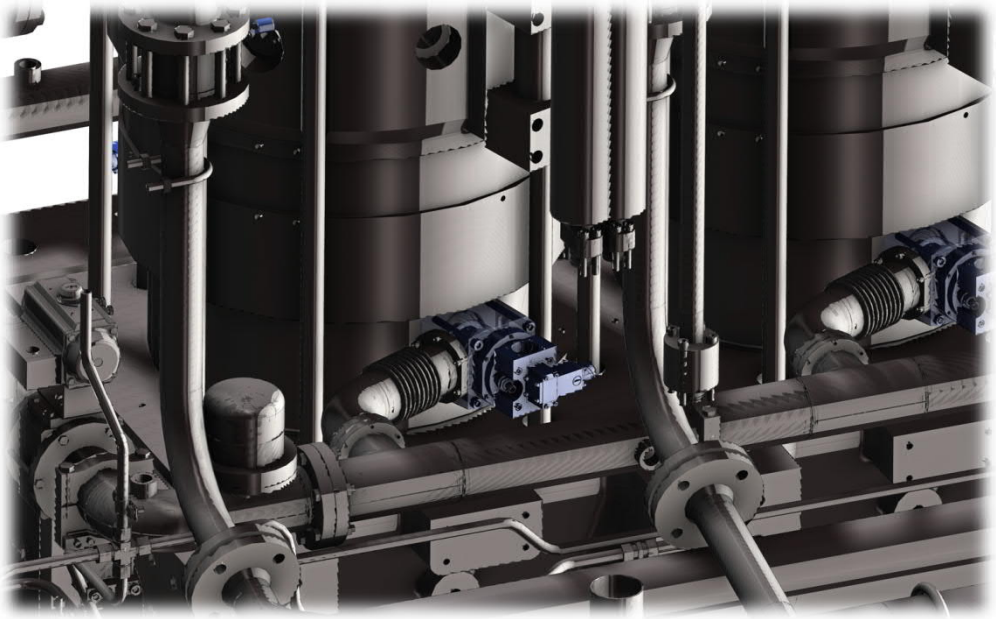
X40DF Rail Unit with improved access

X40DF

DF System – Gas Admission Valve

- Proven WinGD Gas Admission Valve Design
- Optimized to suit X40DF engine design



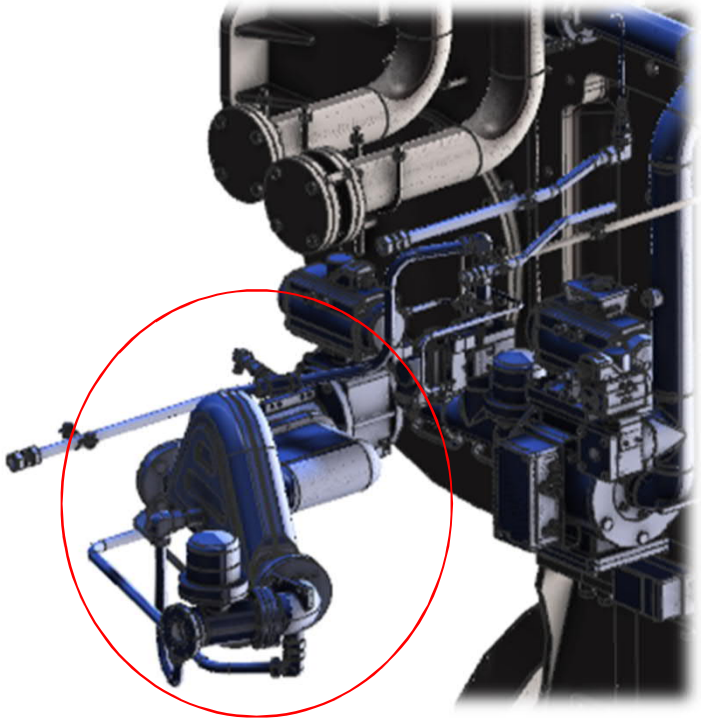


X40DF GAV (Gas Admission Valve)

X40DF

DF System – iGPR (integrated Gas Pressure Regulation)

- Simplified concept for gas feed regulation to the engine
- Fully integrated into the engine design/control system
- Safety ensured with double-wall design
- Reduction of complexity for engine builders, shipyards and operators



X40DF iGPR

Summary

The X40DF is latest addition to the X-DF family, and will introduce our proven low-pressure dual-fuel technology to WinGD's smallest engine bore segment. Its design makes the X40DF the obvious choice for owners demanding environmentally conscious vessel operation at optimal value, while still benefitting from the market leading technology.

- The X40DF basic model is the most environmentally sustainable with the greatest value for money two-stroke available. It is designed to operate on Marine Gas Oil (0.1% Sulphur) in Tier II mode, keeping in line with the Sulphur 2020 regulations, and MGO/LNG during Tier III mode.
- The modular design of the X40DF allows fuel flexibility, giving the owner options to decide which model to install, based on their plans for vessel operation. An MDO/HFO/LNG version requires the addition of a separate pilot fuel supply unit and iCAT (Integrated Cylinder Lubricant Auto Transfer). Most other additions are in the engine room, with the addition of separate fuel storage tanks, fuel heating and treatment equipment etc.
- Designed for LNG carriers, the X40DF can be used in Handysize tankers, bulk carriers, and feeder container vessels. Small tankers, container vessels, multipurpose vessels, and bunkering vessels are also suitable for its application.

X82DF Engine introduction

WinGD Japan Technical Seminar – 07/11/2019

The most environmental sustainable Engine for VLCC's, VLOC's and medium sized Container Vessels

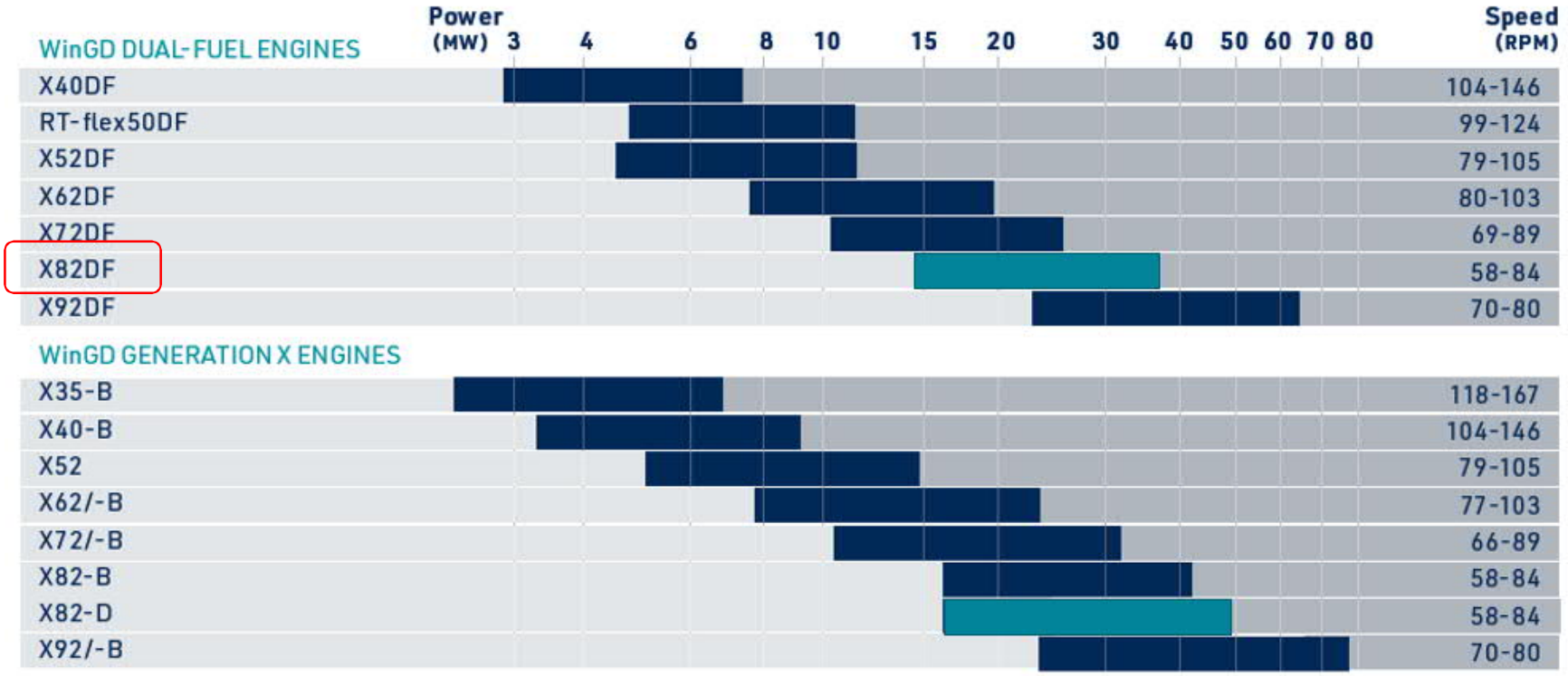
X82DF/X82-D

Target Market

The concept and design of the X82DF/-D incorporates the improvements and new designs of the target market vessels

X82DF/X82-D – Engine parameters

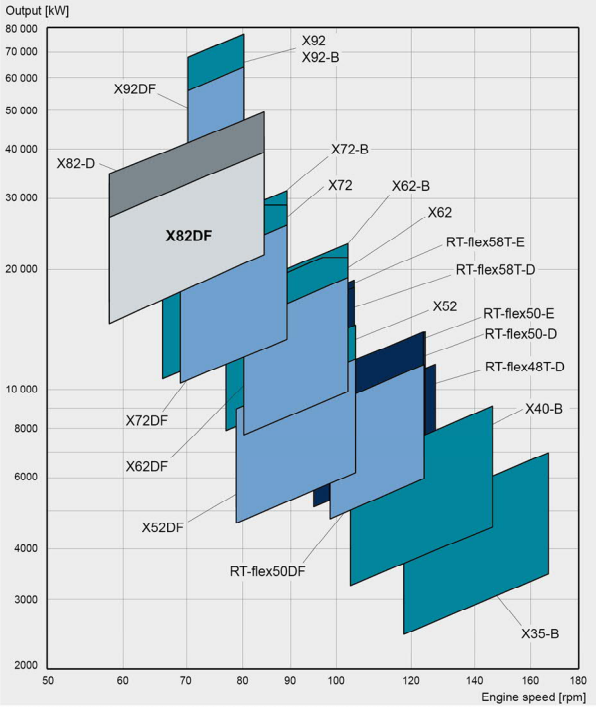
X-Engine power range



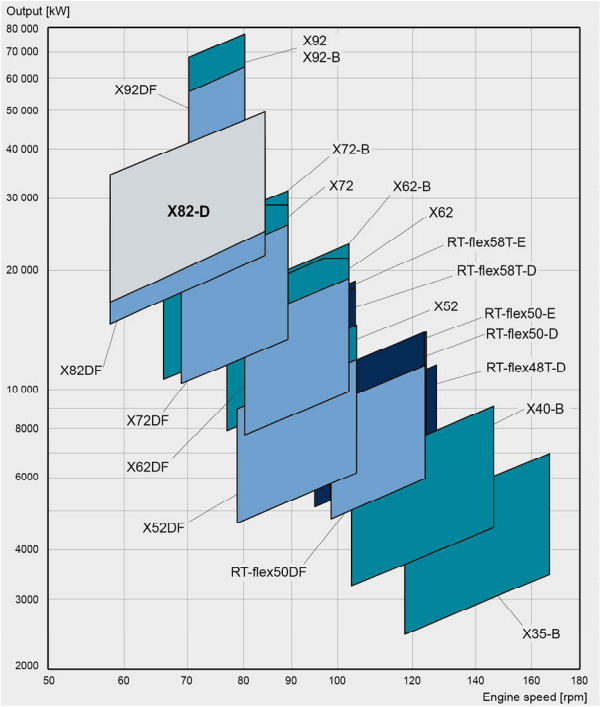
X82DF/X82-D – Engine parameters

Portfolio rating field

- The XDF-engines
  - X40DF
  - X52DF
  - X62DF
  - X72DF
  - X82DF
  - X92DF



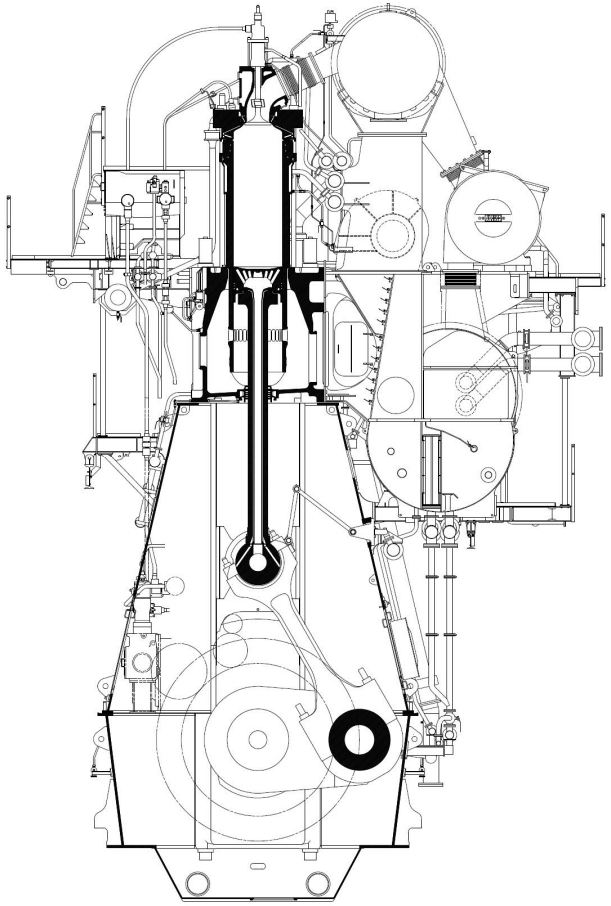
- The X-engines
  - X35
  - X40
  - X52
  - X62
  - X72
  - X82
  - X92



X82DF/X82-D – Design concept

Main particulars

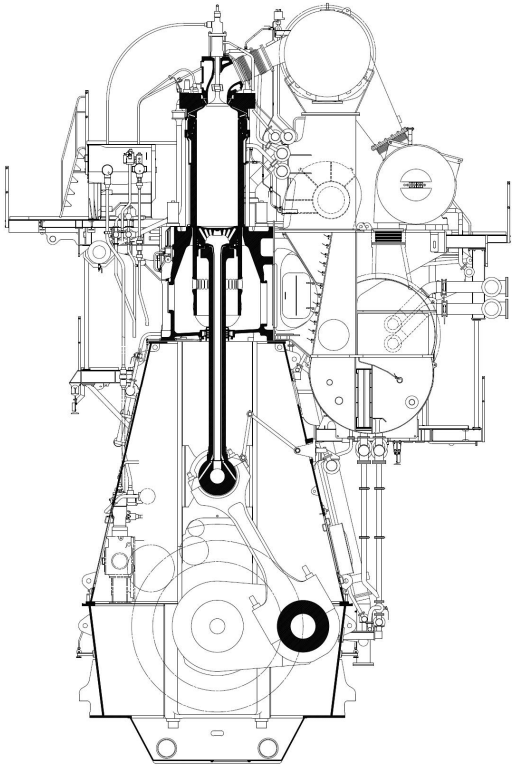
	X82DF	X82-D
Bore [mm]	820	820
Stroke [mm]	3’375	3’375
Cylinder number	6 – 9	6 – 9
Cylinder output [kW] @ R1	4’320	5’500
Engine speed [1/min] @ R1	84	84
Engine speed [1/min] @ R3	58	58
BMEP [bar] @ R1	17.3	22.0
Mean piston speed [m/s] @ R1	9.5	9.5



X82DF/X82-D – Design concept

Basis of the design

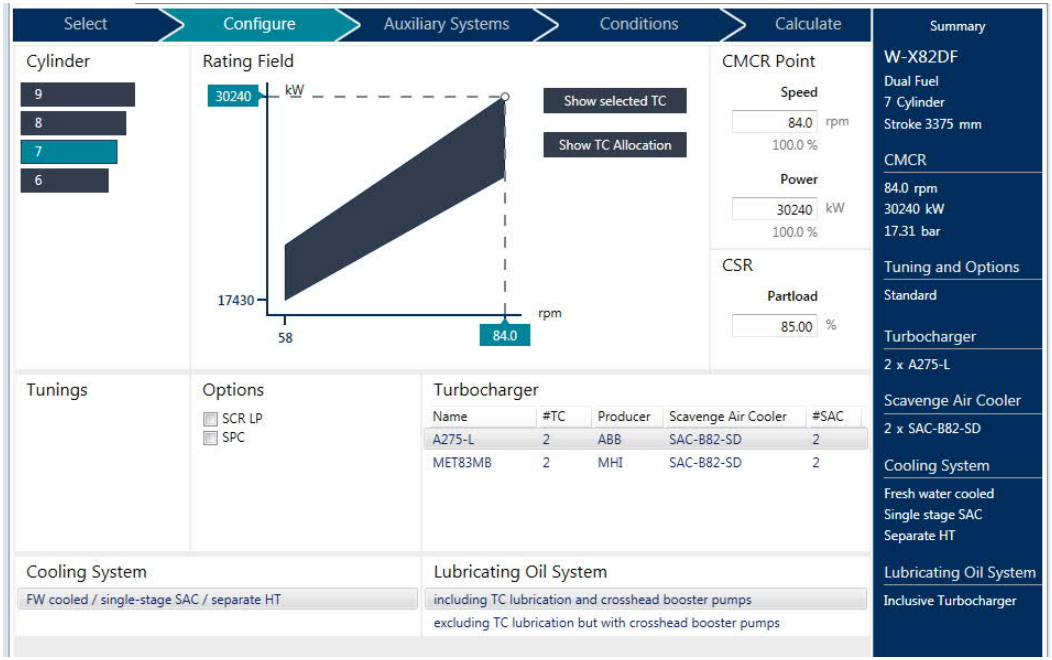
- X92DF has been used as the reference engine for the X82DF/-D with some adaptations
  - New ‘flexible’ (lighter) main bearing girder design
  - Injection control system: ICU’s with conventional injectors
  - Control system WiCE
- Market demands drove the definition of the cylinder power and certain critical engine aspects
  - The overall engine length has been reduced to meet the new VLCC ship design requirements
- The X82-D engine will follow the WinGD DF-ready engine definition by sharing as similar as possible the same engine platform as the X82DF



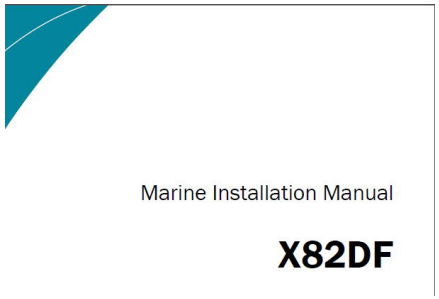
X82DF – Available

WinGD's General Technical Data (GTD) & MIM

- Program for project planning and execution at yards and licensees
- Output
  - Engine performance (fuel consumption)
  - Layout and capacities of ancillary systems
- For X82DF available since March 2019



- X82DF Marine Installation manual released



X92DF Engine introduction

WinGD Japan Technical Seminar – 07/11/2019

The most environmental sustainable Engine for large Container Vessels

X92DF

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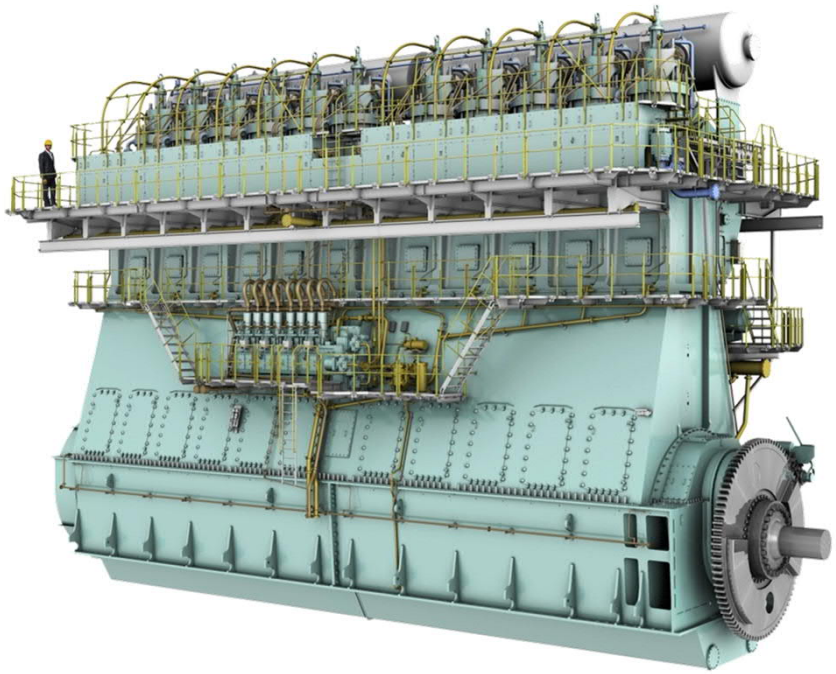
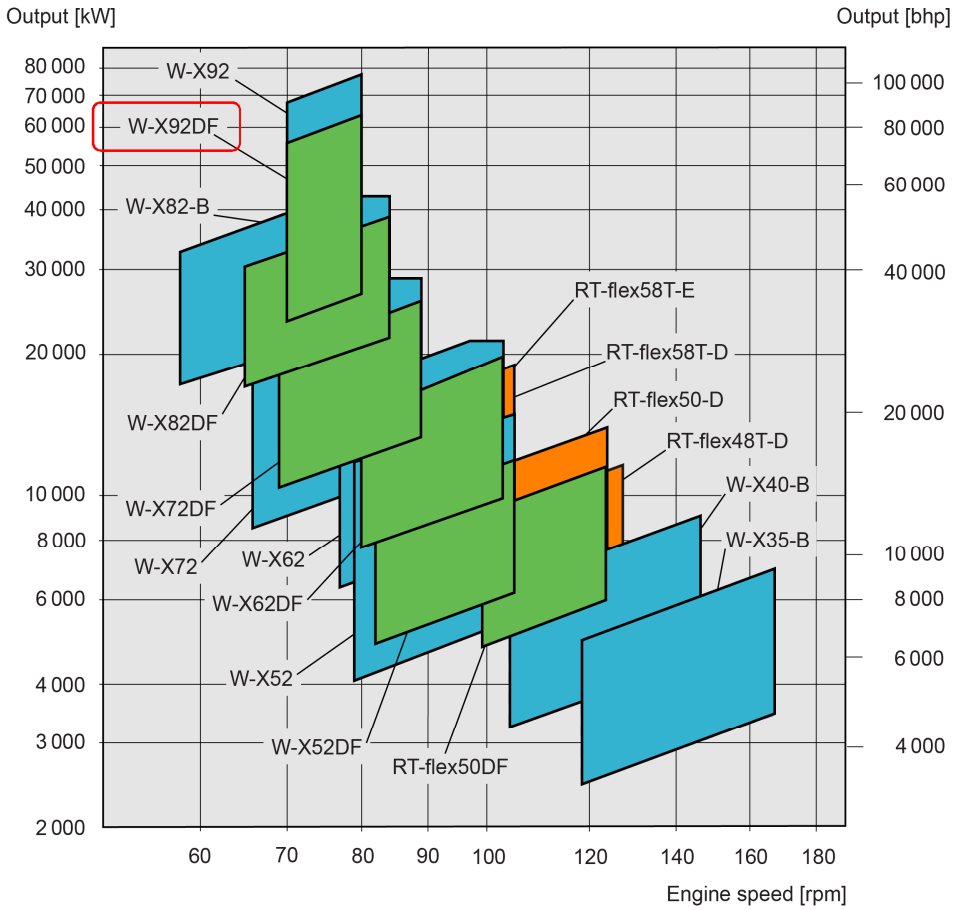


X92DF –Engine Parameters



X92DF

IMO Tier III in gas mode

Cylinder bore	920 mm
Piston stroke	3468 mm
Speed	70-80 rpm
Mean effective pressure at R1	17.3 bar
Stroke / bore	3.77

RATED POWER, PRINCIPAL DIMENSIONS AND WEIGHTS

Cyl.	Output in kW at 80 rpm R1	R2	70 rpm R3	R4	Length A mm	Weight tonnes
6	31 920	26 580	27 930	23 250	11 570	1 120
7	37 240	31 010	32 585	27 125	13 160	1 260
8	42 560	35 440	37 240	31 000	14 750	1 380
9	47 880	39 870	41 895	34 875	17 780	1 630
10	53 200	44 300	46 550	38 750	19 370	1 790
11	58 520	48 730	51 205	42 625	21 030	1 960
12	63 840	53 160	55 860	46 500	22 700	2 140

Dimensions (mm)	B	C	D	
	5 550	1 900	13 140	
	F1	F2	F3	G
	15 520	15 530	14 260	2 970

BRAKE SPECIFIC CONSUMPTIONS IN GAS MODE

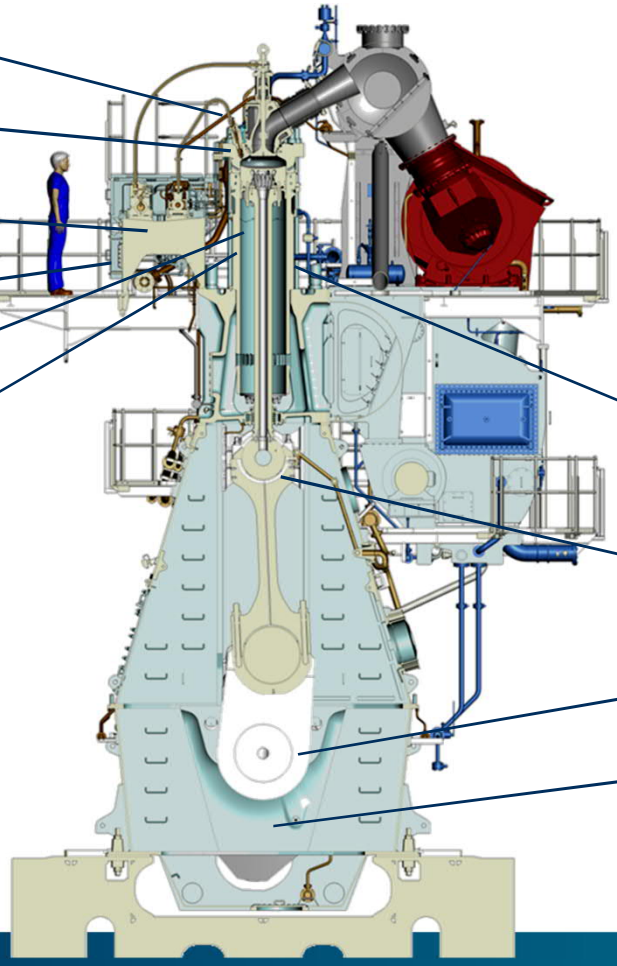
Rating point		R1	R2	R3	R4
BSEC (energy)	kJ/kWh	7 089	6 846	7 192	6 944
BSGC (gas)	g/kWh	141.2	136.2	143.2	138.2
BSPC (pilot fuel)	g/kWh	0.7	0.8	0.7	0.8

BRAKE SPECIFIC FUEL CONSUMPTION IN DIESEL MODE

Rating point		R1	R2	R3	R4
BSFC (diesel)	g/kWh	181.1	179.1	181.1	179.1

Design features – X92 -> X92DF

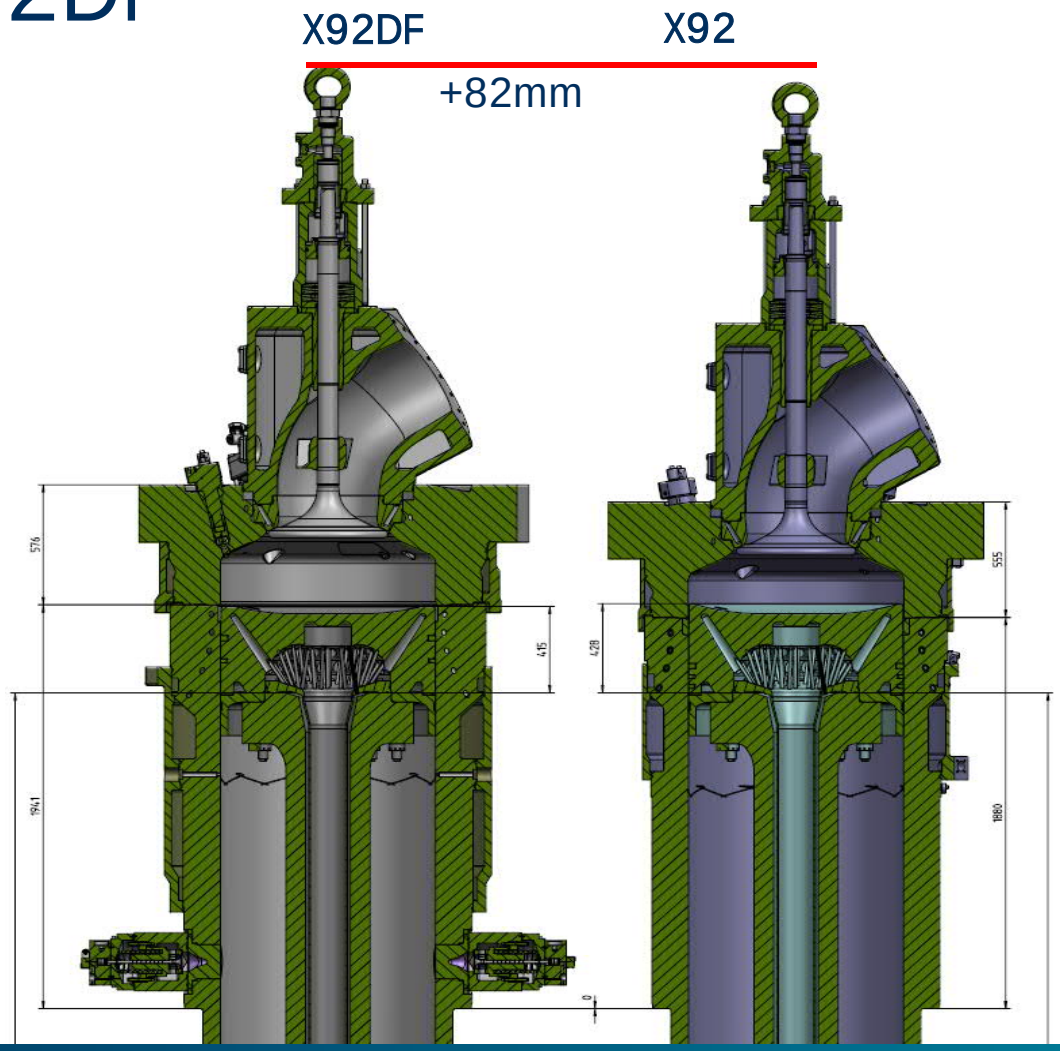
- Pilot fuel injection system
- Reinforced cylinder cover
- Adapted rail unit design
- WiCE engine control system
- Reinforced cylinder liner
- Flexible cylinder cooling system (Diesel–Gas)



- Gas admission system
- Increased crosshead pin diameter
- Aluminum bearing
- Optimized girder design

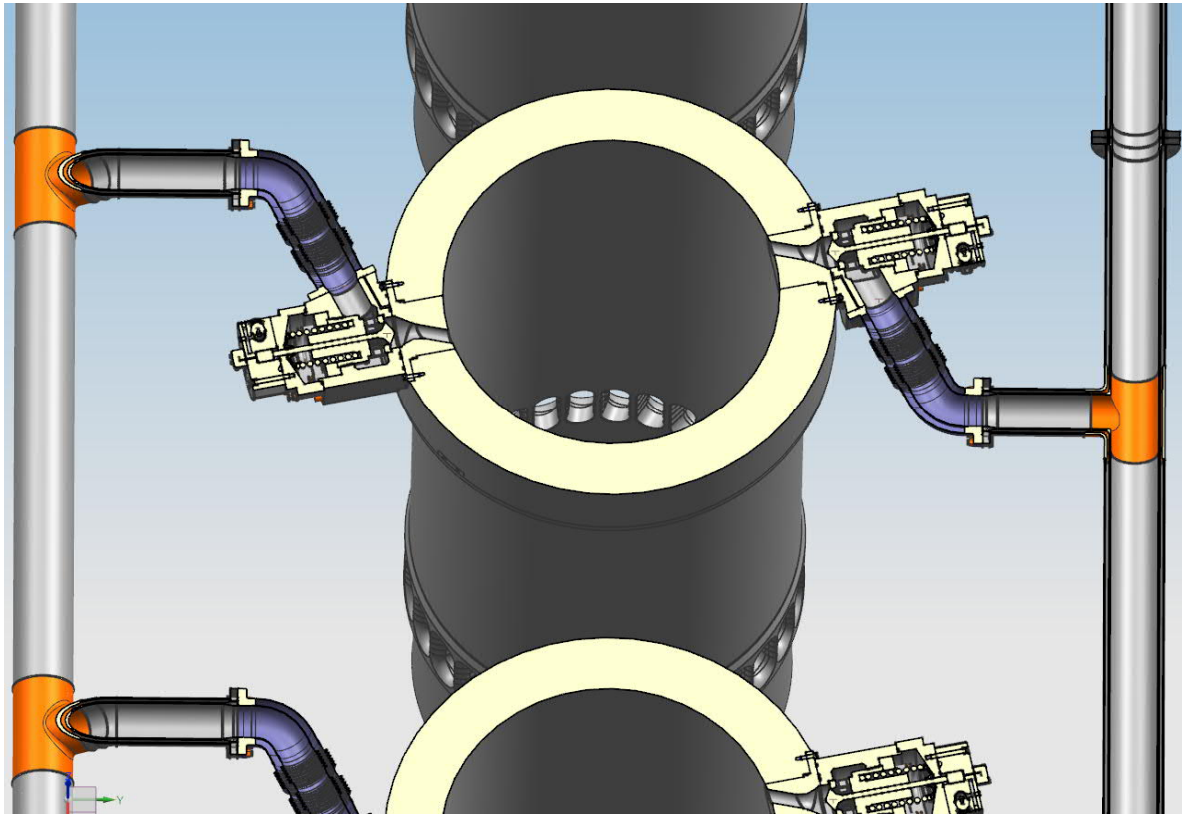
Design features X92DF

Cylinder Liner & Cover lifted to achieve DF compression ratio



Design features X92DF

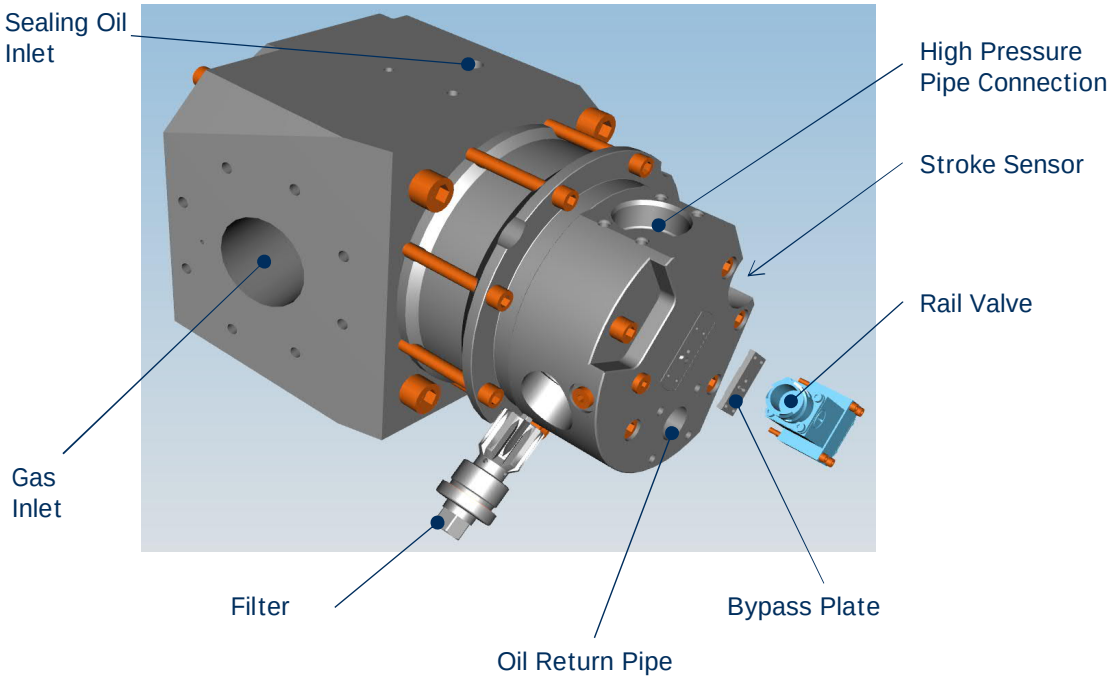
Proven double-wall Gas Manifolds concept from X62/72DF

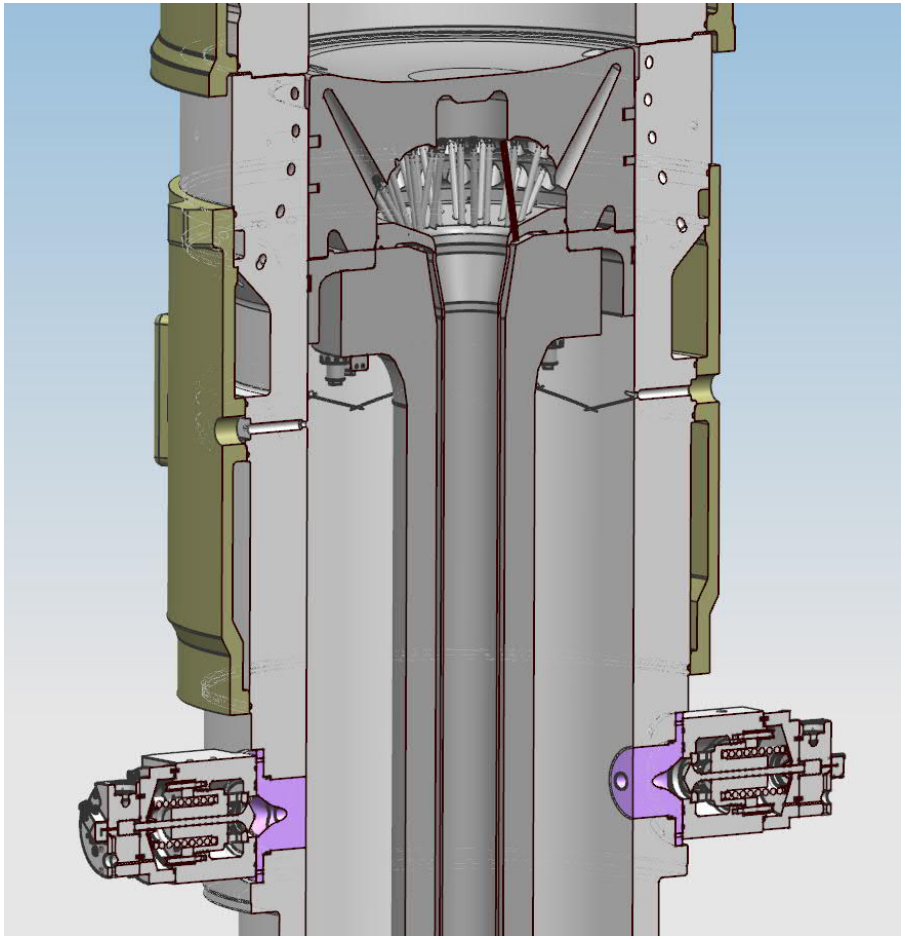


Design features X92DF

Gas admission valves (GAV)

- Gas admission valves located at mid stroke (2pcs/cyl)
- Allowing moderate gas admission pressures < 16bar

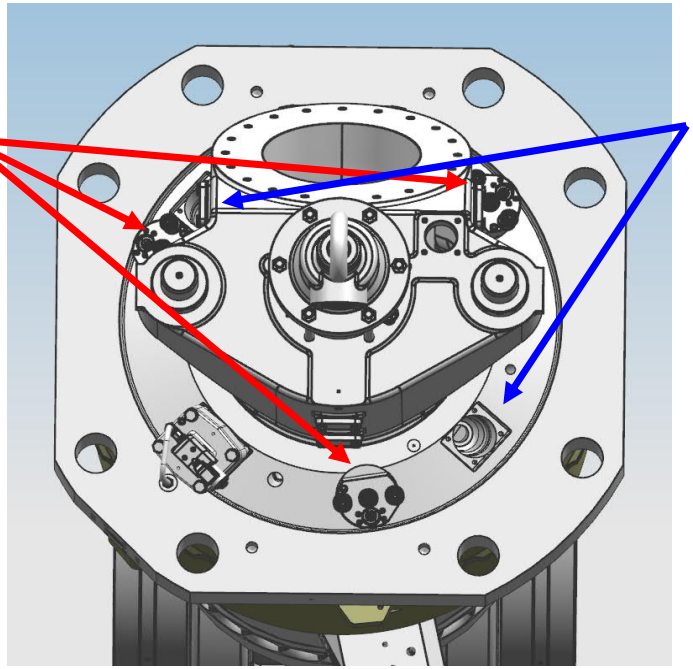




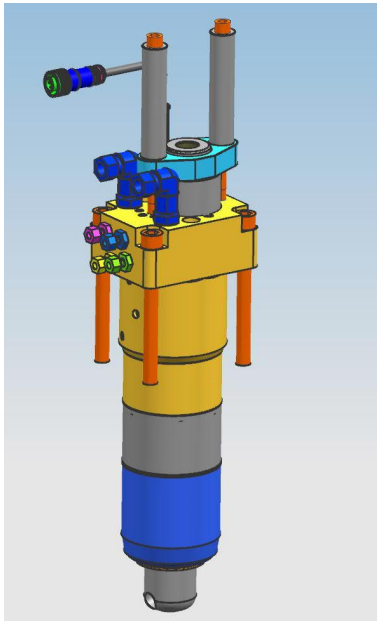
Design features X92DF

Cylinder cover and fuel injectors

3 (conventional) Diesel main fuel injectors



2 electronically controlled Pilot fuel injectors

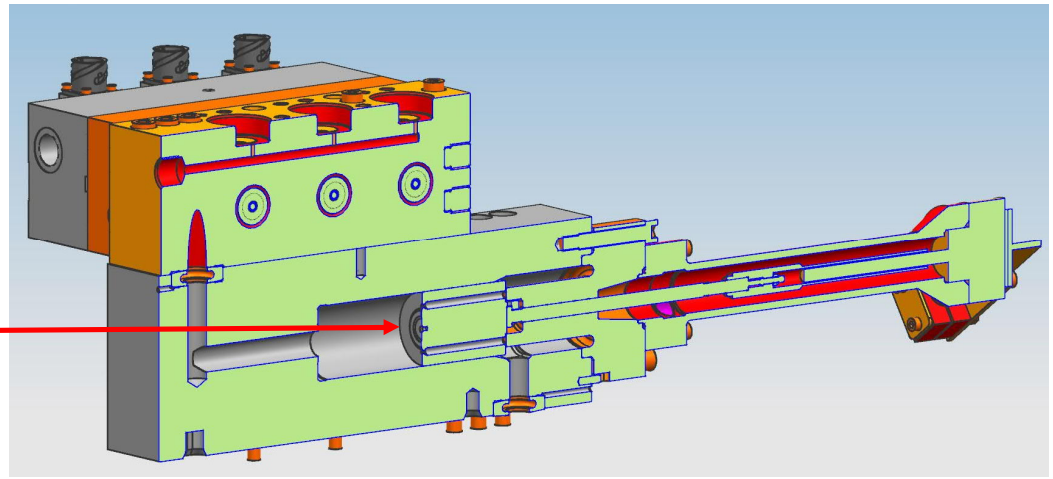


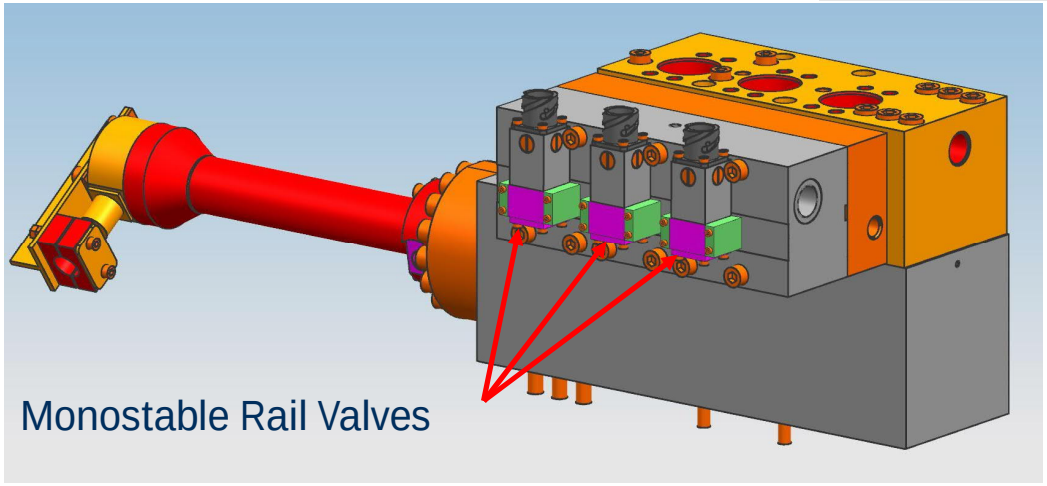
- Pilot Pre-chamber scaled up from X62/72DF, to keep same relative pilot energy
- Integrated cooling, to avoid that cooling water needs to be drained for Pre-chamber removal, and to avoid risk of water leakage into the combustion chamber

Design features X92DF

Injection control unit (ICU)

Piston size adapted
to engine power

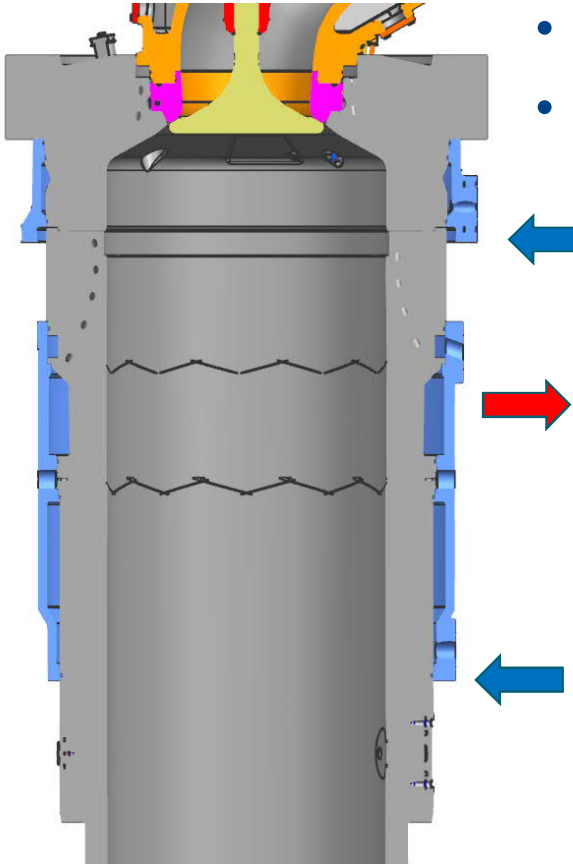




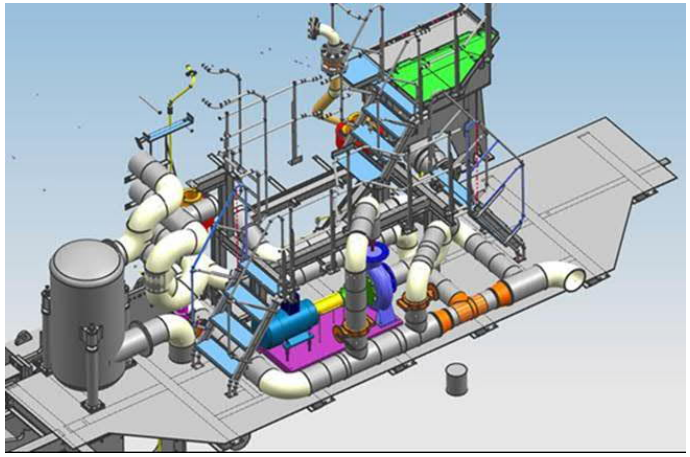
Note: Picture indicative, details might not represent the final design stage

Design features X92DF

Cylinder liner cooling



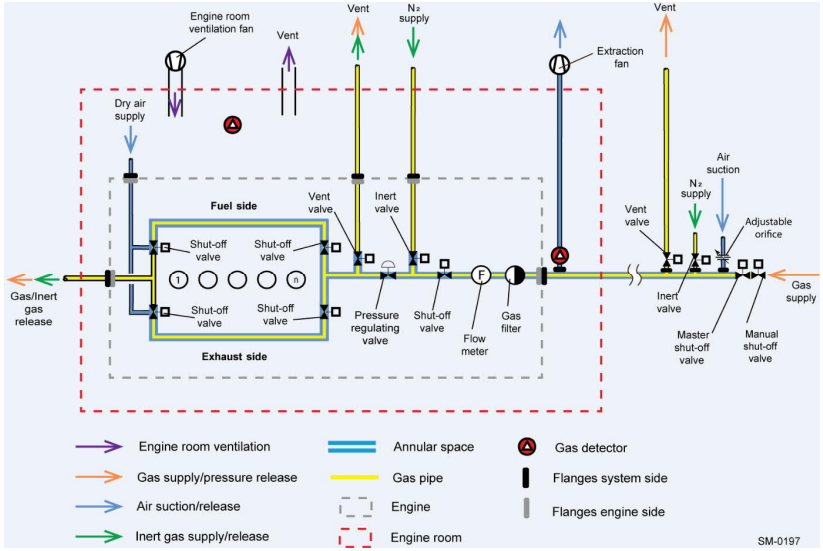
- Electronically controlled cylinder cooling system
- Cooling adaptable to ensure ideal component temperatures depending on operation mode:
  - Gas mode: More intense cooling to ensure stable combustion conditions
  - Diesel mode: Less intense cooling to prevent cold corrosion by increased liner wall temperatures

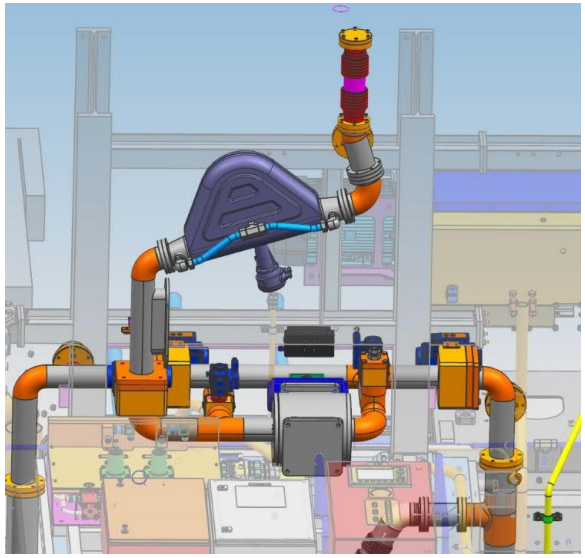


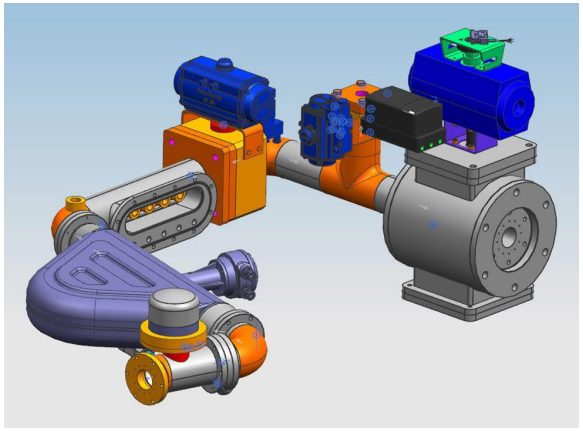
Design features X92DF

Gas pressure regulation – with iGPR

- Integrated gas pressure regulation on the engine
- Standard on new X-DF engines (X52DF, X92DF)



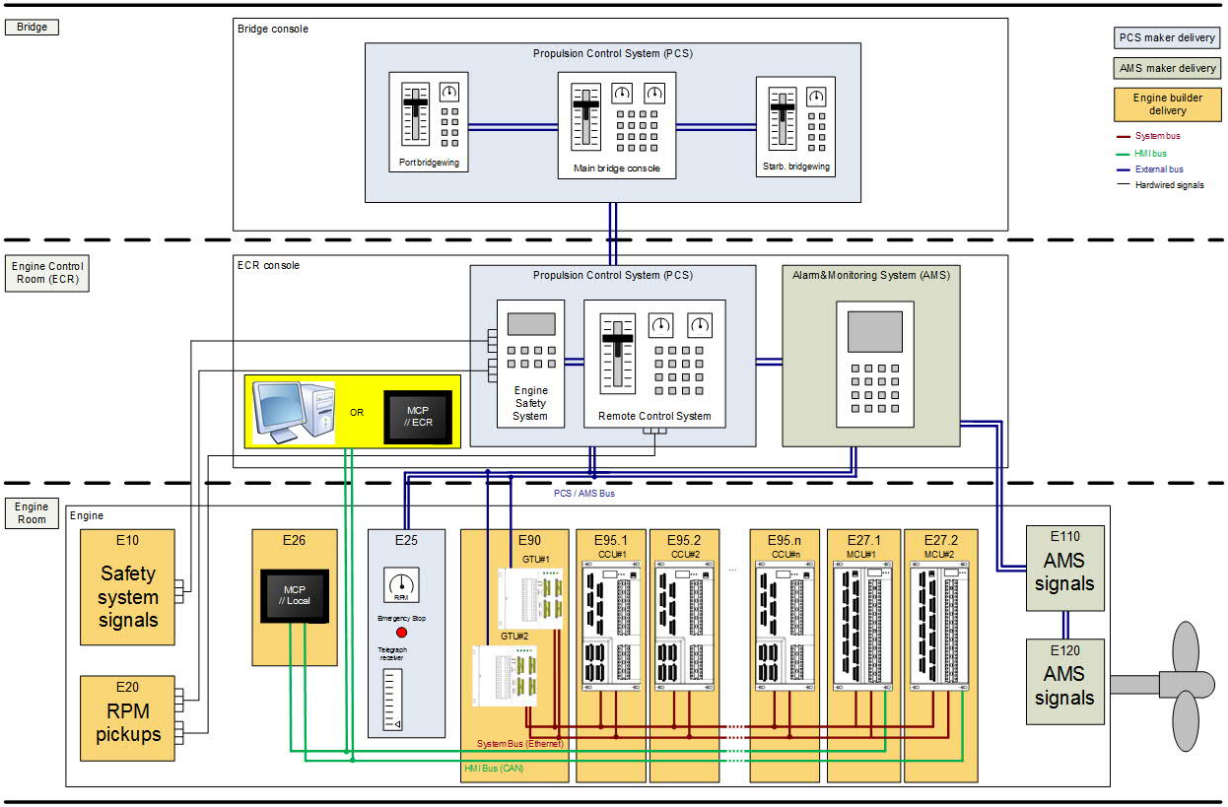




Design features X92D

WiCE (WinGD integrated Control Electronics)

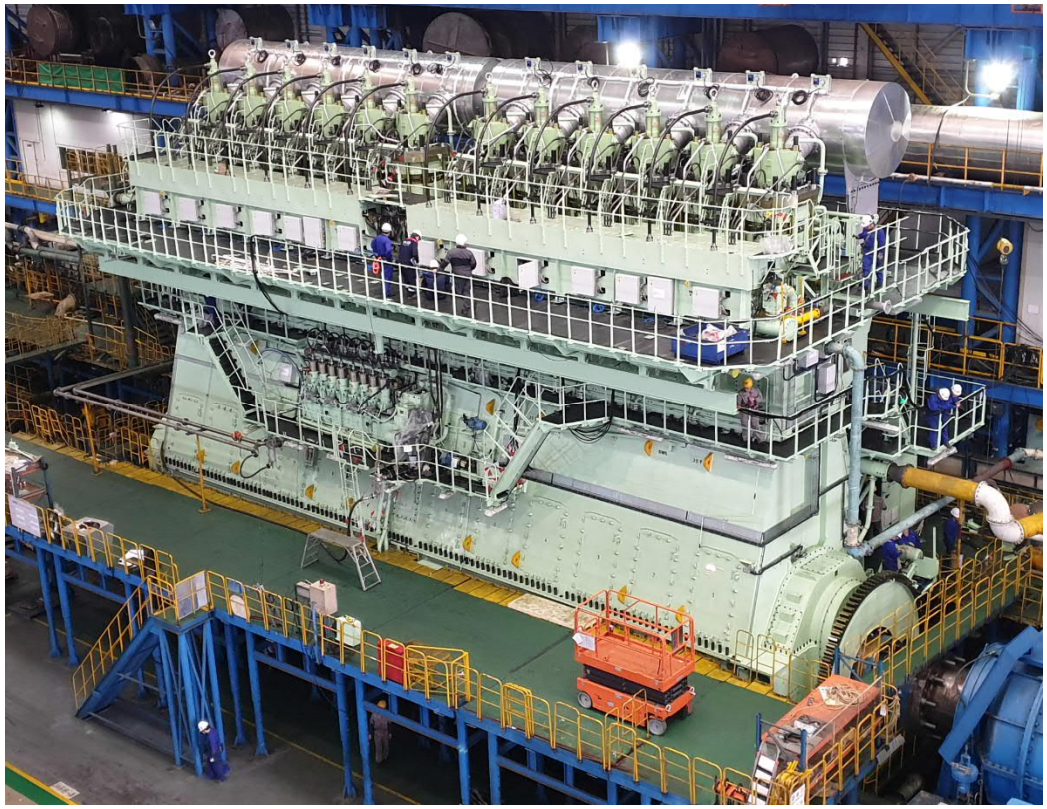
- Well proven core functional units, migrated from UNIC-flex and WECS-9520



X92DF – Conclusions

Combining validated technology with new developments

- Reliability
  - Proven designs from RT-flex50DF/62DF/72DF
- Cost optimised
  - Design for manufacturing
  - Total Cost of Ownership
- IMO TIER III compliant in gas mode like any DF engine



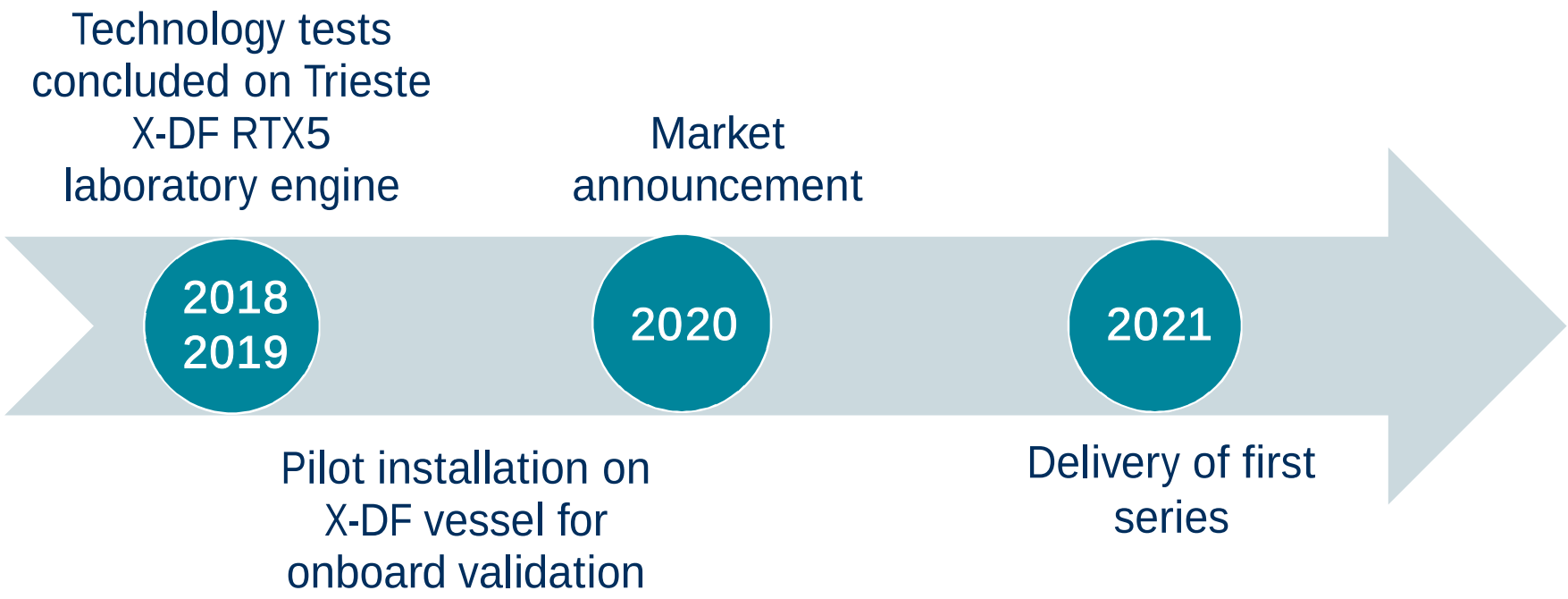
The 12X92DF on testbed

X-DF 2.0 – moving forward

X-DF 2.0 - Improved Engine Performance

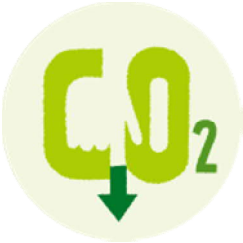
- Reduced gas consumption in gas mode by - 3 g/kWh resp. 2%
- Reduced liquid fuel consumption in diesel mode by 8 g/kWh resp. 4 - 5%
- CH4 emission (methane slip) reduced by 40-50%

X-DF 2.0 - Development Program



X-DF 2.0 - Customer Benefits

Lower operating costs



Reduced Methane slip and CO2 emissions

Proven low-pressure dual-fuel engine technology with high reliability and safety record

Thank you! Questions?