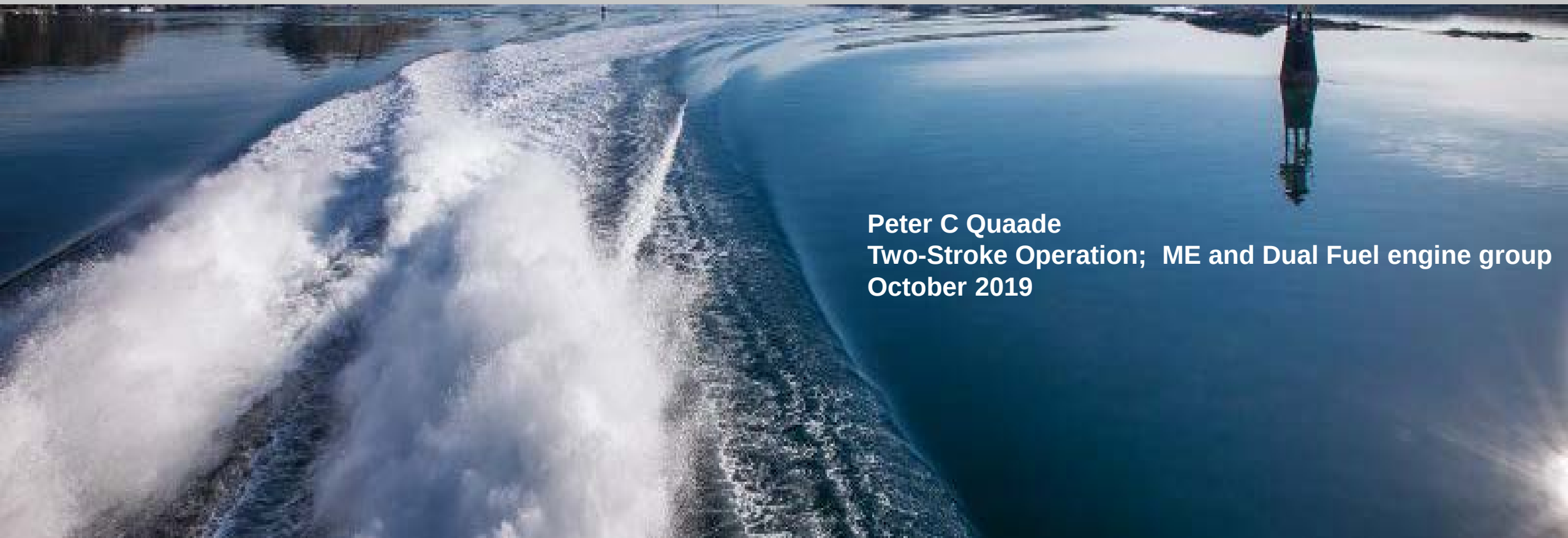
MAN Energy Solutions
Future in the making

Dual Fuel Engines
Service Experience



Peter C Quaade
Two-Stroke Operation; ME and Dual Fuel engine group
October 2019

The Dual Fuel..

An overview

World's first LNG driven ocean going ship

Owner: TOTE
Ship type: Container ship
Capacity: 3,100 Teu

Dual Fuel engine type: 8L70ME-C8.2-**GI**

World's first Methanol driven ocean going ship

Owner: MOL
Ship type: Methanol carrier
Capacity: 50,000 dwt

Dual fuel engine type: 7S50ME-B9.3-**LGIM**

World's first Ethane driven ocean going ship

Owner: Hartmann Gas Carriers
Ship type: LEG Carrier
Capacity: 36,000 M^3

Dual Fuel engine type: 7G50ME-**GIE**

World's first LPG driven ocean going ship (soon to be)

Owner: Exmar
Ship type: VLGC Capacity: 80,000 M^3

Dual Fuel engine type: 6G60ME-**LGIP**

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MAN Energy Solutions
Future in the making

The MAN-ES Dual Fuel engine

½ Million

MAN Energy Solutions
Future in the making

>65.000

MAN Energy Solutions
Future in the making

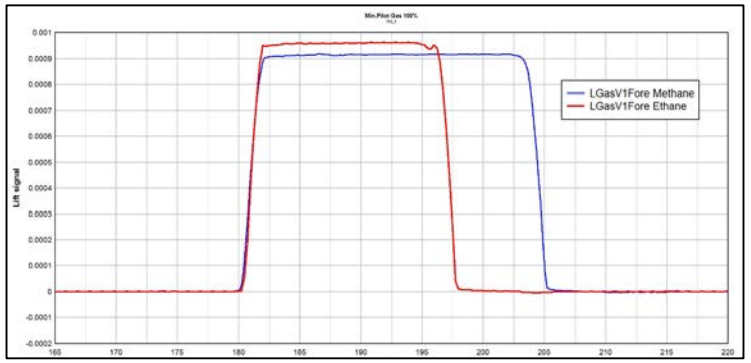
>30.000

The Dual Fuel..

An overview

- **>280 Confirmed sales**
  112 in service (8 LGIM / 4 GIE)
- **April 2019 > 500.000**
  ME-GI design
- **LGIP engines**
  Prototype test December 2019
- **Retro Fit solutions**
  tankers, CV (ME to ME-GI, ME-GI to ME-GIE, ME to LGIP)
- **ME-GIE a new member of the family, G60 ME-GIE**
  Gas atomizers for Methane and Ethane

The Triple Fuel..



- Diesel 6
- HFO GI-6
- Ethan GIE-29
- Me e GIE-29

APPROVED

- 100% load confirmed
- 4% fuel penalty at high load
- 1-3% fuel penalty at part load
- Minimum pilot up to max 85%, SDF above (Methane)
- 25/75 %

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Dual Fuel Service Experience

Gas Injection Valves, Development history

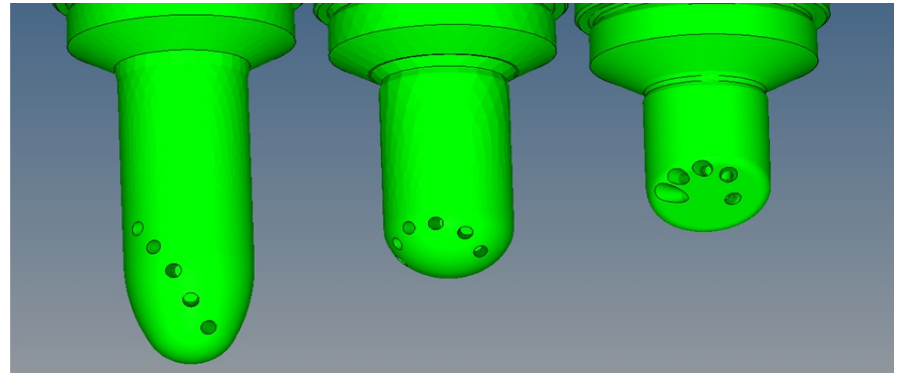
Short nozzle design developed: GI-53

- Significant reduction of bulk temperatures
- Design confirmed on testbed Mar. 2016

Extra short nozzle design developed: GI-63

- Further reduction of bulk temperatures
- Improved stress distribution
- Design confirmed on testbed Aug. 2016

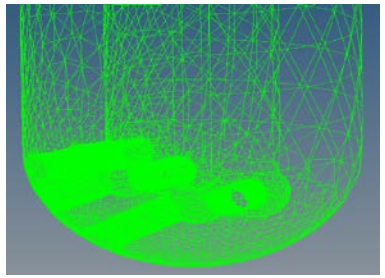
GI-35: Long **GI-53: Short** **GI-63: Extra Short**



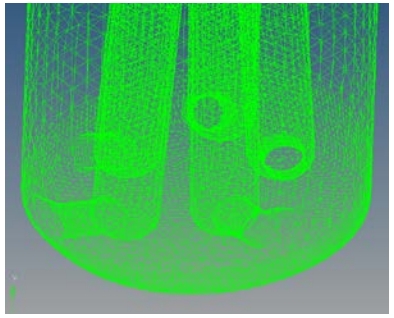
Alternative materials tested in service

–	X90CrMoV18	G70ME-C-GI	Dec	2017	Discontinued due to corrosion
–	Böhler M390	G70ME-C-GI	Dec	2017	Discontinued due to micro crack
–	**Tungsten**	**G70ME-C-GI**	**Jan**	**2019**	
–	X90CrMoV18	L70ME-C-GI	Jan	2018	Discontinued due to corrosion
–	Böhler M390	L70ME-C-GI	Jan	2018	Discontinued due to micro crack
–	**Tungsten**	**L70ME-C-GI**	**Oct**	**2018**	

New improved internal geometry



GI-53

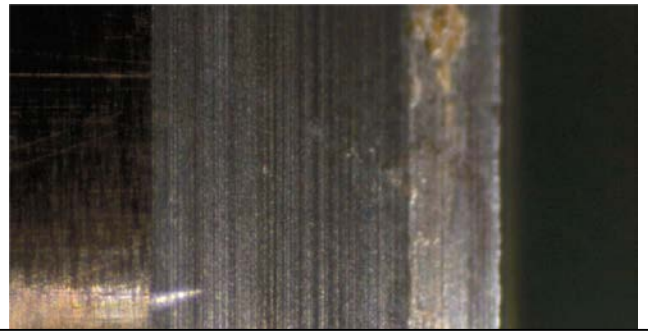


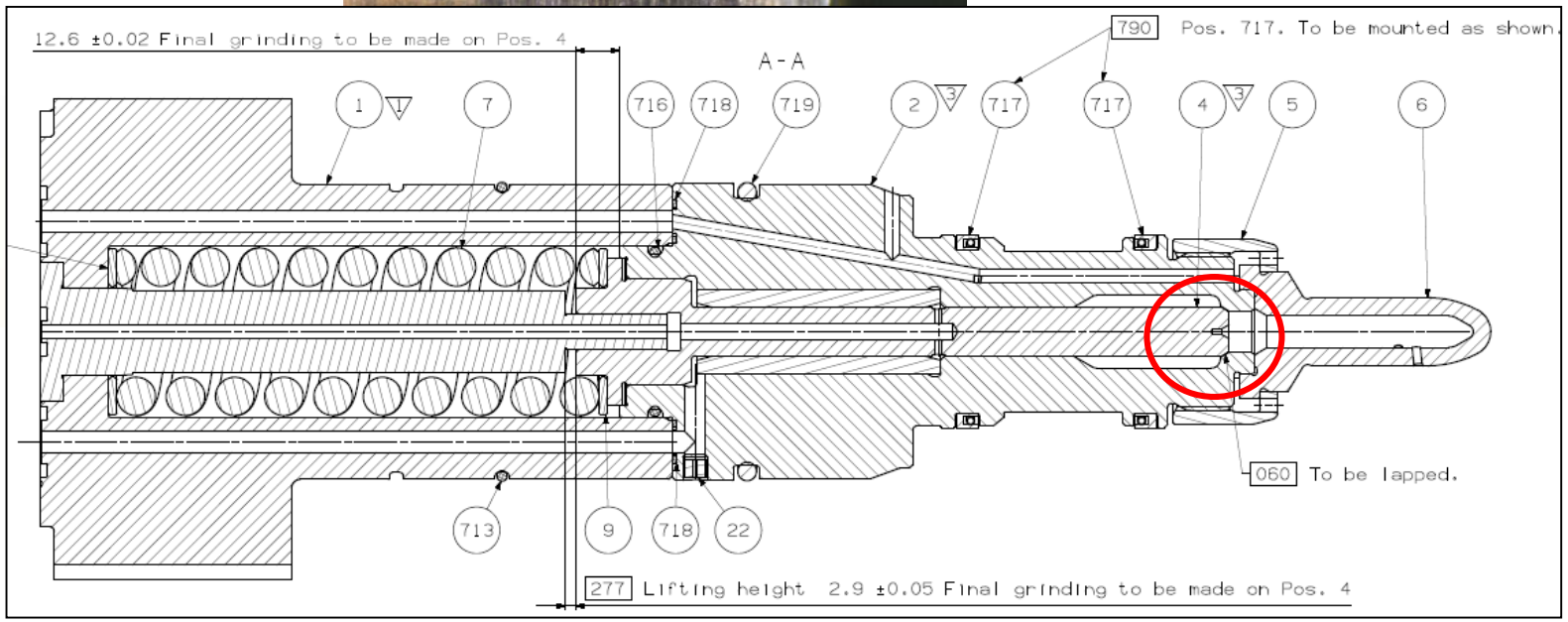
GI-63

ME-GI Service Experience

What is this ?

Spindle tip of GIV





ME-GI Service Experience

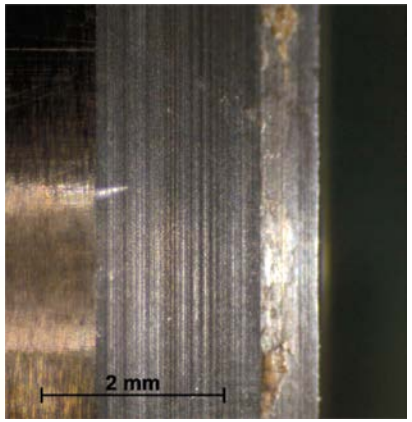
Lifetime of gas injection valves (GIVs)

ME-GI Engines
Guiding Overhaul Intervals and Expected Service Life

Component	Overhaul interval (hours)	Expected service life (hours)	Remarks
Gas injection valve (GIV)		16,000	Check and replace if required.
Valve nozzle	4,000	8,000	

Spindle tip indicates very low wear after 10,000 hours:

Lapping marks are still visible



Conclusion:

GIV lifetime can be expanded to at least 32,000 hours

ME-GI Service Experience

ME-GI Engines
Guiding Overhaul Intervals and Expected Service Life

Component	Overhaul interval (hours)	Expected service life (hours)	Remarks
Gas injection valve (GIV)		32.000	Check and replace if required.
Valve nozzle	4,000	> 8.000	

Cracked gas nozzle

Extra short gas nozzle made in tool steel:

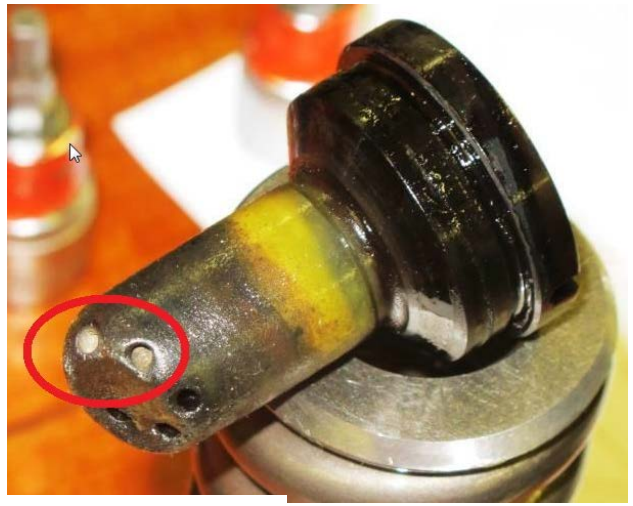
Lifetime 8,000 hours

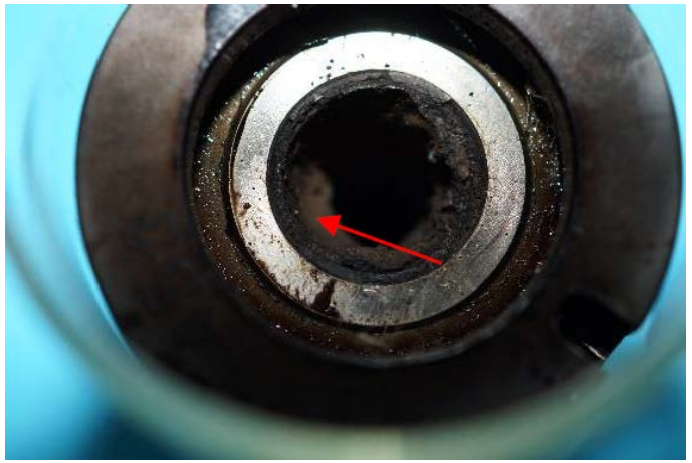
Tungsten gas nozzle inspected after 3,000 hrs.

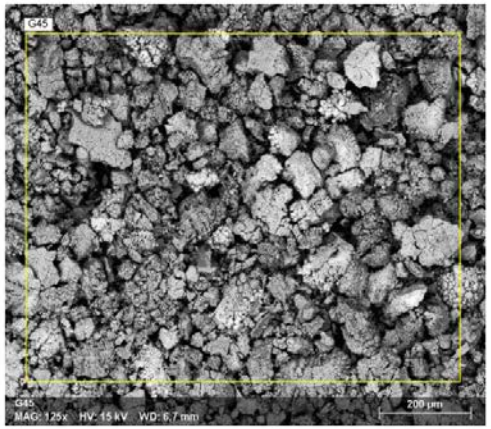
Lifetime >>8,000 hours

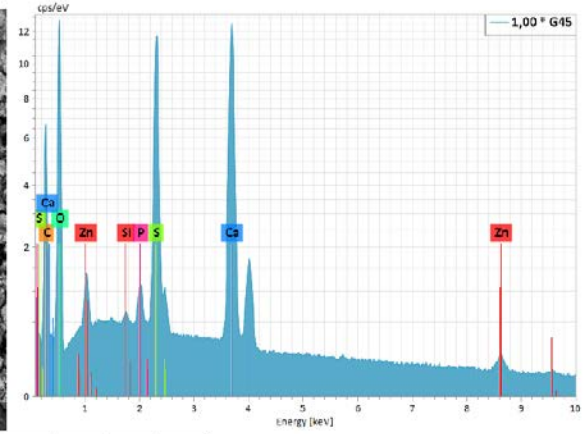
ME-GI Service Experience, GIV atomizers

- Description on how to clean clogged atomizer has been produced
- GIV's with clogged atomizers in service are returned for closer examination in Copenhagen at MAN - ES.
  Smaller bore engines and larger bore engines (45 and 70)
- New atomizer geometry will be tested in order to establish dependencies with atomizer temperatures
  Longer atomizers tested on G45, even longer will be tested.
- Seal Oil test launched this month



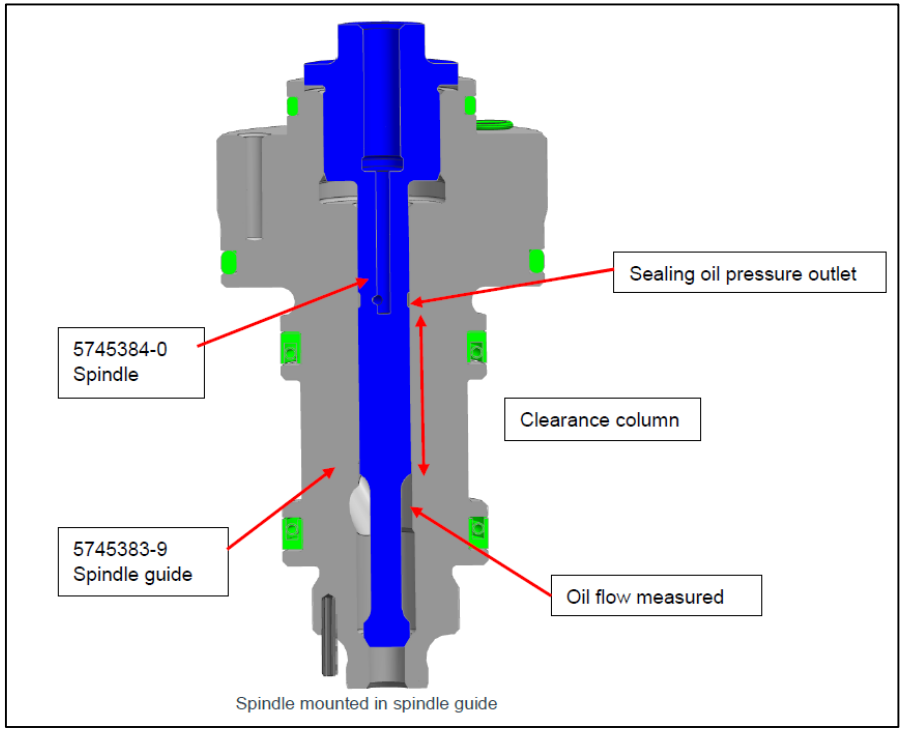






Element	O	Ca	C	S	Zn	P	Si
Mass Norm. [%]	42.5	22.9	21.7	10.3	1.9	0.6	0.1
Atom [%]	49.1	10.6	33.5	6.0	0.5	0.4	0.1
abs. error [%] (2 sigma)	10.2	1.5	5.4	0.8	0.2	0.1	0.0

ME-GI Service Experience, GIV atomizers

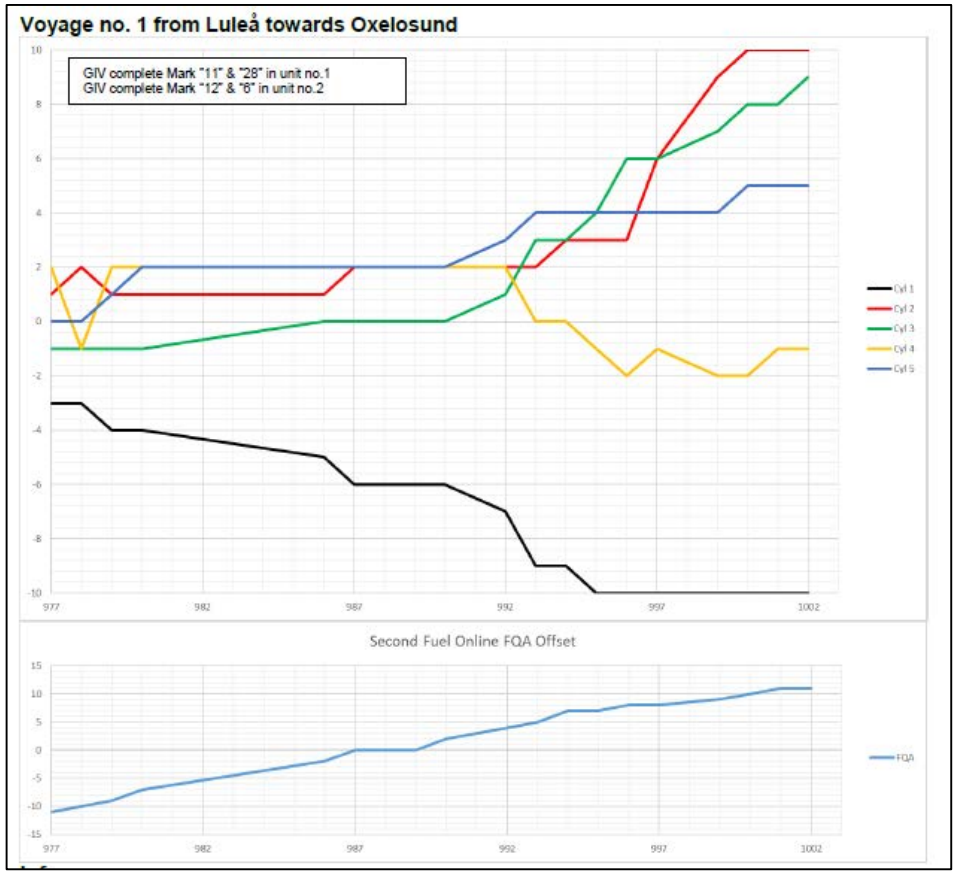


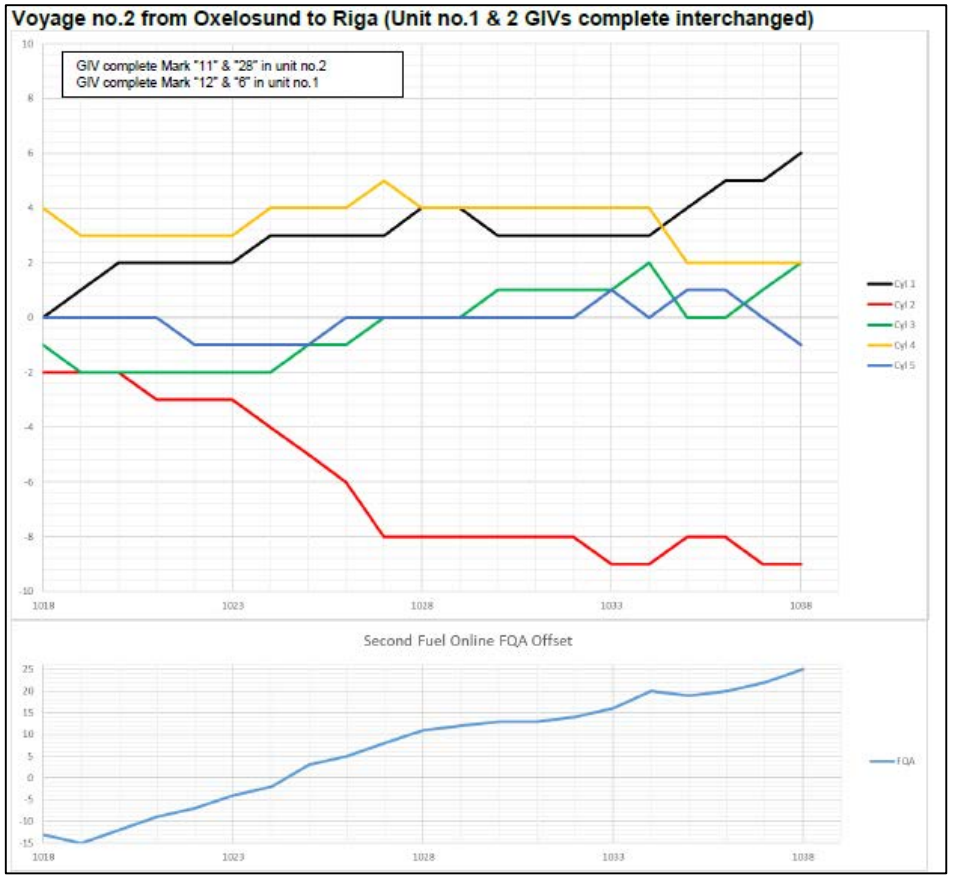
Action Plan (continued)

- Investigate Seal Oil leakage, new GIV's
- Exchange with used GIV's
- Investigate Seal Oil leakage, used GIV's
- G45 and G70 engine type

ME-GI Service Experience, GIV atomizers

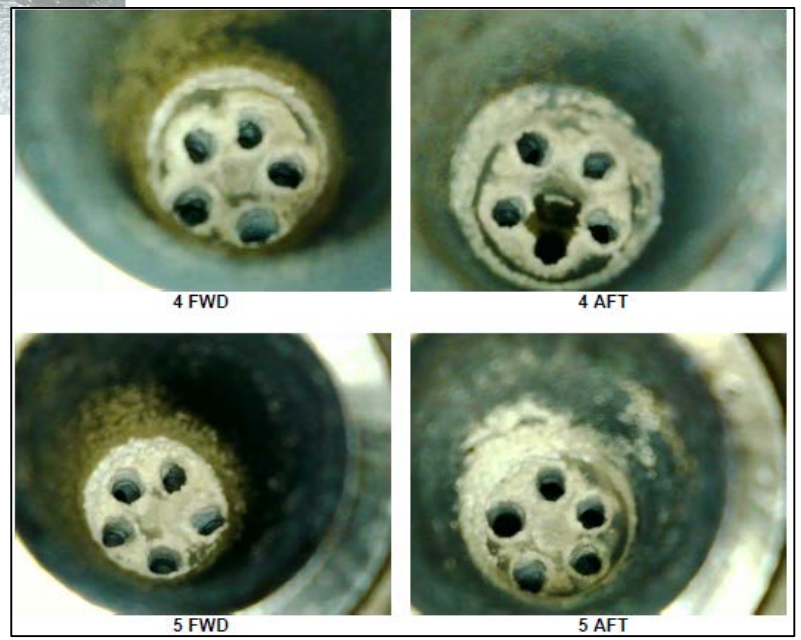
– Test with different length of atomizers





ME-GI Service Experience, GIV atomizers

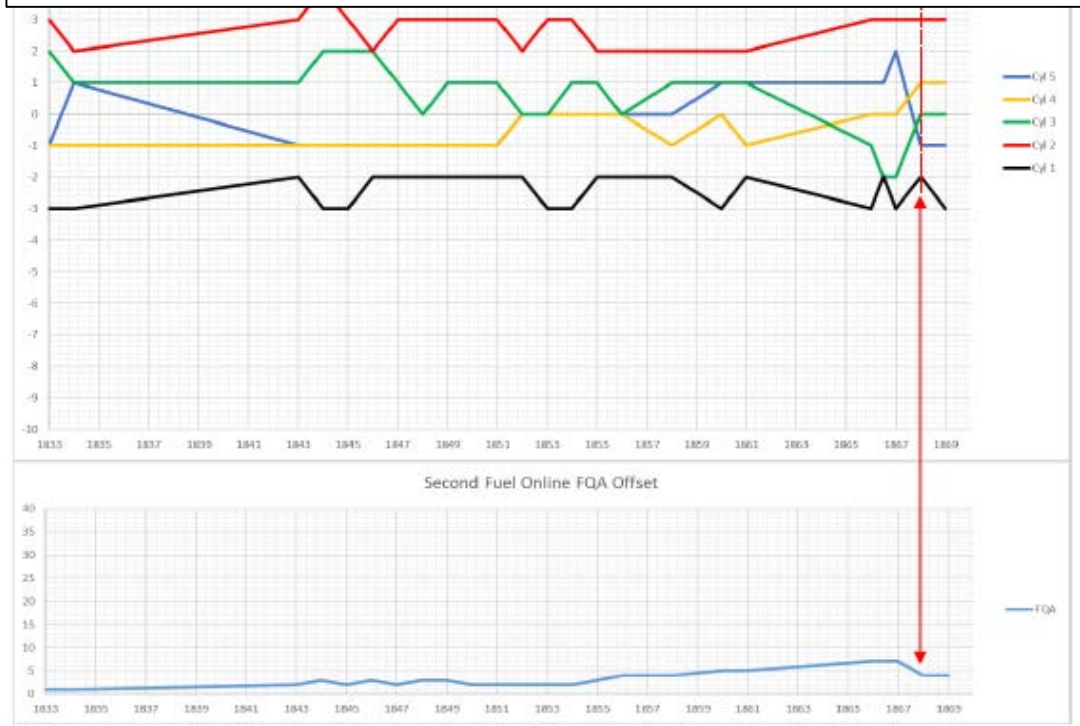
– Test with different length of atomizers



ME-GI Service Experience, GIV atomizers

– Test with different length of atomizers

1) At current load press Dual Fuel “Manual standby” on MOP
2) Take load up to 90% (or as high as possible)
3) Keep high load for about 20min
4) Press Dual Fuel “Start” to start DF mode
5) After change-over to DF mode, keep the high load for 5min
6) Reduce load to desired load staying in DF mode
7) Balance Pi, Pcomp, Pmax



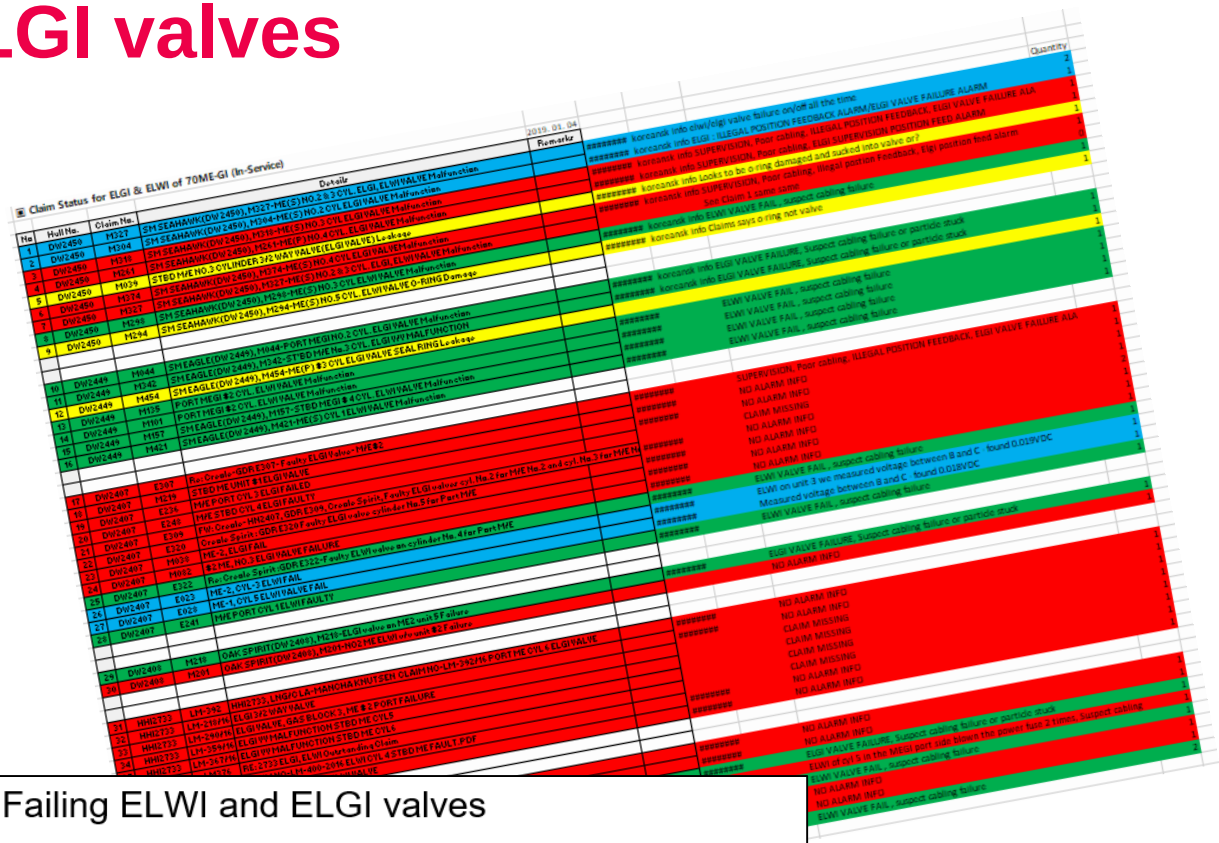
Unit no.2 GIV (AFT)

Before cleaning

After cleaning

ME-GI Service Experience, ELWI / ELGI valves

– ELWI / ELGI
65 pcs investigated



Failing ELWI and ELGI valves

We have received a list from HHI with 63 failures of ELWI and ELGI. Approx 1/3 of the claimed valves are ELWI and 2/3 of the valves are ELGI.

The valves can be arranged in four groups

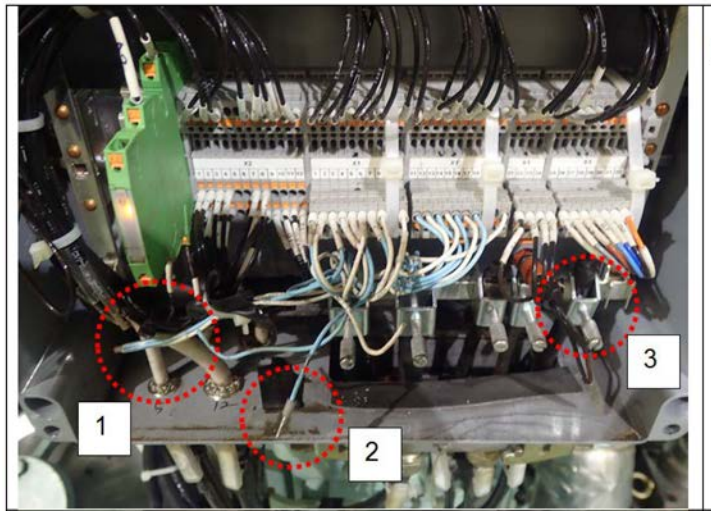
1) Valves with certain malfunction according to claim
2) Valves were sealing ring has failed and in some cases blocked the valve
3) Claims were poor connection/cabling is a likely reason
4) Claims with no info about the failure

Number of failures of each kind

Valves with certain malfunction according to claim	Valves were sealing has failed and blocked the valve	Claims were poor connection/cabling is a likely reason	Claims without any description of failure mode
4	3	36	20

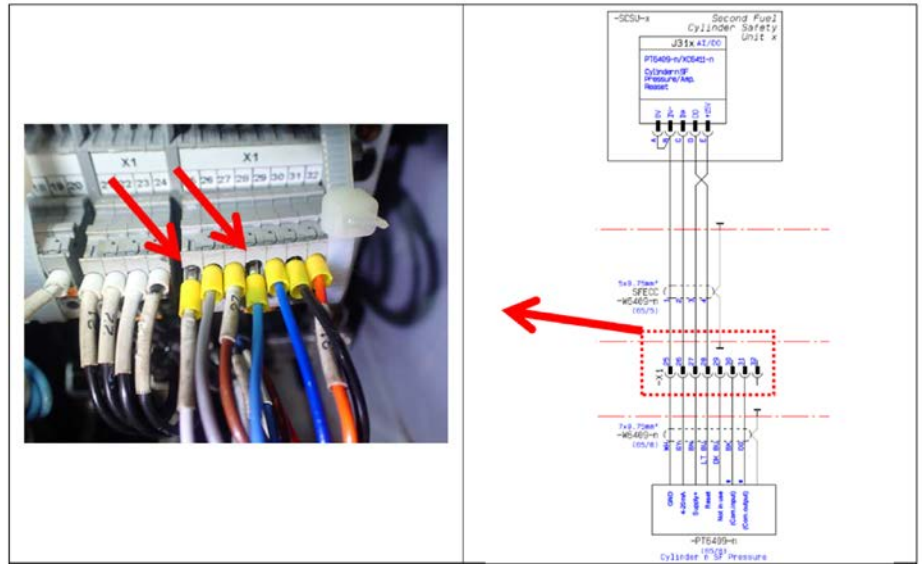
ME-GI Service Experience, ELWI / ELGI valves

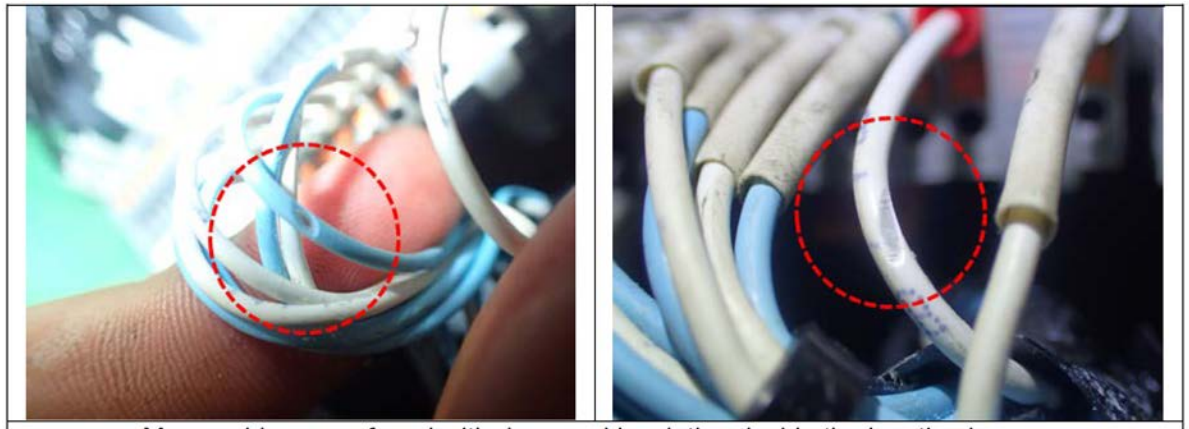
Electrical Health Check



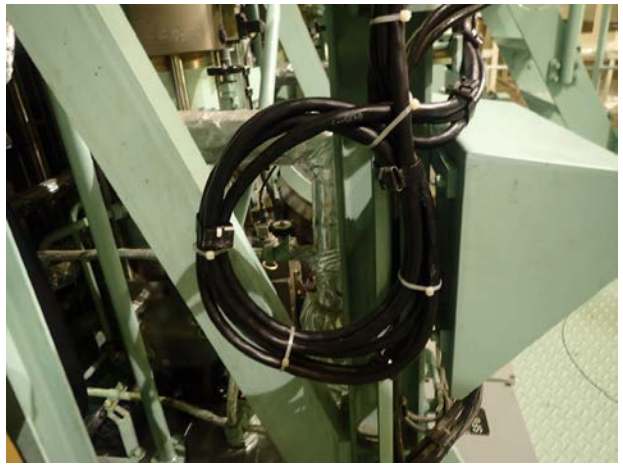
Portside junction box unit #3

1- Loose cables not fixed inside the junction box
2- Loose cables with ferule mounted, not insulated and fixed
3- Cable bracing with no back plate, have been installed and damaged the cable for Cylinder pressure #3





Many cables were found with damaged insulation, inside the junction boxes.

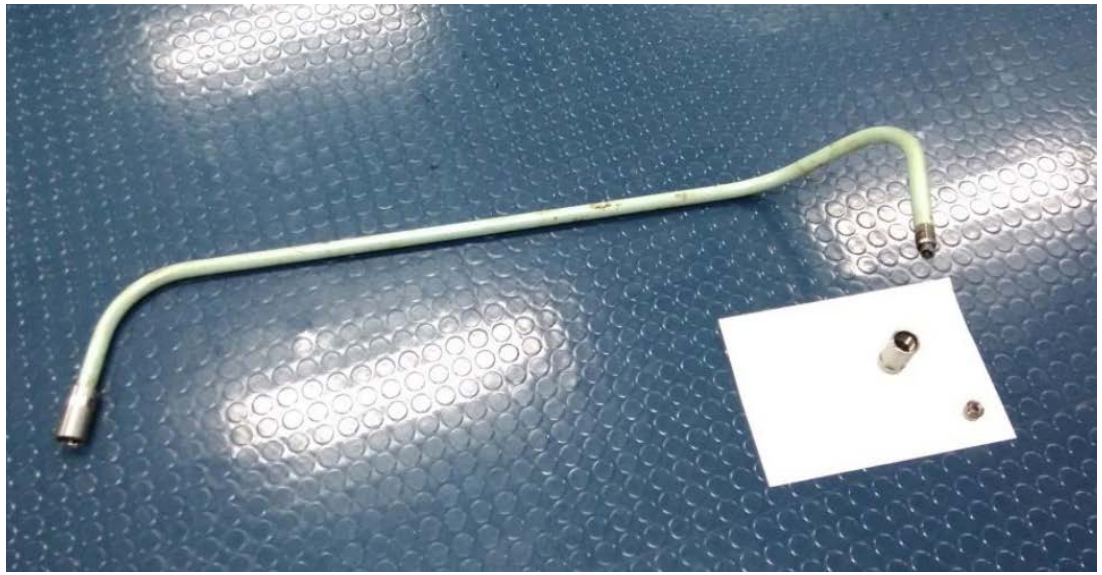


ME-GI Service Experience, Pilot Profile

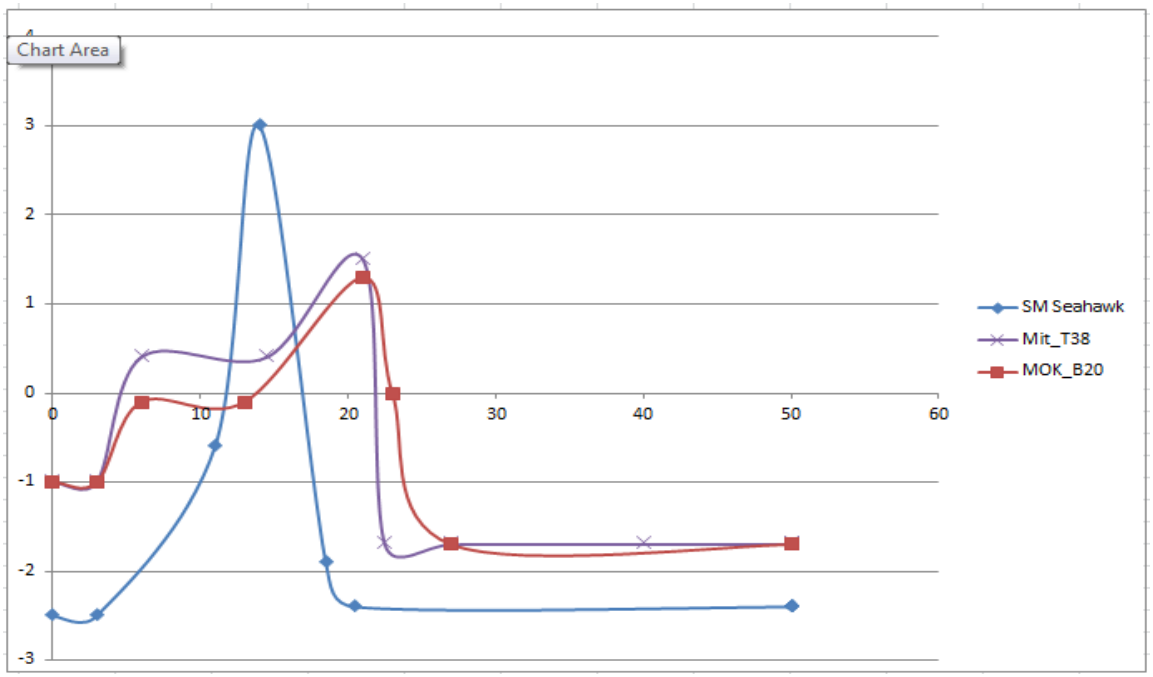
- Fuel Injection Valves
- Solenoid Valves

ME-GI Service Experience, Pilot Profile

- Control Oil Pipe for GIV

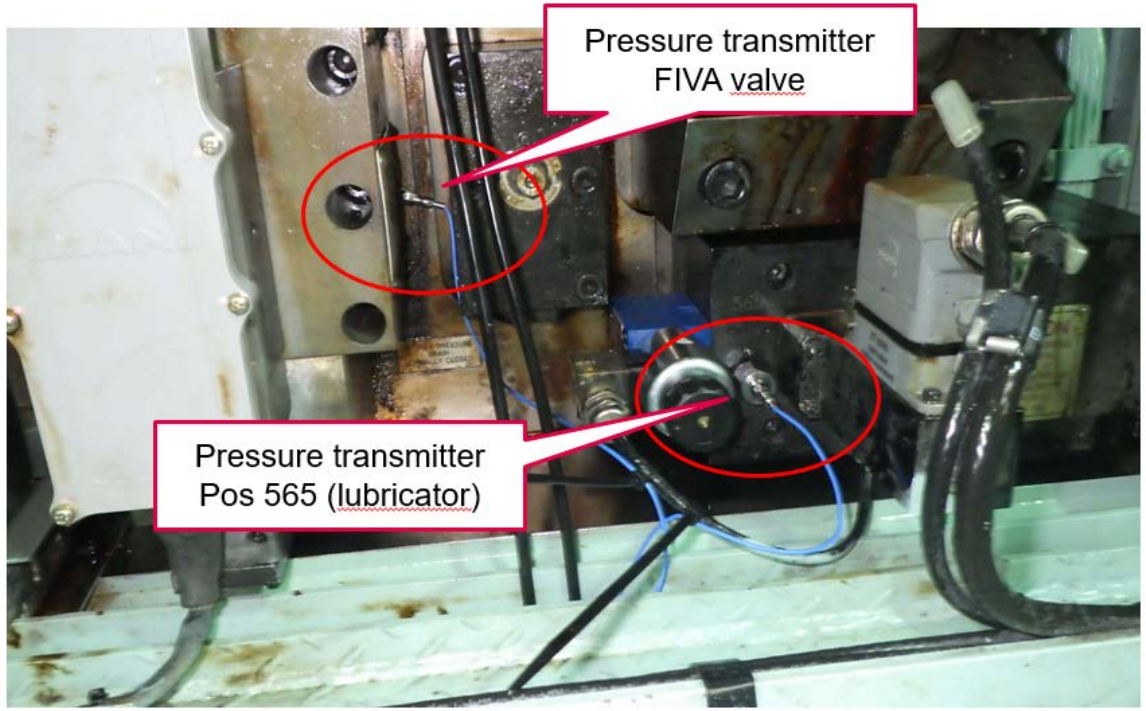


ME-GI Service Experience, Pilot Profile



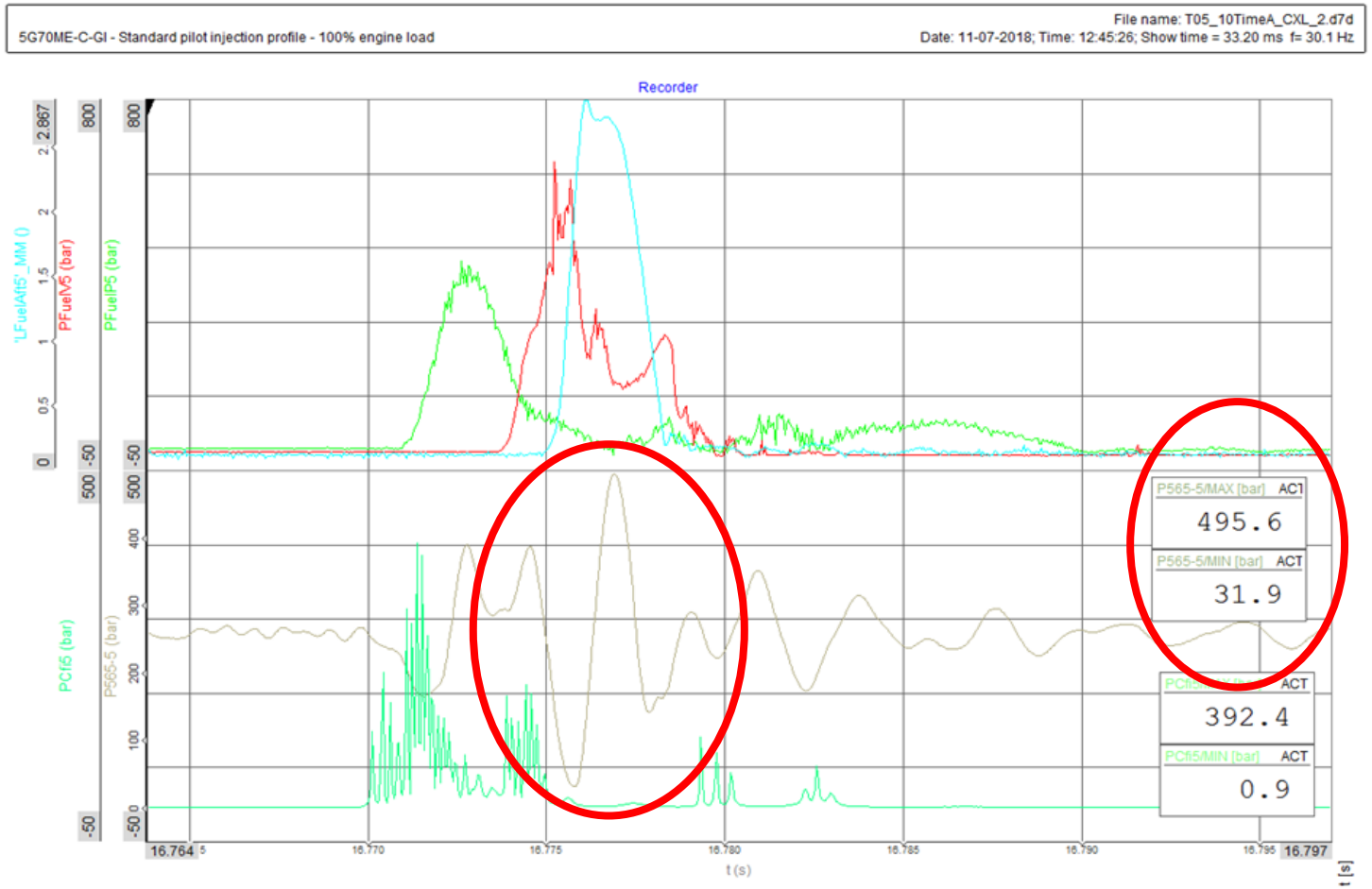
Test of standard pilot injection profile and modified profile:

- Reliable pilot injection
- Pilot Oil consumption (SPOC)



ME-GI Service Experience, Pilot Profile

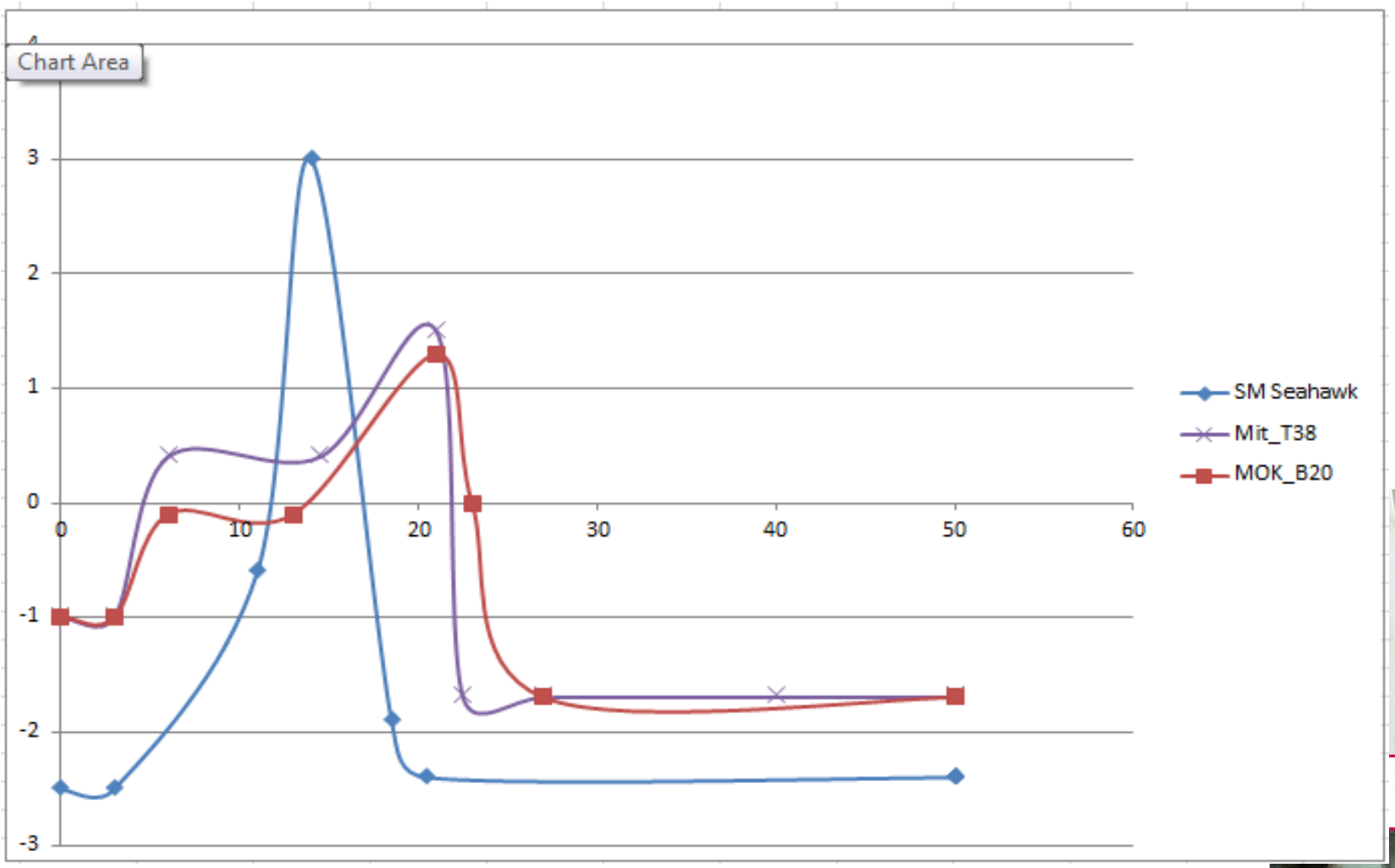
HCU pressures – standard injection profile

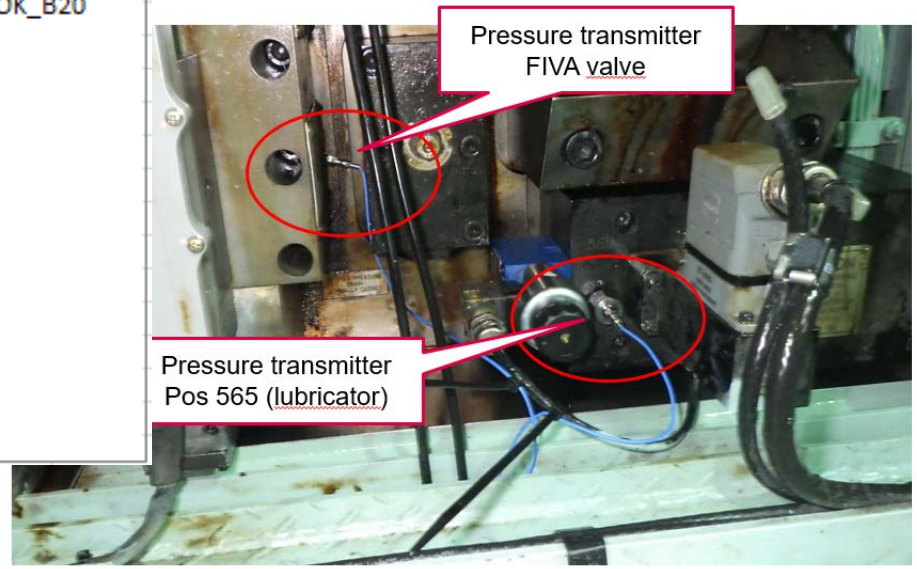


Operation with present standard pilot injection profile:

- Pressure fluctuations before solenoid valve is significant.
- Pressure peak is above design limit of solenoid valve

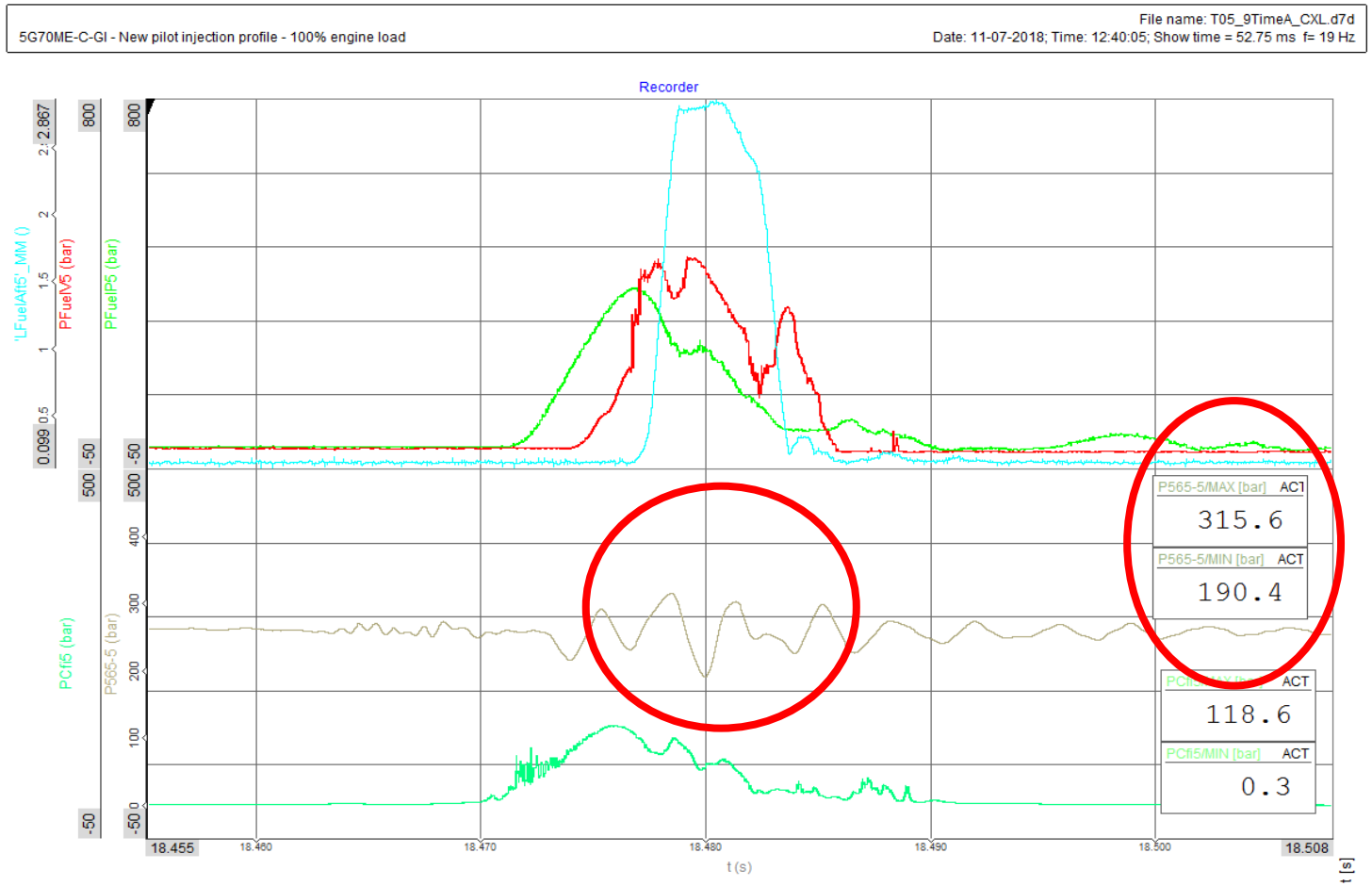
ME-GI Service Experience, Pilot Profile





ME-GI Service Experience, Pilot Profile

HCU pressures – with new injection profile



Operation with new pilot injection profile:

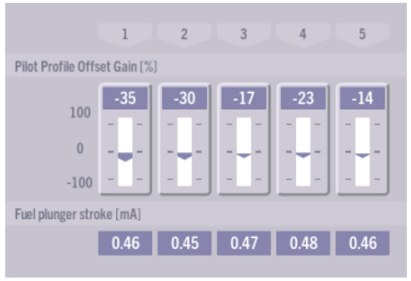
- Pressure fluctuations before solenoid valve are reduced significantly.
- Pressure peak is below design limit of solenoid valve
- Pressure characteristic is now the same as for FO mode operation

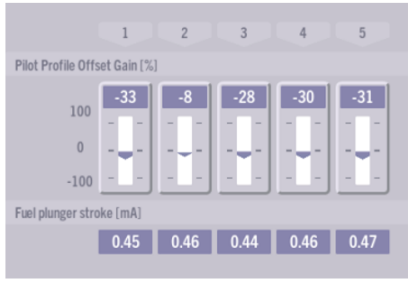
ME-GI Service Experience, Pilot Profile

Status on implementing new pilot injection profile:

- New profile was implemented in service on a few vessel. Improvements have been confirmed by measurements.
- New profile already rolled out as standard on new engines.
- New profile will be installed on vessels in service, completed.

Offset adjusted, to 0,45mA

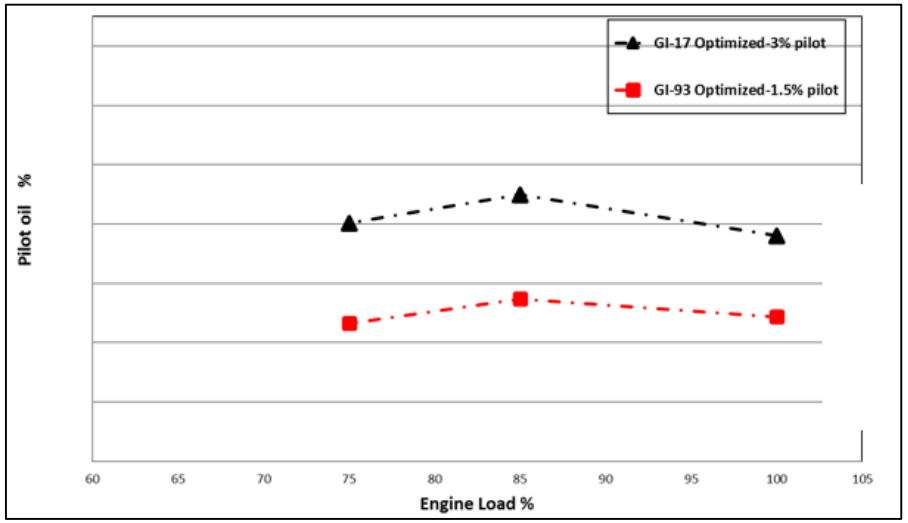


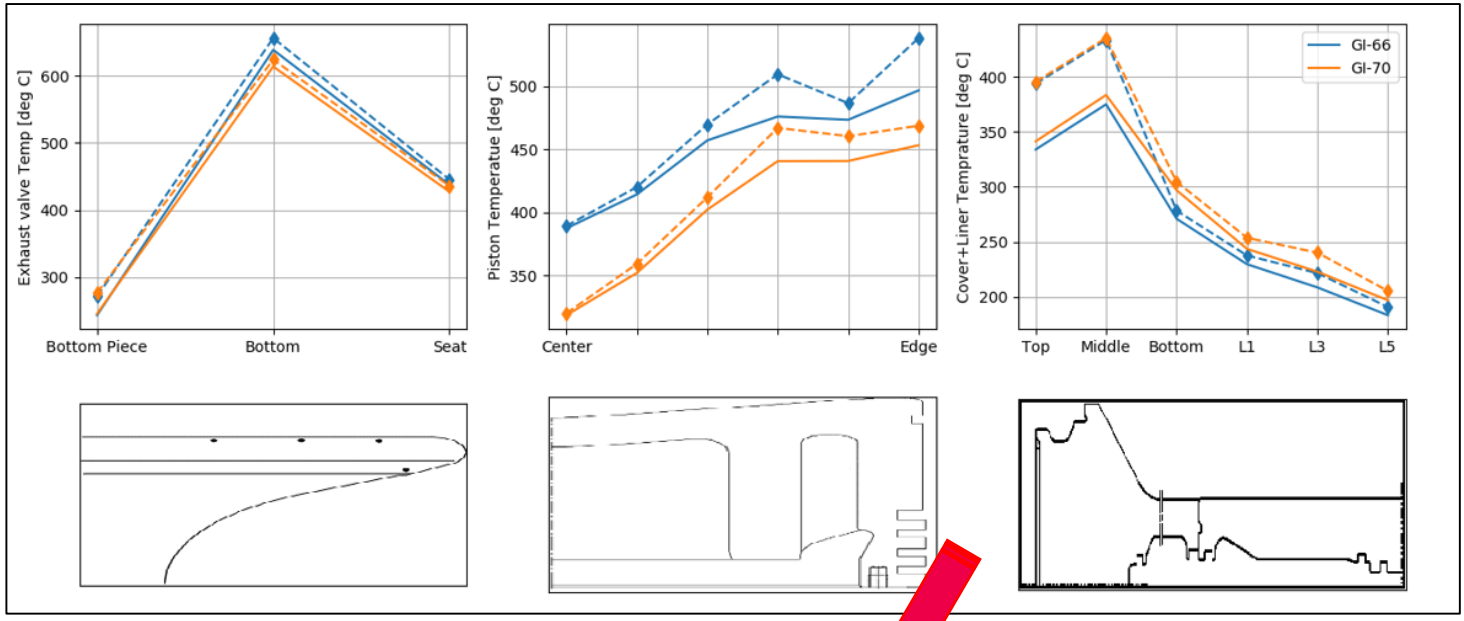


Further reduction in SPOC appr. 43% from VS_Original parameter

MOK_B20 #5	RPM	Measuring time	Measured Consumption	Consumption l/hour	Consumption l/24 hour
Stbd	65.1	35 min 09 sec	46.6	79.5	1.909
Port	65.1	34 min 53 sec	42.7	73.5	1.762

Pilot Profiles, SPOC
Low Load Gas operation

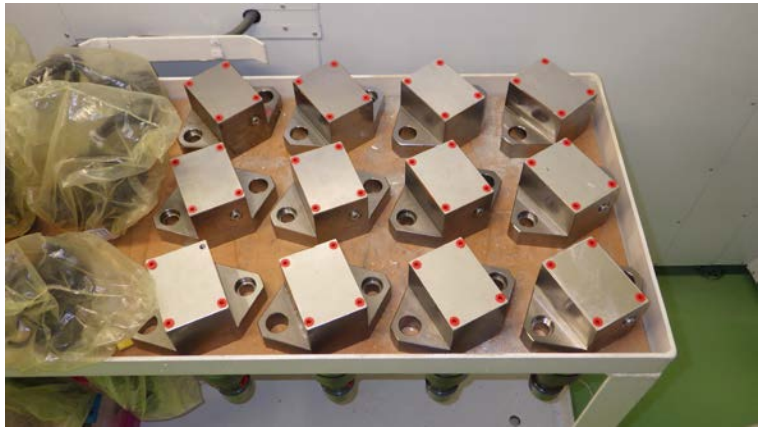




D.S.		Diesel atomizer	Gas atomizer	Change to PI-93: For 1.5% pilot	Change to GI-70: For improved LL	New PIV: For 0.5% pilot
9.5	G70 MEGI	GI-15	GI-66	Possible	Possible	Possible, when released
9.2		GI-15	GI-66	Possible / cert.	Possible / cert.	Possible / cert.
9.5	EGR	GI-17	GI-66	Possible	Possible	Possible, when released

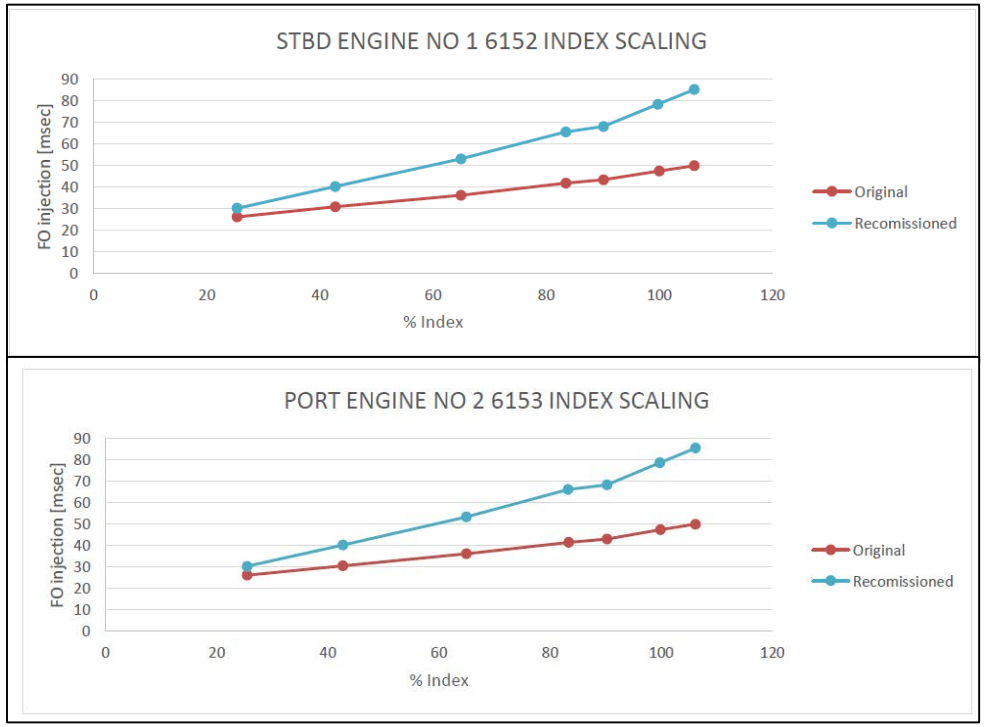
Test of reduced SPOC (1,5%) and Low Load Operation in service

- **Re-building in Singapore after delivery from Korea:**
  - Pilot atomizers, GI-15 to PI-93 incl. new spindle guide
  - Gas atomizers, GI-66 to GI-70
  - ECS parameter update (IMO Design checksum)
  - Amendment to IMO NOx technical file
- **MAN ES Attendance:**
  - Diesel re-commissioning and performance measurements
  - Gas re-commissioning, pilot oil profile / low load gas optimization



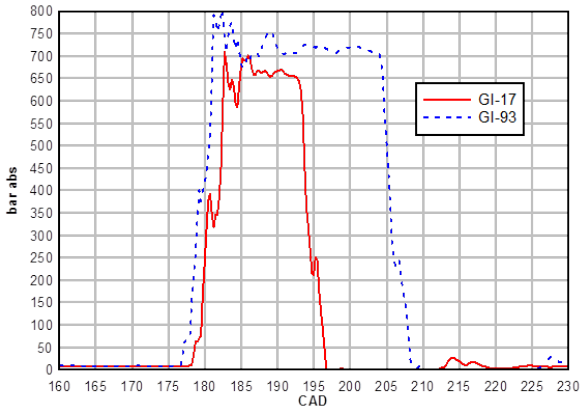
Test of reduced SPOC (1,5%) and Low Load Operation in service

- **Diesel operation, Performance measurements**
  - Re-commissioning of fuel index scaling and engine performance due to the increased injection duration of PI-93

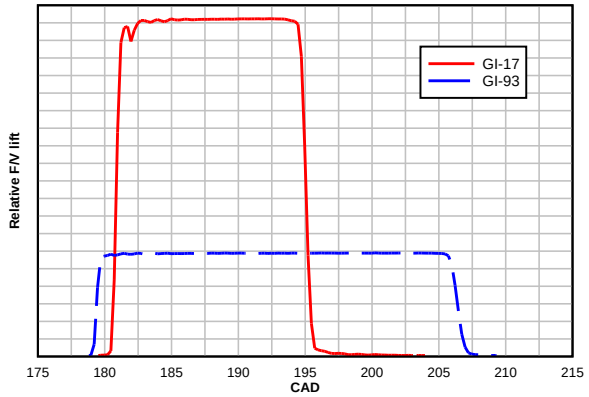


R&D measurements Shop Test

Fuel valve pressure

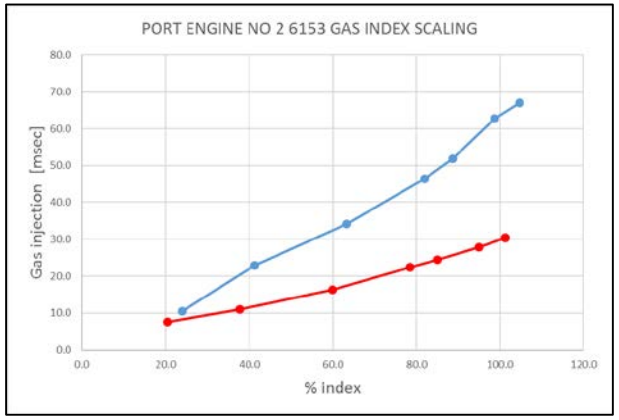


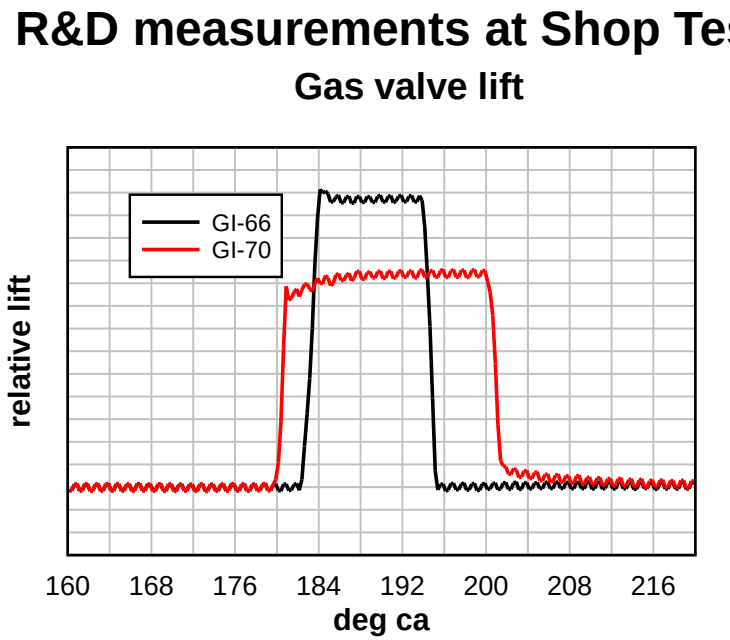
Fuel valve lift



Test of reduced SPOC (1,5%) and Low Load Operation in service

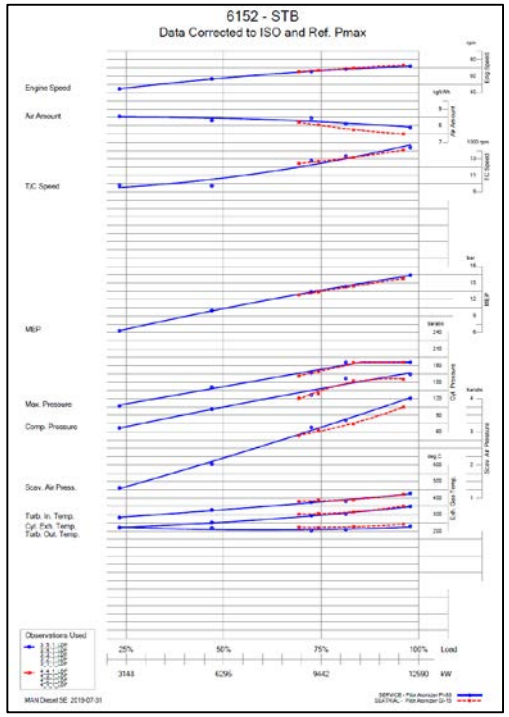
- **Gas operation,** **Performance measurements**
  - Re-commissioning of fuel index scaling and engine performance due to the increased injection duration of GI-70
  - Gas change over tuning/optimization
  - Pilot oil profile optimization and low load gas operation

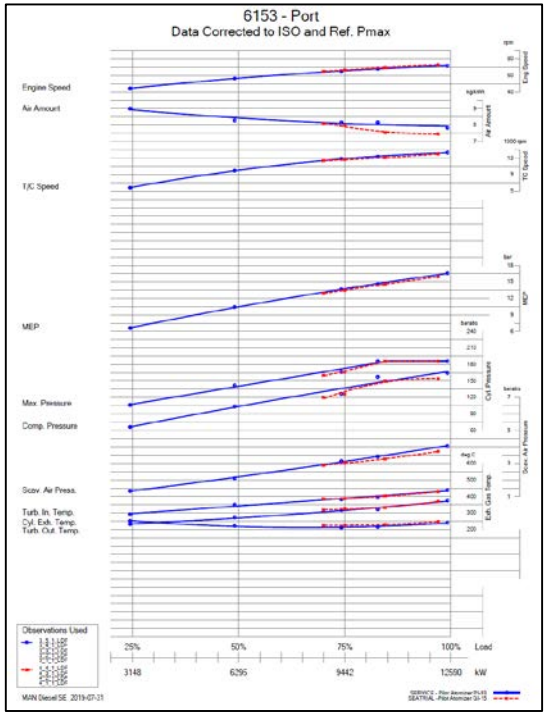




Performance measurements

- **Diesel operation**

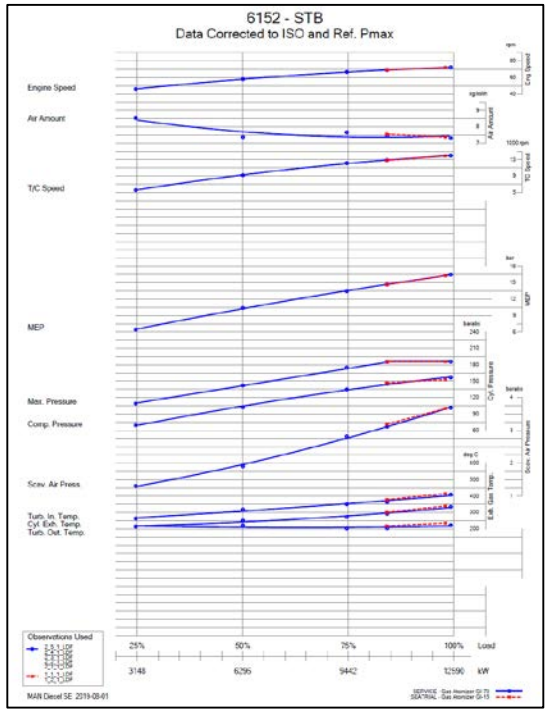


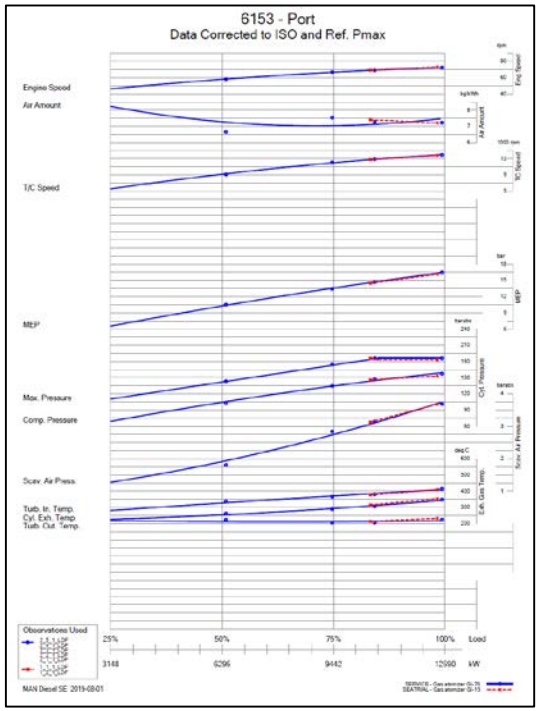


- **Comparison against sea-trial meas.**
  - In general according to our expectations and in agreement with our previous RD measurements
  - Higher Pscav for PI-93 at high load due to slightly higher SFOC
  - Higher Air amount for PI-93 at high load due to slightly higher SFOC
  - Slightly lower exhaust temp. for PI-93

- **Comparison against sea-trial meas.**
  - In general according to our expectations
  - Similar Pscav/air amount for GI-70 at 85, 100% load. Similar tendency seen during R&D testing
  - Slightly lower exhaust temp. for GI-70

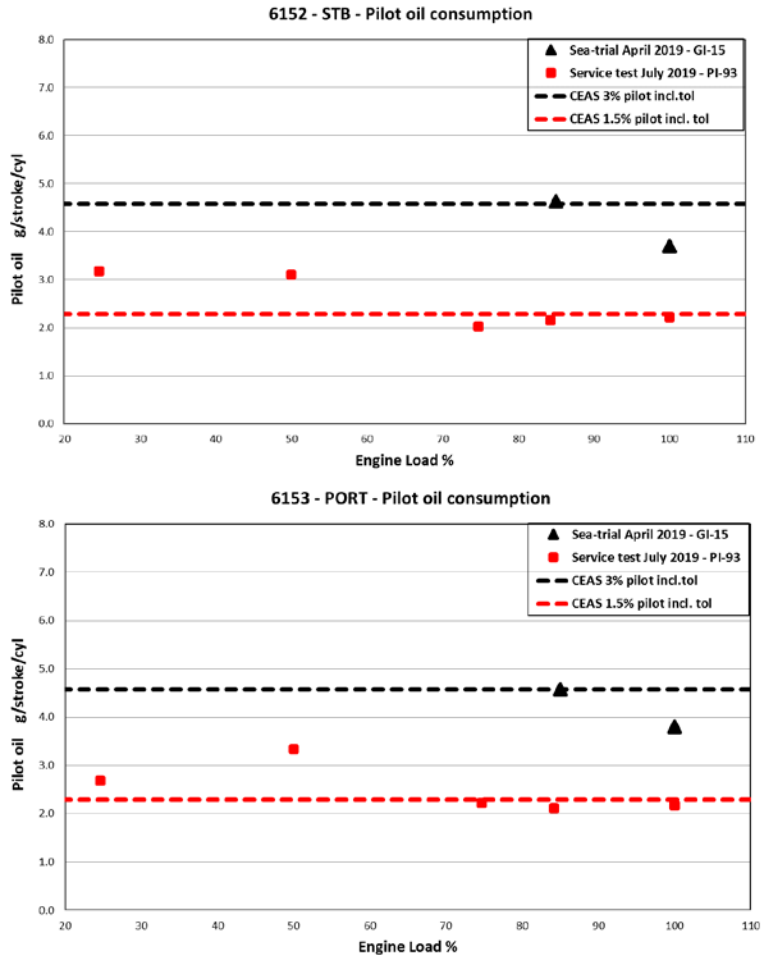
- **Gas operation**





Performance measurements

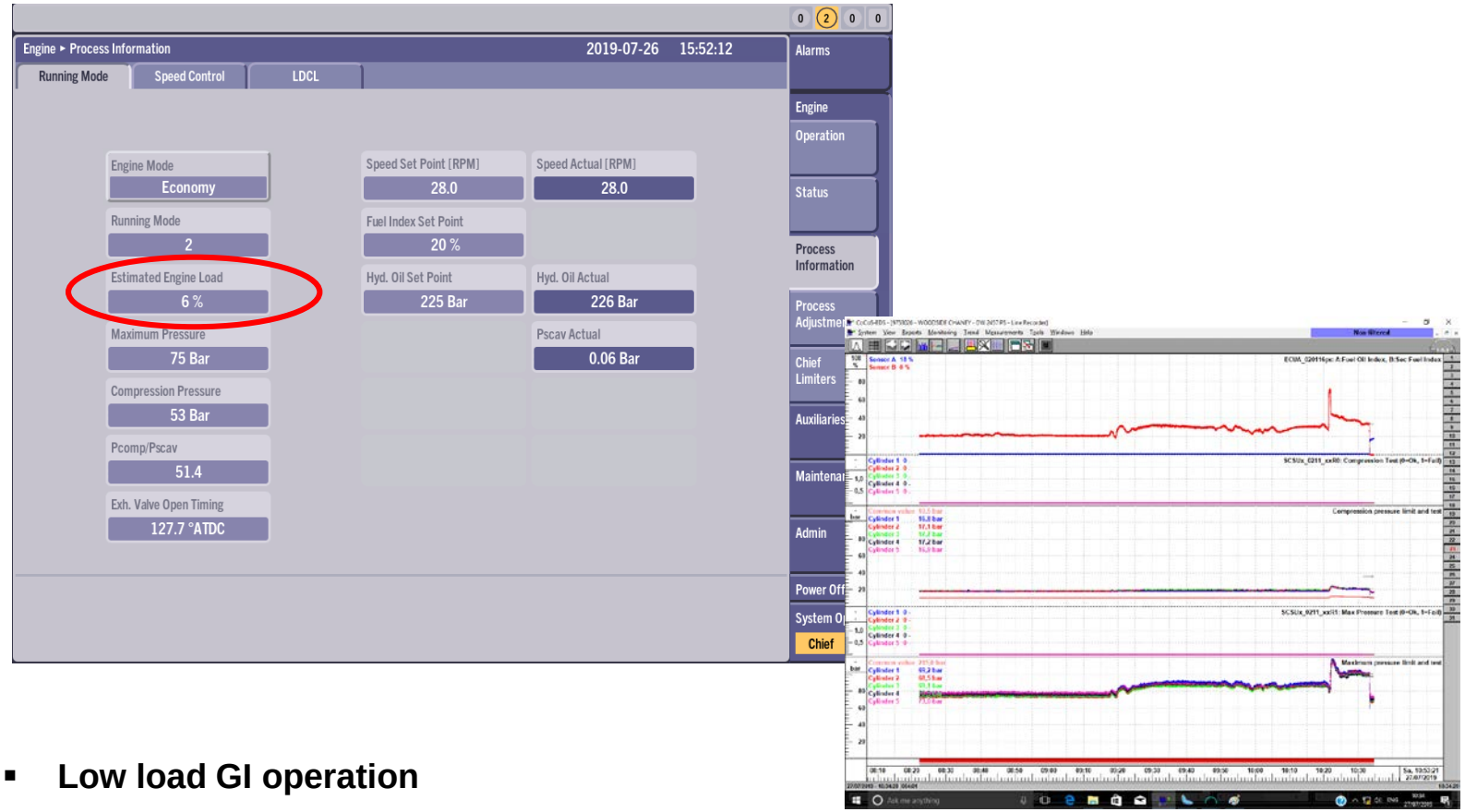
- **Gas operation, SPOC**



- **Pilot oil consumption**
  - Measured during 1 hour with flowmeter after optimization
  - 45-50% reduction compared to sea-trial measurements at NCR/MCR
  - As expected and according to our previous R&D results

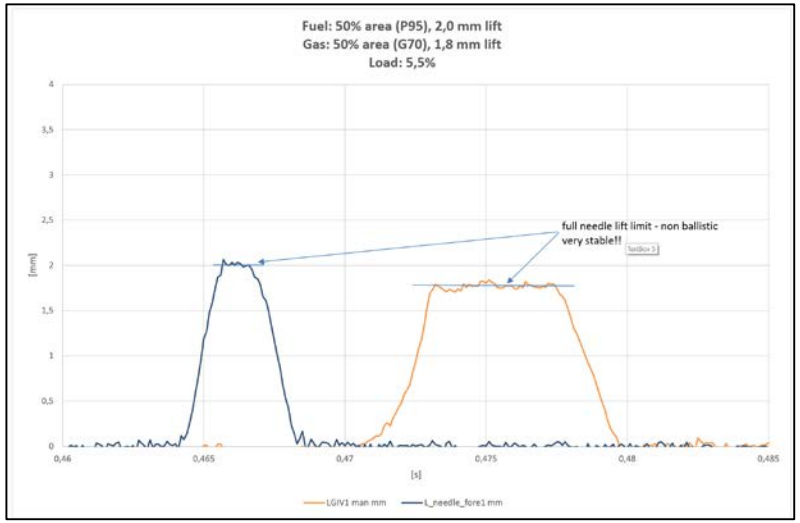
Performance measurements

- **Gas operation, low load**



- **Low load GI operation**
  - Small endurance (15h) test showed successful low load gas operation is possible
  - Index ~20% (~6% load), Eng.Speed = 28 rpm (just below barred speed range)

R&D measurements on DW2469#2

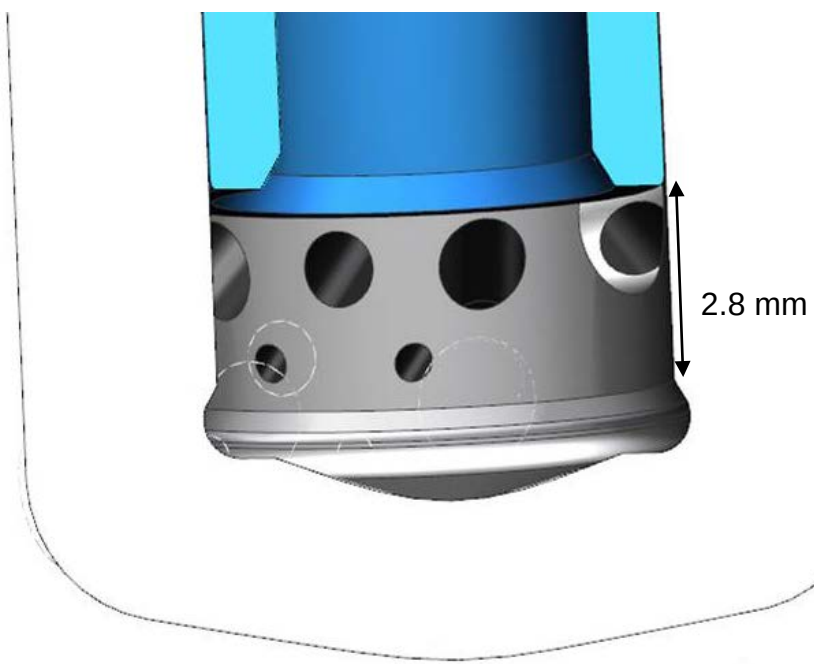


- More stable GI operation with small flow atomizer
- Full and stable GIV lift possible at low load

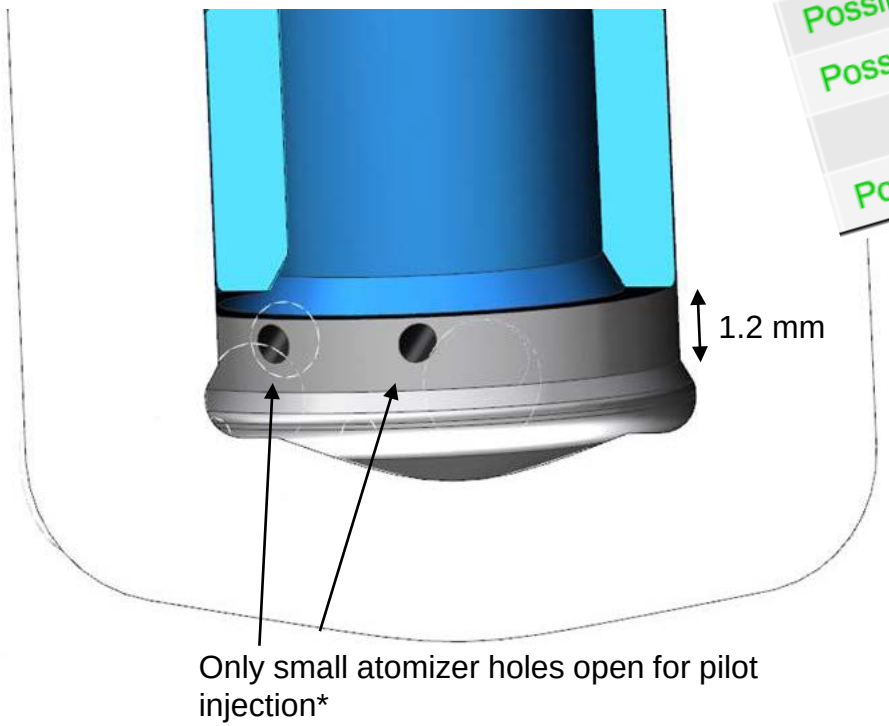
Pilot Injection Technology, PIV

Cut-off shaft lift

2.8 mm lift:



1.2 mm lift: reduced for pilot injection:



New PIV:
For 0.5 % pilot

Possible, when released

Possible / cert.

Possible, when released

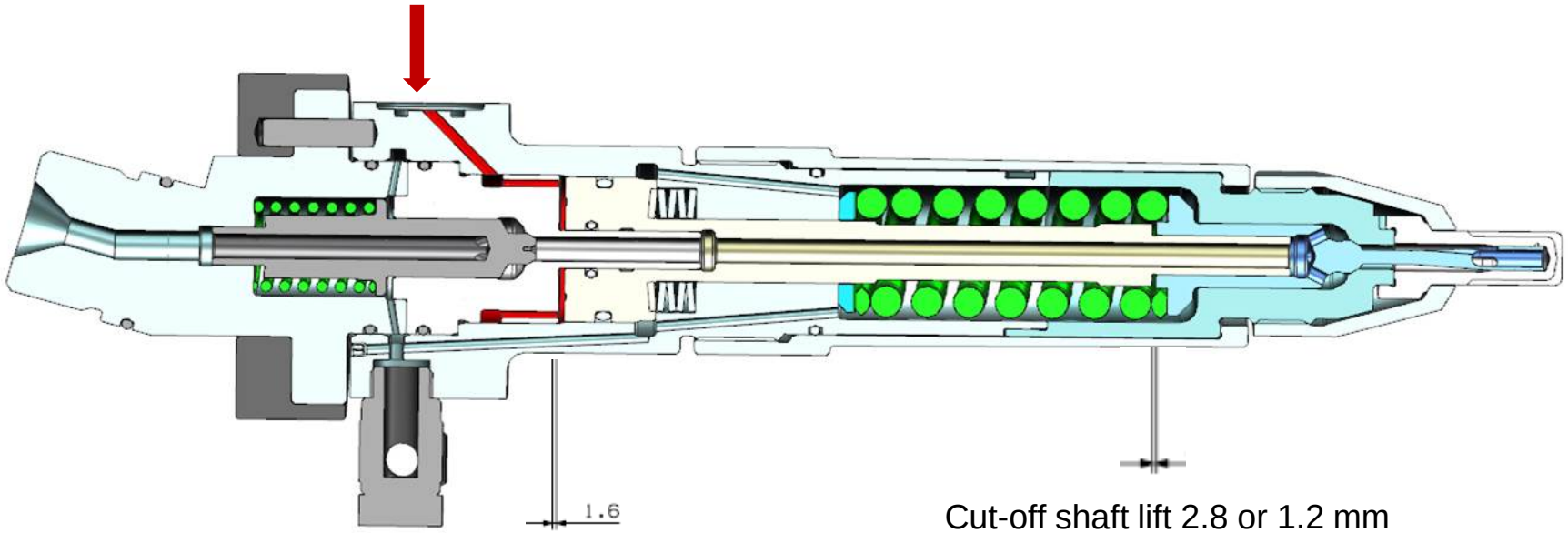
*Total nozzle flow area unchanged compared to standard FO nozzle

Pilot Injection Technology, PIV

Pilot Injection Valve

Standard fuel valve with new pilot injection technology

225/300 bar HP oil is moving the thrust piece to reduce movement of cut-off shaft



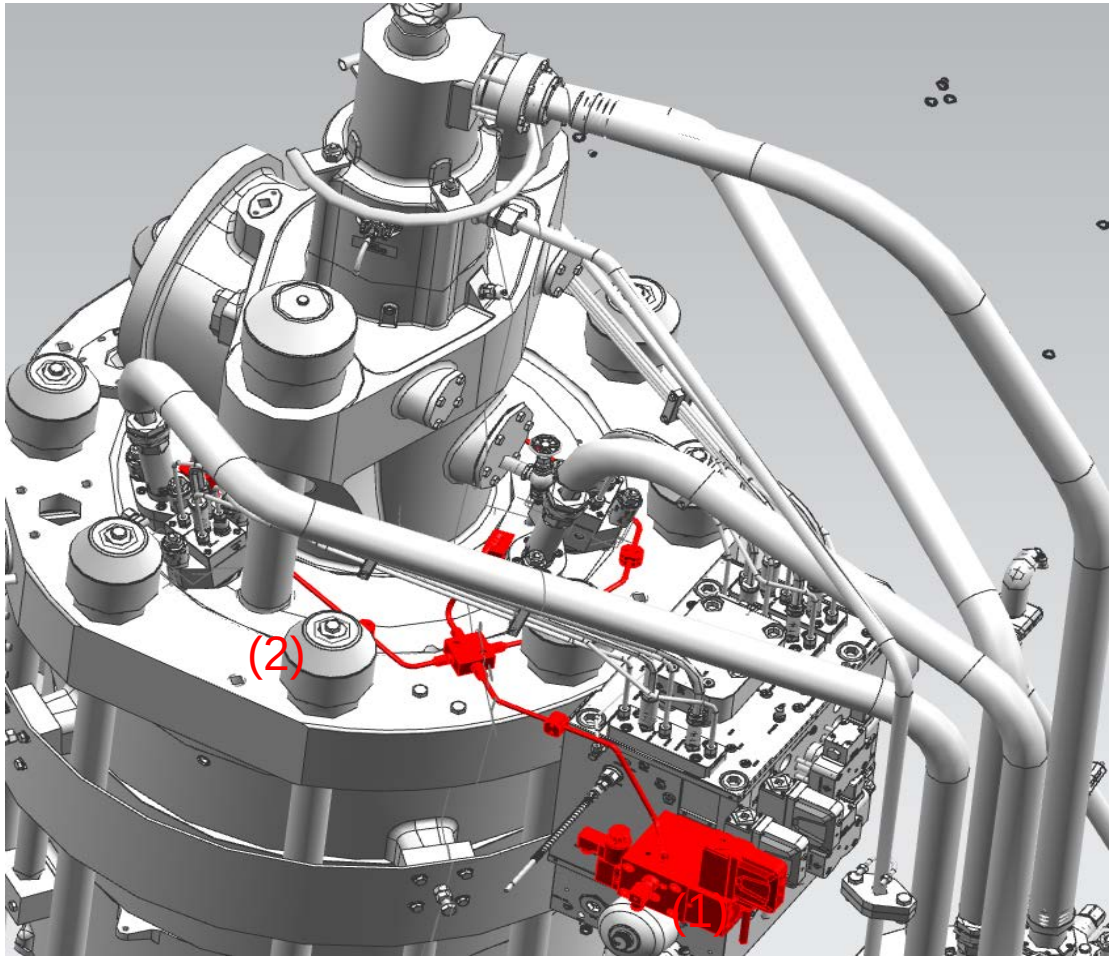
Cut-off shaft lift 2.8 or 1.2 mm

Thrust piece lift 0 or 1.6 mm

G70 bore design

Pilot Injection Technology

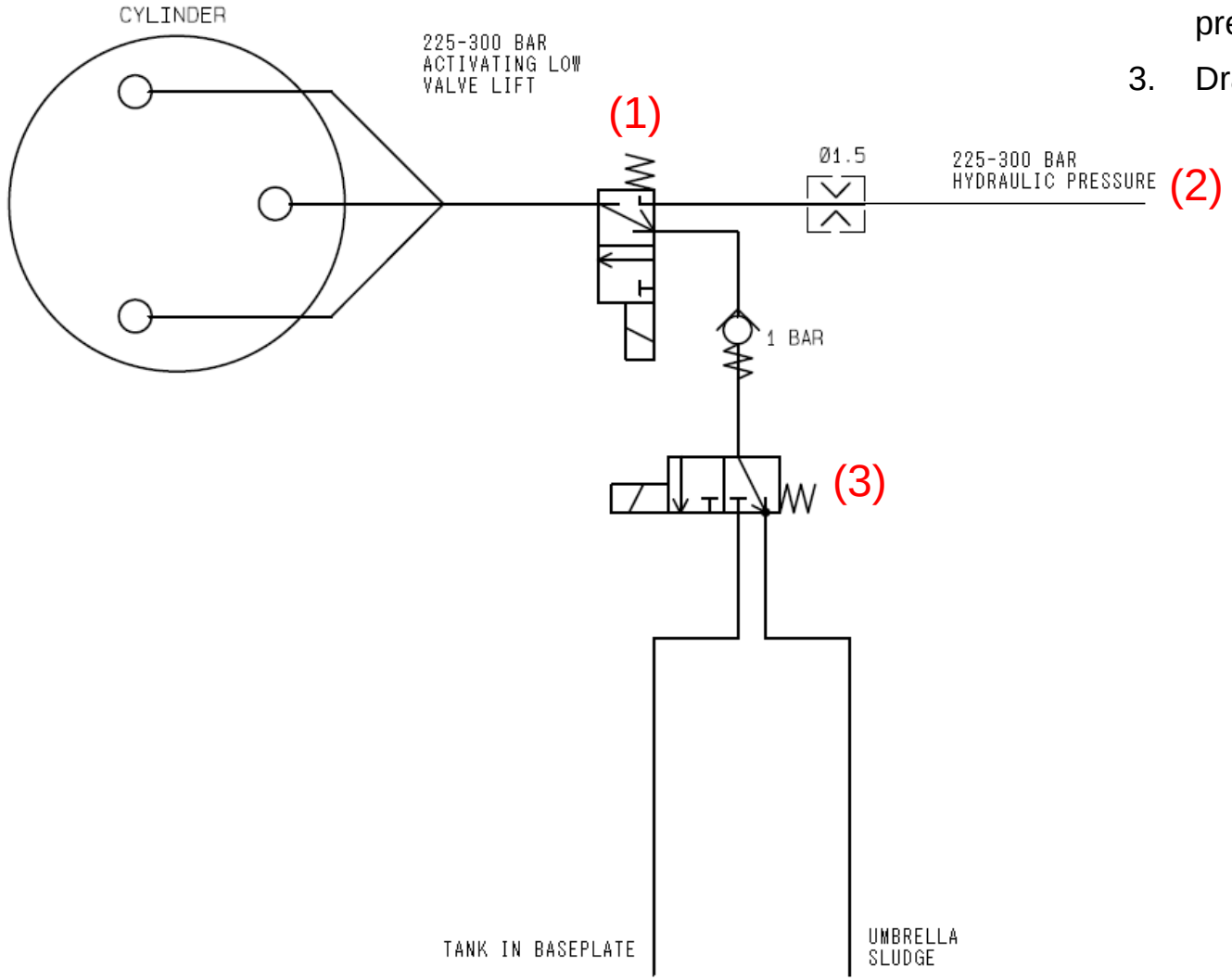
Application



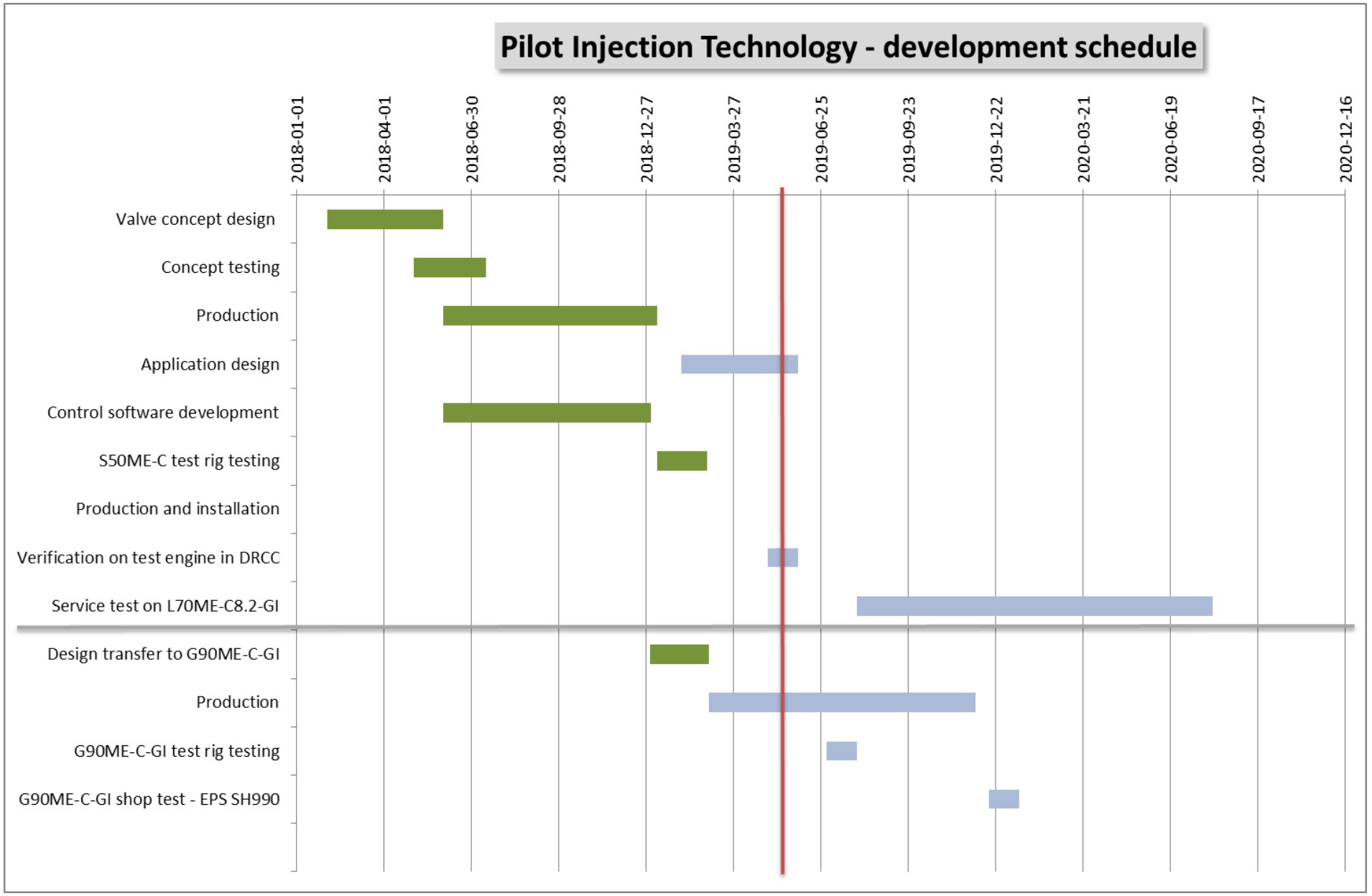
1. Distribution block.
2. Arrangement of additional piping for PIV activation

Pilot Injection Technology

Control system



1. One on/off valve per cylinder.
2. Connection to hydraulic pressure supply.
3. Drain to baseplate or sludge


Pilot Injection Technology - development schedule
2018-01-01
2018-04-01
2018-06-30
2018-09-28
2018-12-27
2019-03-27
2019-06-25
2019-09-23
2019-12-22
2020-03-21
2020-06-19
2020-09-17
2020-12-16
Valve concept design
Concept testing
Production
Application design
Control software development
S50ME-C test rig testing
Production and installation
Verification on test engine in DRCC
Service test on L70ME-C8.2-GI
Design transfer to G90ME-C-GI
Production
G90ME-C-GI test rig testing
G90ME-C-GI shop test - EPS SH990

Thank you for your time…