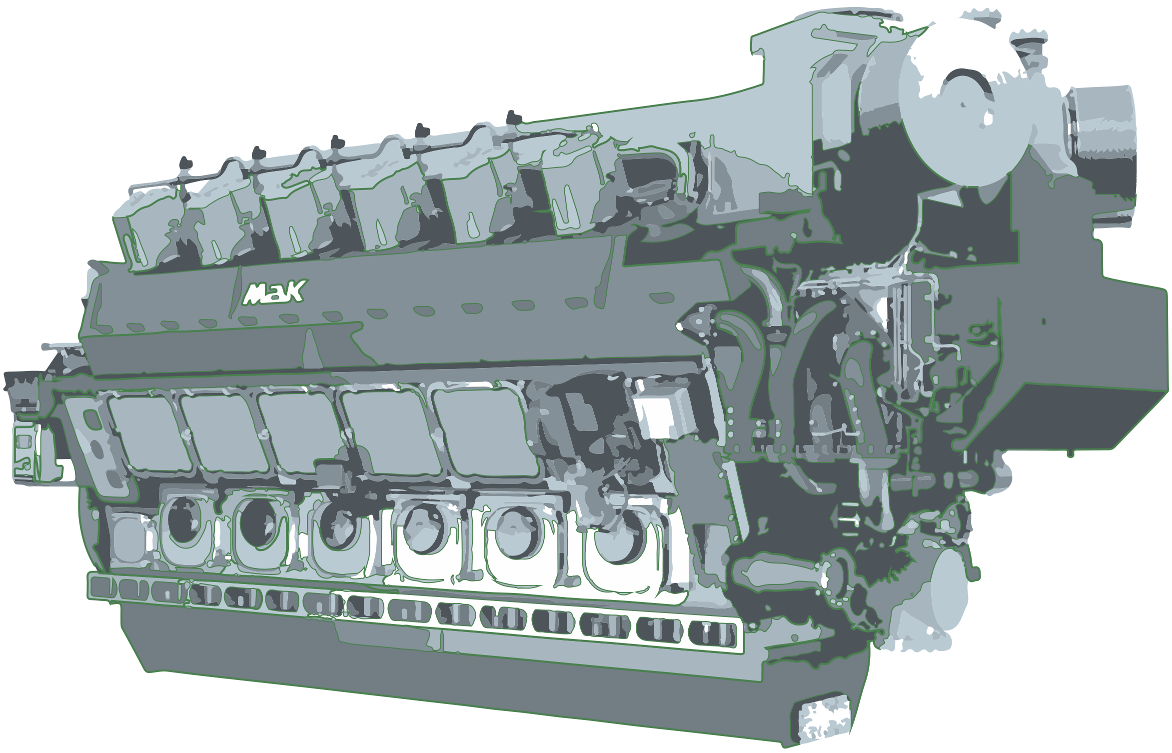
VM 46 DF

PROJECT GUIDE



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This edition supersedes the previous edition of this project guide.

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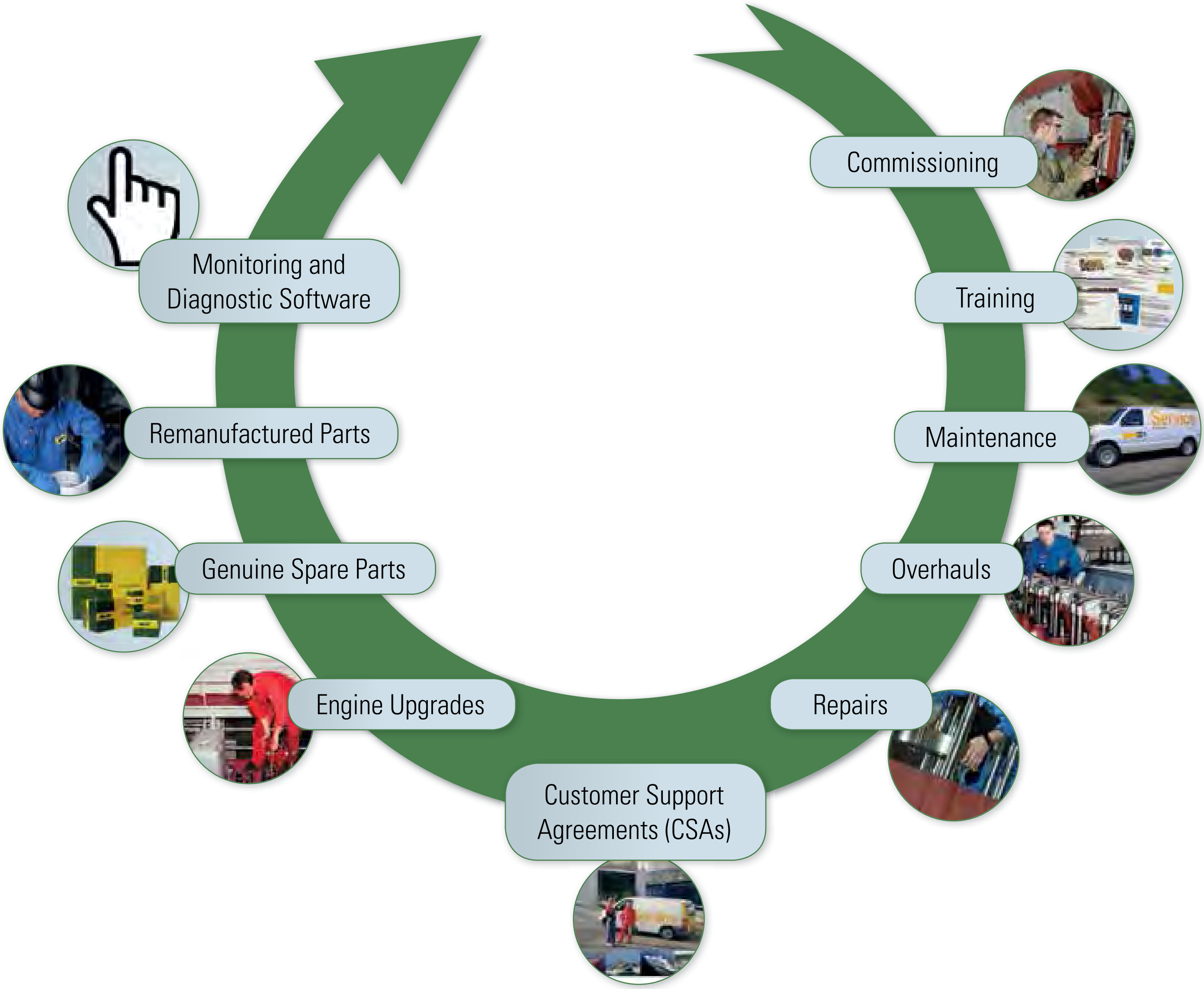

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Initial Certification date:
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1.1 Definitions

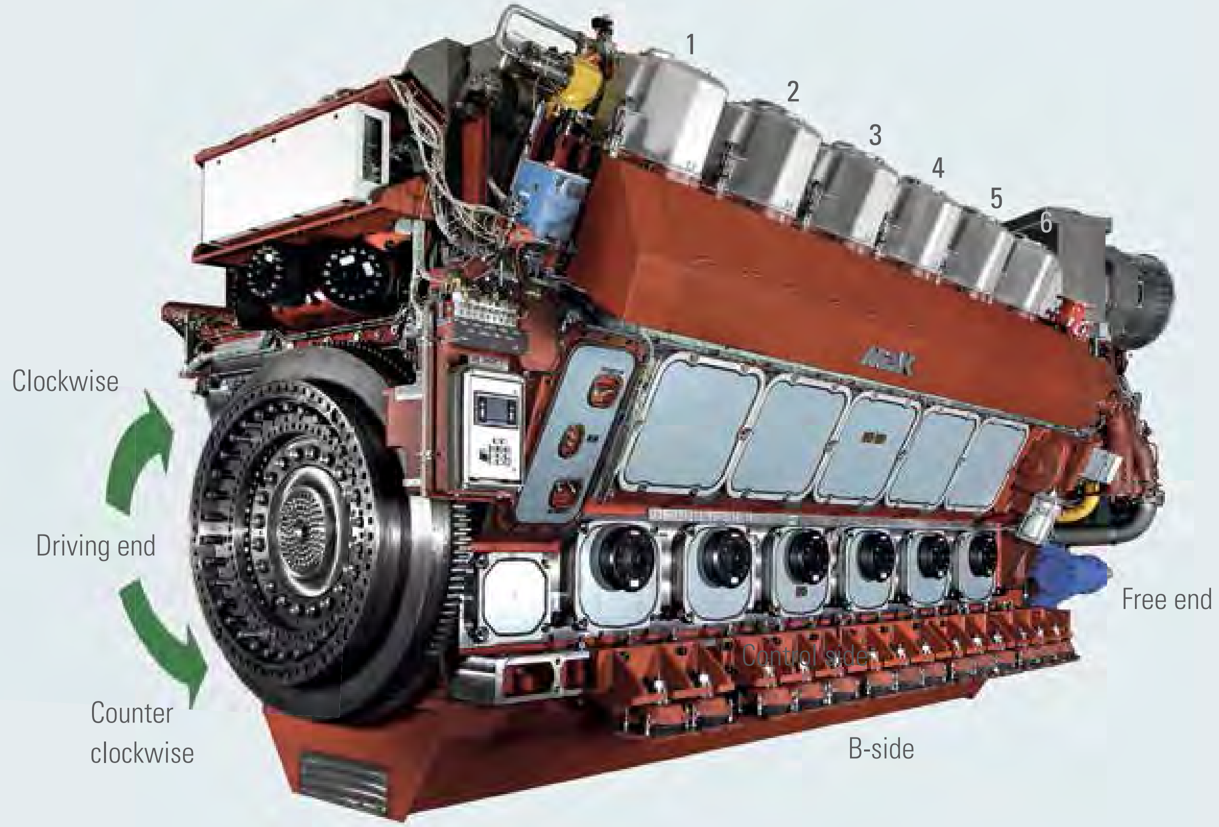

Fig. 1-1 12 M 46 DF Propulsion

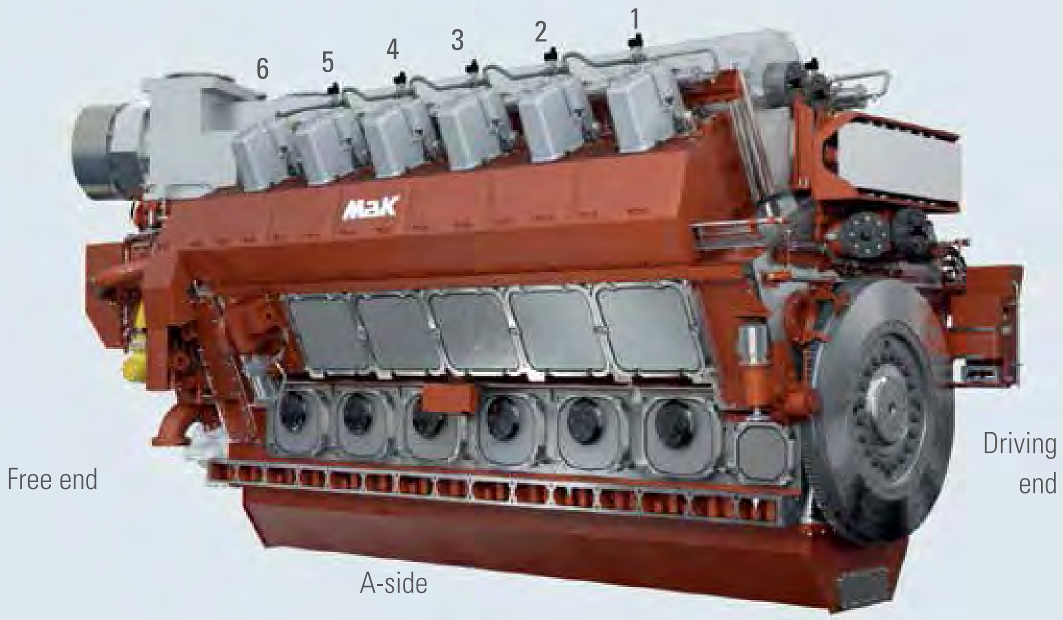

Fig. 1-2 12 M 46 DF Propulsion

		12 M 46 DF	16 M 46 DF
Output (HFO and MDO)	[kW]	10,800	14,400
Output (MDO only)	[kW]	11,580	15,440

Cylinder configuration:	12,16 vee
Bore:	460 mm
Stroke:	610 mm
Output/cyl:	900 kW / 965 kW
BMEP:	20.7 - 22.8 bar
Revolutions:	500/514 rpm
Mean piston speed:	10.2/10.5 m/s
Turbocharging:	single log
Direction of rotation:	clockwise, option: counter-clockwise

1.2 Main components and systems

1.2.1 Main features and characteristics

Building on its marine engine legacy Caterpillar Motoren designed the inherently gas safe VM 46 DF for a variety of marine applications without sacrificing the typical MaK marine engine attributes like operational reliability and efficiency as well as service and maintenance simplicity.
Capable to operate on multiple fuels (NG/MDO/HFO) the VM 46 DF is designed to meet stringent conditions of upcoming exhaust gas emission- and fuel sulphur regulations, providing the operational flexibility for vessel operating in regulated- as well as lesser emission regulated areas.
The optimized design of the VM 46 DF in combination with the system solutions provided by Caterpillar Motoren is the basis for the installation and engine/engine room type approval simplicity, reducing changes to engine and engine related systems at the same time.
Low emissions and high engine efficiency, paired with fast service access and service and maintenance simplicity make the MaK VM 46 DF the perfect choice for single engine main propulsion installations as well as multiple engine installations.

Fig. 1-3 A-side

Fig. 1-4 B-side

1.2.2 Description of components

Cylinder head

- The cylinder heads are made of nodular cast iron with 2 inlet and 2 exhaust valves, which are equipped with valve rotators.
- The exhaust valve seats are directly water cooled.
- The injection nozzles for heavy fuel operation are cooled by engine lube oil.

Connecting rod and piston

- The pistons are of composite type with steel crown and forged steel or nodular cast iron skirt.
- The piston ring sets consist of two compression rings, first ring with chromium diamond plated running surfaces, the second ring with chromium plated running surfaces, and one chromium diamant plated oil scraper ring.
- All ring grooves are located in the steel crown, which is cooled by lube oil.
- The ring grooves are hardened.
- 3-piece connecting rod, supporting removal of the piston without opening the big end bearing.

Engine block

Core element of the VM 46 DF is the engine block, which is made of nodular cast iron in one piece.
The advantages of the engine block design are:

- The one-piece design makes the engine block extremely robust and warp resistant.
- The charge air manifold is cast integral, which avoids vibration and leakage problems.
- Lube oil lines are routed through the block in cast and drilled holes, reducing the number of connecting points and leakage problems to a minimum.
- The camshaft housing contains a camshaft, which is made of sections per cylinder allowing a removal of the segments sideways.
- The underslung crankshaft allows the removal of the complete crankshaft without disassembly of the entire engine.
- The engine block is not integrated into the cooling water circuit, therefore the engine block is completely dry.

Safe and simple power train

The safe and simple designed power train of cylinder head, piston with liner, connecting rod and camshaft is parted in cylinder compartments, while the crankshaft is one-piece. The advantage is simplification of maintenance work saving costs.
Additional advantages are:

- Service friendly distribution of media in maintenance-free plugged pipes and cast blocks
- 2-stage fresh water cooling system with 2-stage charge air cooler
- Turbocharger supplied with inboard plain bearings which are lubricated by engine lube oil
- Service friendly ignition fuel injector location

1.3 Prospective life times

General

The expectable TBO (time between overhaul) and actual life time may deviate significantly as a result of, fuel quality, load and operating profile, conditions, the quality of maintenance and other external factors.

Core components	Life time operating hours [h]			
	VM 46 DF Propulsion and Generator Set			
	Gas	MDO	HFO	TBO VM 46 DF
Piston crown (life time incl. 2 stages rework)	90,000			30,000
Piston skirt cast iron (standard)	60,000			–
Piston skirt steel (optional)	90,000			–
Piston skirt Aluminium	–			–
Piston rings	30,000			–
Piston pin bearing	60,000			–
Cuff / Antipolishing ring	30,000			–
Cylinder liner	90,000		60,000	–
Cylinder head	90,000			15,000
Inlet valve	30,000			15,000
Exhaust valve	30,000			15,000
Nozzle element	7,500		5,000	–
Gas admission valve	7,500			–
Cylinder pressure sensor	7,500			–
Pump element	15,000			–
Pilot injector	7,500			–
HD-pump	7,500			–
Main bearing	30,000			–
Big end bearing	30,000			–
Camshaft bearing	45,000			–
Turbocharger plain bearing	12,000			–
Vibration damper camshaft	15,000			–
Vibration damper crankshaft	60,000			30,000

The above mentioned data are only indicative and relate to an average component life time under favourable operating conditions.

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Type	in HFO and MDO mode 500/514 rpm	in MDO mode only 500/514 rpm
	[kW]	[kW]
12 M 46 DF	10,800	11,580
16 M 46 DF	14,400	15,440

The maximum fuel rack position is mechanically limited to 100 % output for CPP applications.

2.1 General definition of reference conditions

The maximum continuous rating (locked output) stated by Caterpillar Motoren refers to the following reference conditions according to „IACS" (International Association of Classification Societies) for main and auxiliary engines (tropical conditions):

Air pressure:	100 kPa (1 bar)
Air temperature:	318 K (45 °C)
Relative humidity:	60 %
Seawater temperature:	305 K (32 °C)

2.2 Reference conditions regarding fuel consumption

Fuel consumption data is based on the following reference conditions:

Intake temperature:	298 K (25 °C)
Charge air temperature:	318 K (45°C)
Charge air coolant inlet temperature:	298 K (25°C)
Net heating value of the diesel oil:	42,700 kJ/kg
Net heating value of the natural gas:	43.3 MJ/Nm³
Tolerance:	5 %
Fuel gas minimum lower heating value (LHV):	28.0 MJ/Nm³
Fuel gas methane number for rated output:	> 80

Specification of fuel consumption data without engine driven pumps;
For engine driven oil pump: n=const. 1% at 100%, 1.2% at 85%, 1.3% at 75%, 2% at 50%, 4% at 25%.
For engine driven cooling water pump: 0.4% at 100%, 0.47% at 85%, 0.53% at 75%, 0.8% at 50%, 1.6% at 25%.

2.3 Lube oil consumption

- 0.6 g/kWh
- Value is based on rated output
- Tolerance ± 0.3 g/kWh

NOTE:
Please also compare the technical data (see chapter 4).

2.4 Emissions

2.4.1 Exhaust gas 900 kW/Cyl., 500/514 rpm (HFO/MDO) – preliminary

Tolerance: mass flow ± 5 %, temperature ± 20 K
Relative humidity: 60 %
Atmospheric pressure: 100 kPa (1 bar)
Constant speed 500/514 rpm

Engine	Output [kW]	Output [%] [kg/h] [°C]					
		100	90	80	70	60	50
Intake air temperature 25 °C – Diesel operation							
12 M 46 DF	10,800	79,205 345	72,655 350	65,560 350	57,960 352	50,745 367	43,280 383
16 M 46 DF	14,400	105,360 348	96,235 350	86,990 347	77,040 352	67,410 367	57,515 385
Intake air temperature 25 °C – Gas operation							
12 M 46 DF	10,800	67,154 385	61,760 390	55,730 405	49,270 425	43,133 440	36,790 453
16 M 46 DF	14,400	90,600 375	82,765 385	74,810 400	66,255 420	57,975 440	49,465 455
Intake air temperature 45 °C – Diesel operation							
12 M 46 DF	10,800	76,040 366	69,750 371	62,940 371	55,642 373	48,715 389	41,550 406
16 M 46 DF	14,400	101,145 369	92,385 371	83,510 368	73,960 373	64,715 389	55,215 408
Intake air temperature 45 °C – Gas operation							
12 M 46 DF	10,800	64,470 408	59,290 413	53,500 429	47,299 450	41,408 466	35,318 480
16 M 46 DF	14,400	86,976 397	79,455 408	71,818 424	63,605 445	55,656 466	47,486 482

2.4.2 Exhaust gas 965 kW/Cyl., 500rpm (MDO only) – preliminary

Tolerance:	mass flow ± 5 %, temperature ± 20 K
Relative humidity:	60 %
Atmospheric pressure:	100 kPa (1 bar)
Constant speed	500 rpm

Engine	Output [kW]	Output [%] [kg/h] [°C]					
		100	90	80	70	60	50
Intake air temperature 25 °C – Diesel operation							
12 M 46 DF	11,580	84,780 336	77,740 341	70,150 341	62,020 343	54,300 358	46,310 374
16 M 46 DF	15,440	113,035 335	102,970 337	93,080 334	82,430 352	72,130 354	61,540 372
Intake air temperature 25 °C – Gas operation							
12 M 46 DF	11,580	77,150 366	71,025 371	64,090 386	56,660 406	49,600 421	42,310 434
16 M 46 DF	15,440	102,860 365	93,525 375	84,535 390	74,870 410	65,510 430	55,895 445
Intake air temperature 45 °C – Diesel operation							
12 M 46 DF	11,580	79,695 356	73,075 361	65,940 361	58,300 364	51,040 379	45,530 396
16 M 46 DF	15,440	106,250 355	96,790 357	87,495 354	77,485 373	67,970 375	57,850 394
Intake air temperature 45 °C – Gas operation							
12 M 46 DF	11,580	72,520 388	66,765 393	60,245 409	53,260 430	46,625 446	39,770 460
16 M 46 DF	15,440	96,690 387	87,915 397	79,460 413	70,380 435	61,580 456	52,540 472

2.4.3 Exhaust gas 965 kW/Cyl., 514 rpm (MDO only) – preliminary

Tolerance:	mass flow ± 5 %, temperature ± 20 K
Relative humidity:	60 %
Atmospheric pressure:	100 kPa (1 bar)
Constant speed	514 rpm

Engine	Output [kW]	Output [%] [kg/h] [°C]					
		100	90	80	70	60	50
Intake air temperature 25 °C – Diesel operation							
12 M 46 DF	11,580	83,084 336	76,185 341	68,750 341	60,780 343	53,215 358	45,385 374
16 M 46 DF	15,440	110,771 335	100,910 337	91,220 334	80,780 352	70,690 354	60,310 372
Intake air temperature 25 °C – Gas operation							
12 M 46 DF	11,580	75,606 366	69,605 371	62,810 386	55,530 406	48,610 421	41,465 434
16 M 46 DF	15,440	100,800 365	93,525 375	84,535 390	74,870 410	65,510 430	55,895 446
Intake air temperature 45 °C – Diesel operation							
12 M 46 DF	11,580	78,100 356	71,615 361	64,620 361	57,135 364	50,020 379	42,660 396
16 M 46 DF	15,440	104,125 355	90,980 357	85,745 354	75,935 373	66,610 375	56,695 34
Intake air temperature 45 °C – Gas operation							
12 M 46 DF	11,580	71,070 388	65,430 393	59,040 409	52,195 430	45,690 446	38,975 460
16 M 46 DF	15,440	94,750 387	86,155 397	77,870 413	68,970 435	60,350 456	51,490 472

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2.4.4 Nitrogen oxide emissions (NO_x-values)

NO_x-limit values according to IMO II:	10.54 g/kWh (n=500 rpm)
Main engine: DE-drive acc. to cycle E2:	10.3 g/kWh
Auxiliary genset acc. cycle D2:	10.3 g/kWh
NO_x-limit values according to IMO III:	2.60 g/kWh (n=500 rpm)
Gas mode (cycle E2 and D2):	2.60 g/kWh

2.4.5 Engine International Air Pollution Prevention Certificate

The MARPOL Diplomatic Conference has agreed about a limitation of NO_x emissions, referred to as Annex VI to MARPOL 73/78.
When testing the engine for NO_x emissions, the reference fuel is marine diesel oil (distillate) and the test is performed according to ISO 8178 test cycles:

	Test cycle type E2			
Speed	100 %	100 %	100 %	100 %
Power	100 %	75 %	50 %	25 %
Weighting factor	0.2	0.5	0.15	0.15

Subsequently, the NO_x value is calculated using different weighting factors for different loads that have been corrected to ISO 8178 conditions.

A NO_x emission evidence will be issued for each engine showing that the engine complies with the regulation. The evidence will come as EAPP (Engine Air Pollution Prevention) Statement of Compliance, EAPP Document of Compliance or EIAPP (Engine International Air Pollution Prevention) Certificate according to the authorization by the flag state and related technical file. For the most part on basis of an EAPP Statement of Compliance or an EAPP Document of Compliance an EIAPP certificate can be applied for.

According to the IMO regulations, a technical file shall be provided for each engine. This technical file contains information about the components affecting NO_x emissions, and each critical component is marked with a special IMO number. Such critical components are piston, cylinder head, injection nozzle (element), camshaft section, fuel injection pump, turbocharger and charge air cooler. The allowable settings and parameters for running the engine are also specified in the technical file.

The marked components can be easily identified on-board of the ship by the surveyor and thus an IAPP (International Air Pollution Prevention) certificate for the ship can be issued on basis of the EIAPP certificate and the on-board inspection.

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2.5 Engine dimensions and weight – preliminary

Turbocharger at free end

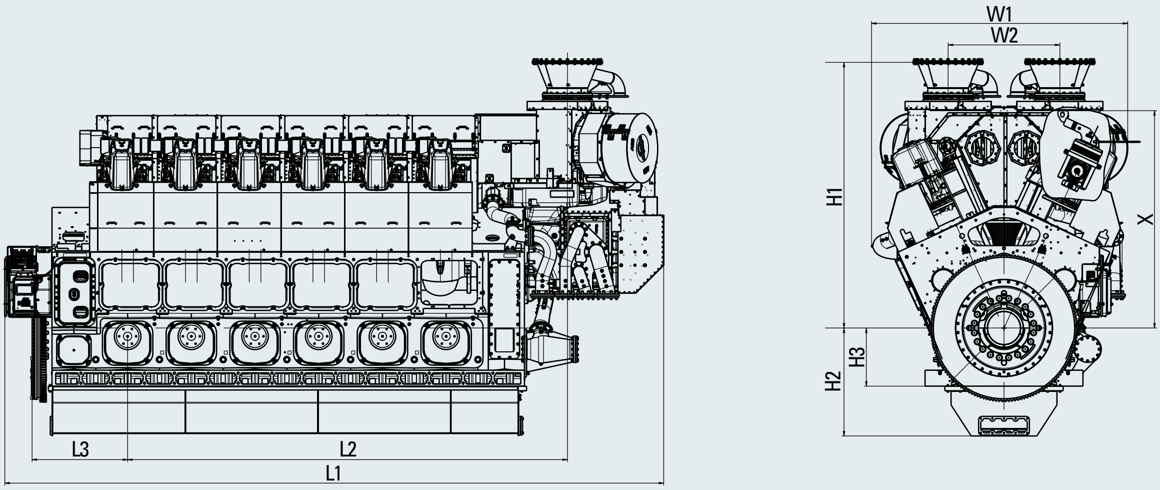

Fig. 2-1 Turbocharger at free end – B-side

Type	Dimensions [mm]								Weight
	L1	L2	L3	H1	H2	H3	W1	W2	[t]
12 M 46 DF	9,930	6,628	1,440	4,000	1,625	875	3,860	1,685	160.0
16 M 46 DF	11,850	9,974	1,440	3,975	1,625	875	3,997	1,670	220.0

Turbocharger at driving end

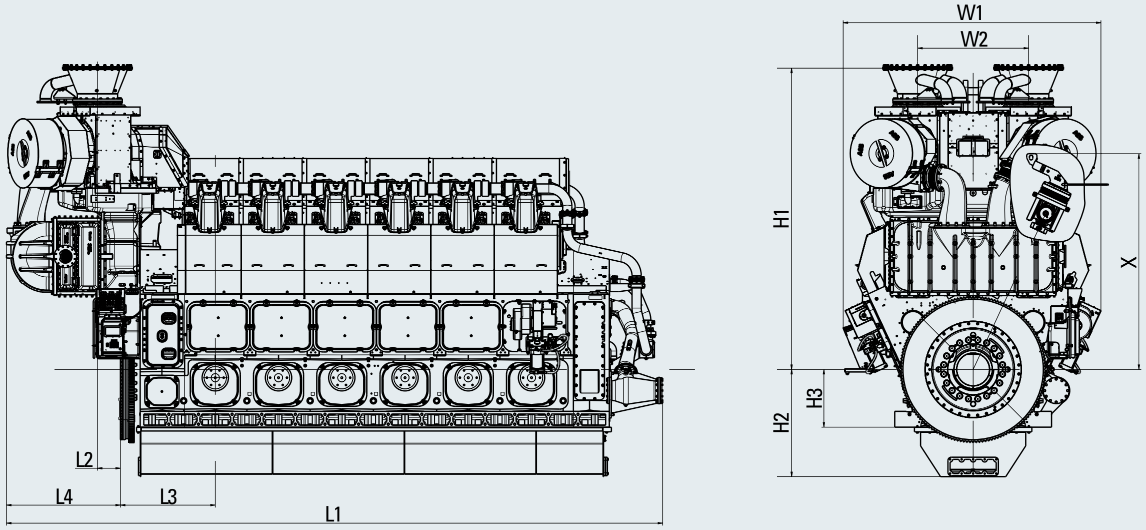

Fig. 2-2 Turbocharger at driving end – B-side

Type	Dimensions [mm]									Weight
	L1	L2	L3	L4	H1	H2	H3	W1	W2	[t]
12 M 46 DF	9,960	348	1,440	1,729	4,568	1,625	875	3,912	1,685	160.0
16 M 46 DF	11,880	333	1,440	1,729	4,543	1,625	875	4,016	1,670	220.0

2.6 System connecting points – preliminary

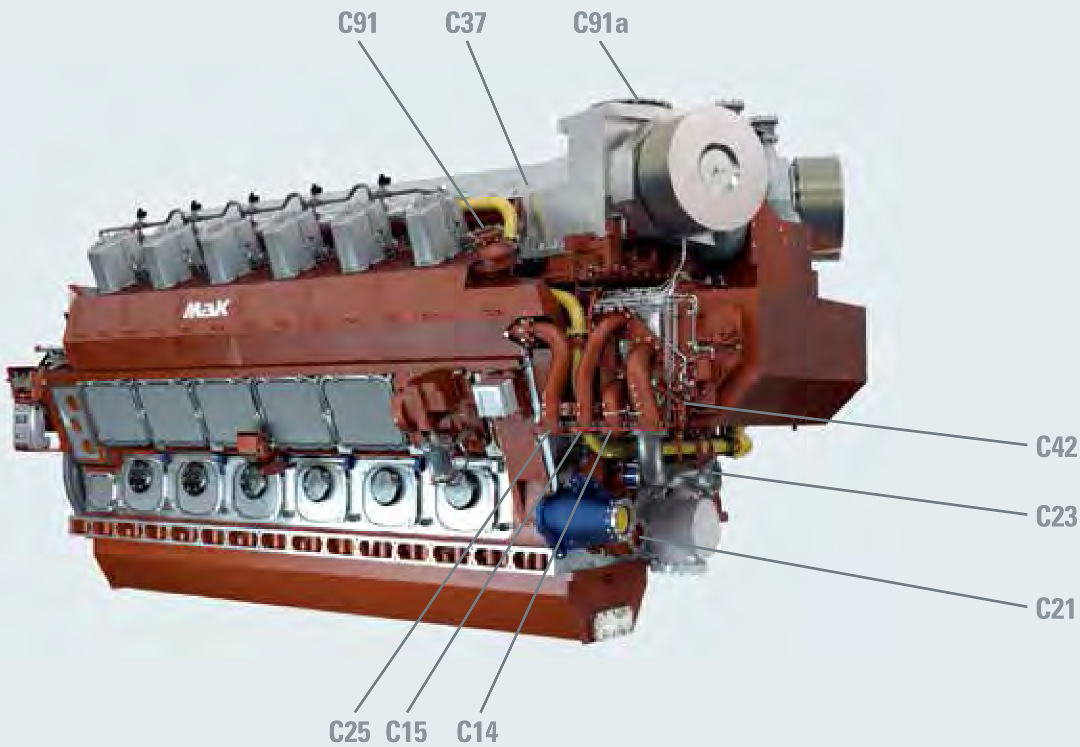

Fig. 2-3 Connecting points at the engine – 1

C14	Charge air cooler LT, inlet	C37	Vent
C15	Charge air cooler LT, outlet	C42	Turbine cleaning connection
C21	Fresh water pump HT, inlet	C91	Crankcase ventilation to stack
C23	Fresh water pump HT, outlet	C91a	Exhaust gas outlet
C25	Cooling water, engine outlet		

Fig. 2-4 Connecting points at the engine – 2

C36	Drain, turbocharger washing
C51	Force pump, suction side
C58	Force pump, delivery side
C59	Lube oil, inlet
C86	Connection starting air

Not shown in the image:

C76	Duplex filter, inlet
C76a	Pilot fuel, inlet
C78	Fuel outlet
C78a	Pilot fuel, outlet
C81b	Drip fuel connection (filter pan)
C96	Gas inlet
C97	Flushing connection gas pipe (inert gas)

3.1 Propulsion

3.1.1 Controllable pitch propeller (CPP) operation

A load above the power limit curve is to be avoided by the use of the load control device of overload protection device. Binding data (depending on the type of vessel, rated output, speed and the turbocharging system) will be established upon order processing.

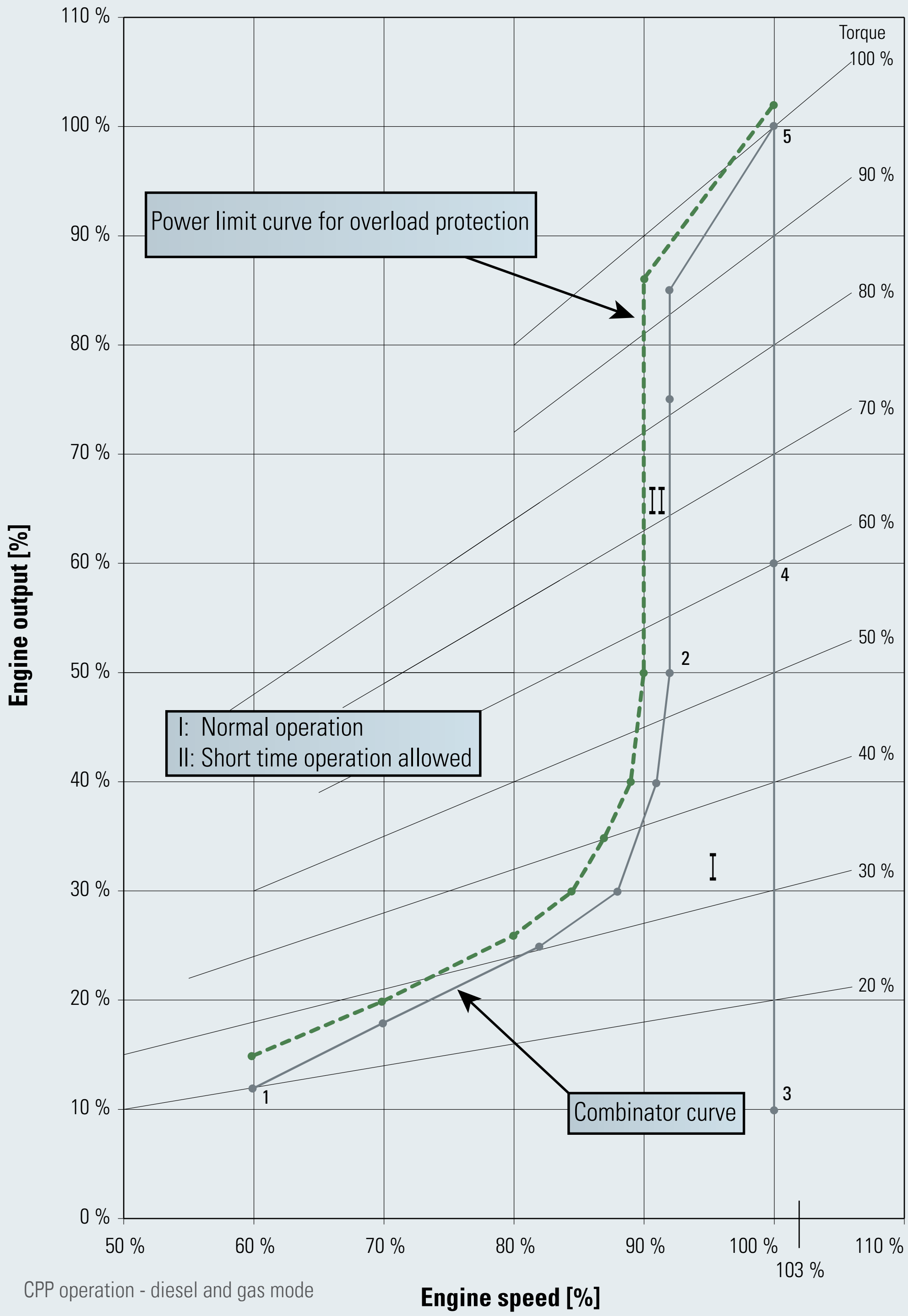

Fig. 3-1 CPP operation - diesel and gas mode

Remarks

- Standard acceleration time will provide longest component lifetimes.
- Emergency acceleration possible, but not recommended due to higher thermal stresses of engine components.
- Reduction from 100% to 0% MCR in 20 s normal operation and 8 s in emergency operation.
- In gas mode the engine changes at 20 % MCR from diesel fuel to liquified petroleum gas

Acceleration ramps

		Maximum ramp up rates		Normal operation			
		combinator	n constant	combinator		n constant	
		1 to 5	3 to 5	1 to 2	2 to 5	3 to 4	4 to 5
		[s]	[s]	[s]	[s]	[s]	[s]
Diesel	12 M 46 DF	40	25	40	140	35	120
Diesel	16 M 46 DF	45	30	45	140	40	120

Gas	12 M 46 DF	60	50	50	140	40	120
Gas	16 M 46 DF	60	50	50	140	40	120

3.1.1.1 Diesel electric drive operation – diesel mode

	Time in seconds	
	0 to 70%	70 to 100%
Standard operation	40	100
Emergency	20	10

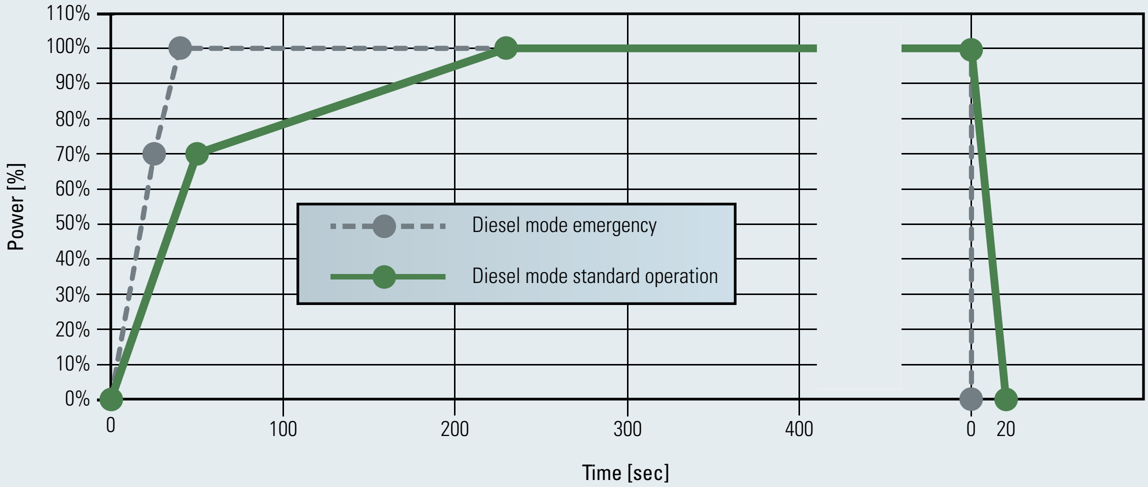

Fig. 3-2 Ramp up time M 46 DF in diesel mode

Remarks

Loading time in seconds, Tol ± 10 sec., engine warmed up in operating conditions
Minimum operating time 10 minutes
Lube oil > 50 °C
Coolant > 65 °C

Standard ramp up time will provide longest component life times.
Emergency ramp up is possible, but not recommended, due to higher thermal stresses of the engine components. In emergency mode with liquid fuel smoke will be visible.

Same ramprates even during fuel transfer.

3.1.1.2 Diesel electric drive operation – gas mode

	Time in seconds	
	20 to 70%	70 to 100%
Standard operation	50	100

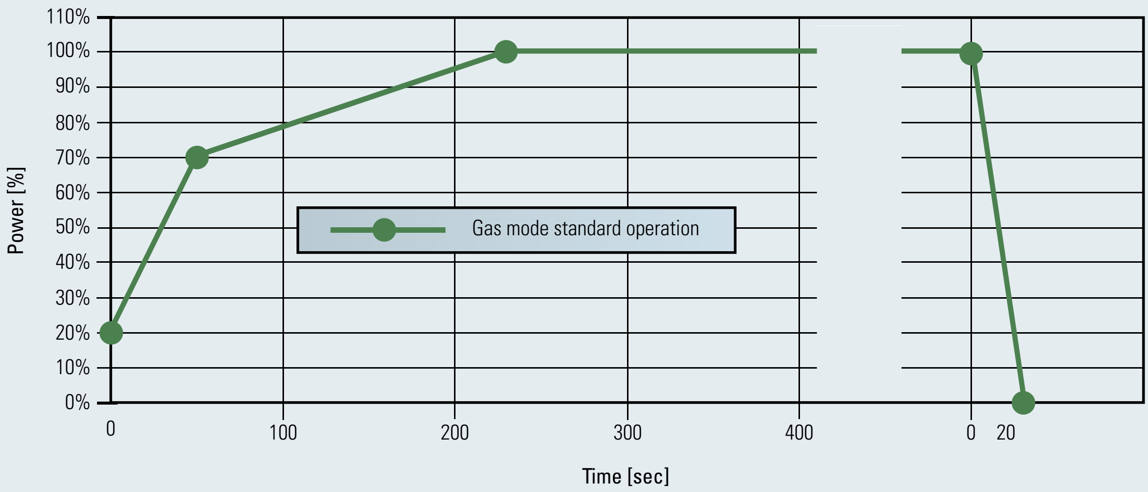

Fig. 3-3 Ramp up time M 46 DF in gas mode

Remarks
Loading time in seconds, Tol ± 10 sec., engine warmed up in operating conditions
Minimum operating time 10 minutes
Lube oil > 50 °C
Coolant > 65 °C

Standard ramp up time will provide longest component life times.
Emergency ramp up is possible, but not recommended, due to higher thermal stresses of the engine components. In emergency mode with liquid fuel smoke will be visible.

Same ramprates even during fuel transfer.

3.2 Generator Set

3.2.1 Load application and recovery behaviour

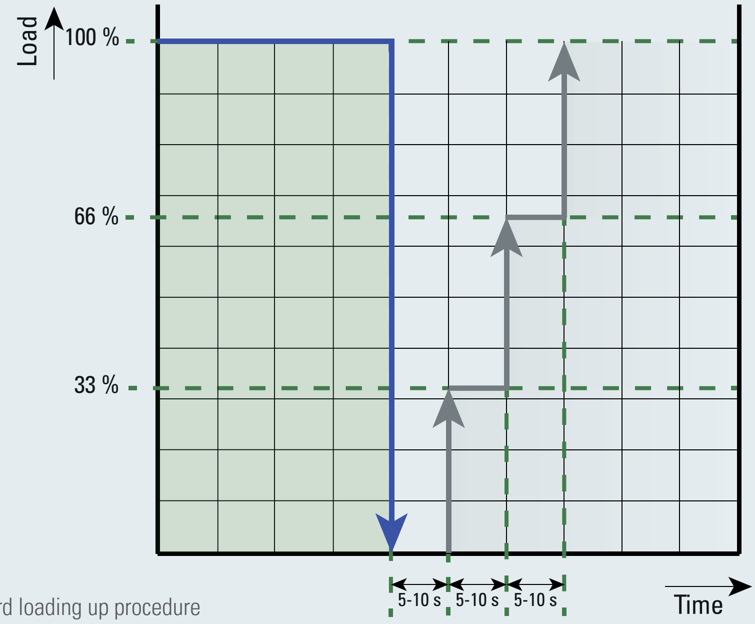

Fig. 3-4 Standard loading up procedure

	Power [%]		
Steps	1.	2.	3.
Diesel mode	33.3 %	33.3 %	33.3 %

	Power [%]				
Steps	1.	2.	3.	4.	5.
Diesel mode	33.3 %	33.3 %	33.3 %		
Gas mode	33.0 %	17.0 %	17.0 %	16.0 %	17.0 %

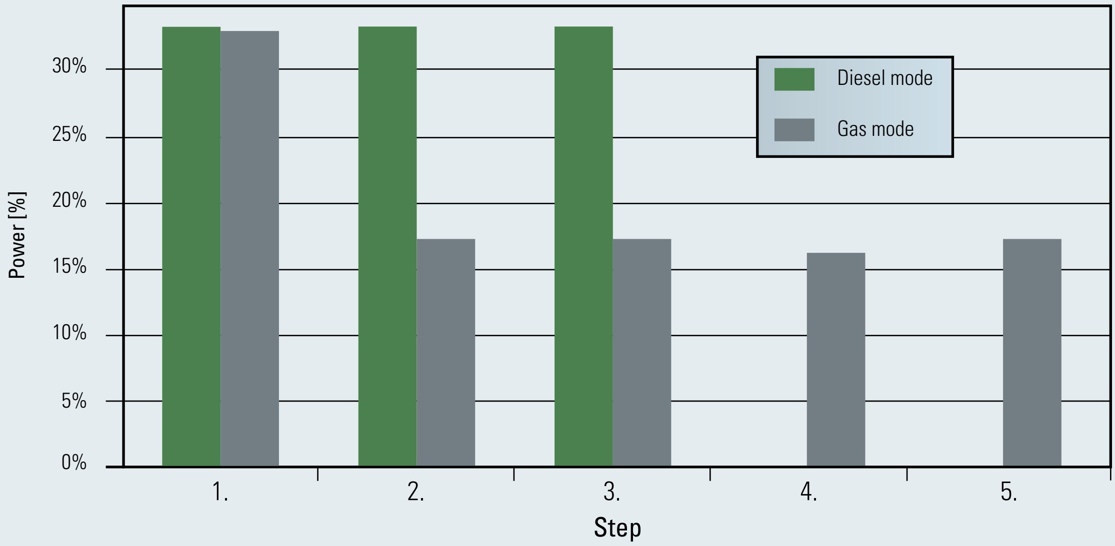

Fig. 3-5 Load steps VM 46 DF

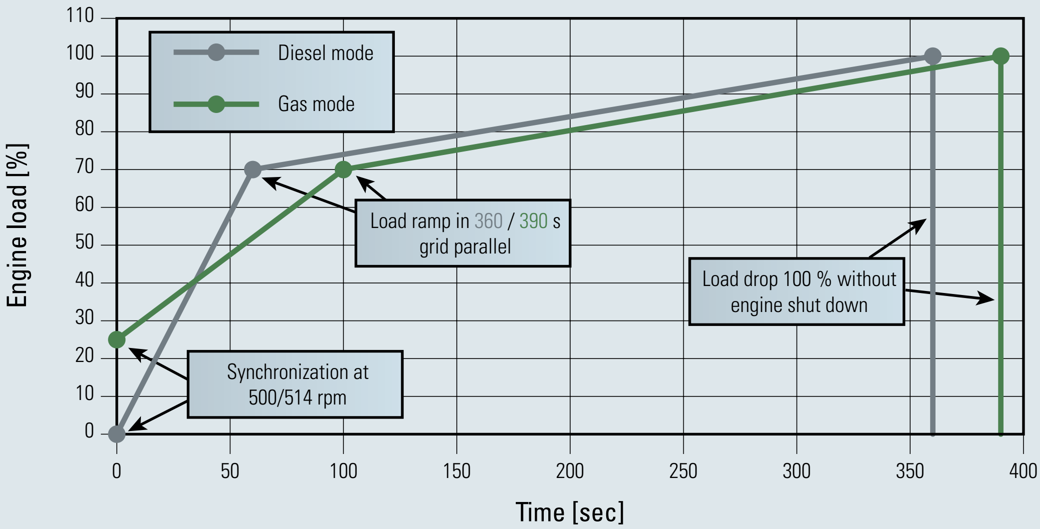

Fig. 3-6 Overview of engine load increment - diesel and gas

Remarks:
Instant loading with recovery time in 5 seconds, Tol.: ± 5 seconds, engine warmed up in operating conditions
Minimum operating time 10 minutes
Lube oil > 50 °C
Coolant > 65 °C

3.3 Restrictions for low load operation

3.3.1 Load restrictions in diesel mode

- The engine can be started, stopped and run on heavy fuel oil under all operating conditions.
- The HFO system of the engine remains in operation and keeps the HFO at injection viscosity. The temperature of the engine injection system is maintained by circulating hot HFO and heat losses are compensated.
- The lube oil treatment system (lube oil separator) remains in operation, the lube oil is separated continuously.
- The operating temperature of the engine cooling water is maintained by the cooling water preheater.
- Below 25 % output heavy fuel operation is neither efficient nor economical.
- A change-over to diesel oil is recommended to avoid disadvantages as e.g. increased wear and tear, contamination of the air and exhaust gas systems and increased contamination of lube oil.

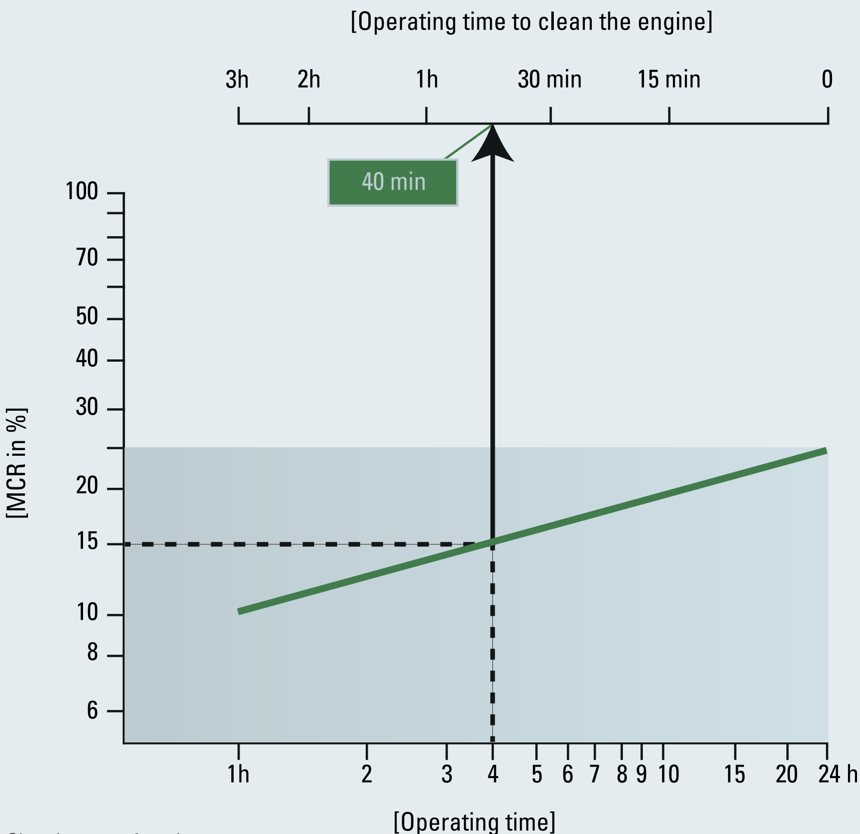

Fig. 3-7 Cleaning run of engine

3.3.2 Load restrictions in gas mode

According to the low load restrictions given by the required air to fuel ratio, the engine starts and stops in diesel and in gas operation. A gas operation above 100% load is prohibited. A gas operation below 20% load is not possible or limited for a certain time. A direct fuel change over from HFO operation to gas operation is prohibited. The engine needs to run a certain time with MDO before change over to gas operation.

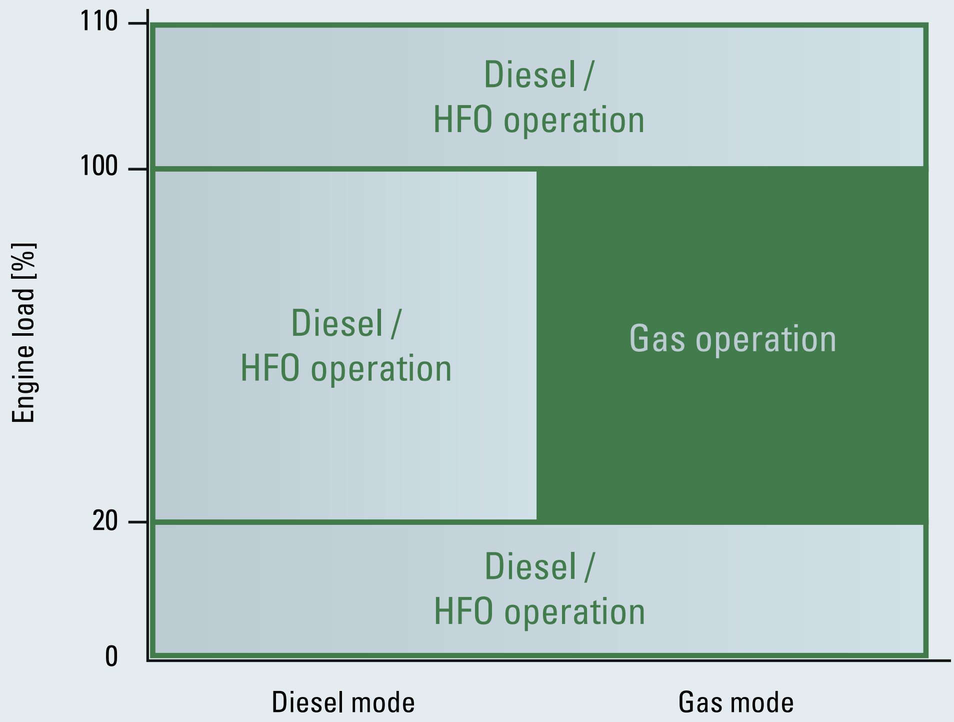

Fig. 3-8 Load restrictions in gas mode

01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

3.4 Emergency operation without turbocharger

Emergency operation is permissible with MDO only up to approx. 15% of the MCR.

3.5 Operation in inclined position

Inclination angles of ships at which engine running must be possible:

Rotation X-axis:
Heel to each side: 15 °
Rolling to each side: 22.5 °

Rotation Y-axis:
Trim by head and stern: 5 °
Pitching: ±7.5 °

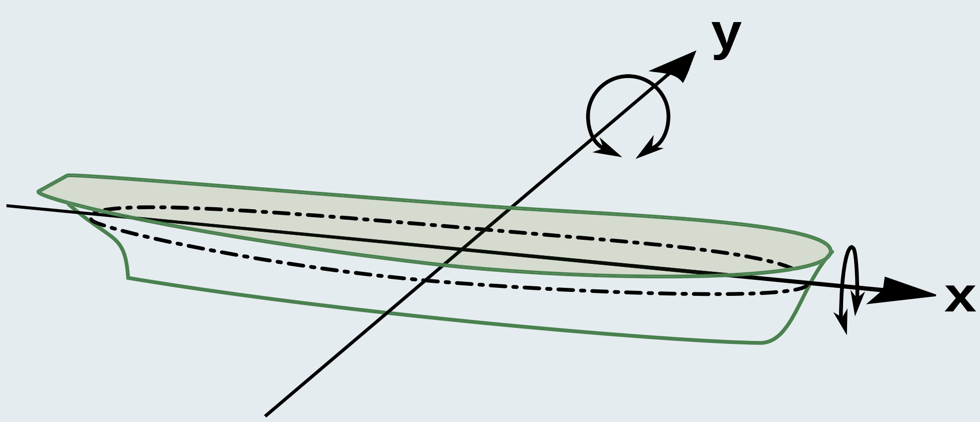

Fig. 3-9 Rotation axis

3.6 Fuel changeover and recovery behaviour

a) Changeover from gas to diesel operation:

- Changeover from gas to diesel fuel operation is done within approx. 1 second at any load, if required due to emergency switch over. The normal switchover takes approx. 30 seconds.
- Changeover can be started manually by operator or automatically by MACS, if the gas operation conditions are not given anymore (e.g. load window for gas operation has been left).

  - Main liquid fuel injection activated
  - Gaseous fuel slowly cut back / liquid fuel amount rises
  - FCT: Valve timing adjusts depending on running condition (e.g. load)
  - Air fuel ratio control is shut-off (Blow-Off and Waste Gate)
  - Ignition shot is still active

b) Changeover from diesel to gas operation:

- Changeover from diesel to gas fuel operation is possible in the load range between 25% and 100% power.
- If gas mode is activated, the load is constant in the correct range and all systems are running, the engine control will change over to gas operation:

  - Start air fuel ratio control with exhaust Waste Gate and Blow-Off
  - Change valve timing over to gas operation depending on running conditions
  - Start gas supply and raise gas amount, if gas pressure is sufficient
  - Main liquid fuel injection cuts back and switches off, if minimum fuel rack position is reached

- The procedure will take approx. 2 minutes, which depends on gas supply system and self check procedures.
- If the procedure is completed, power ramp up to 100% power or instant loading is possible.

3.7 Derating

In case of a fuel gas methane number lower than 80, the power output has to be redetermined in gas operation.
For an alternative derating curve please consult Caterpillar Motoren in advance.

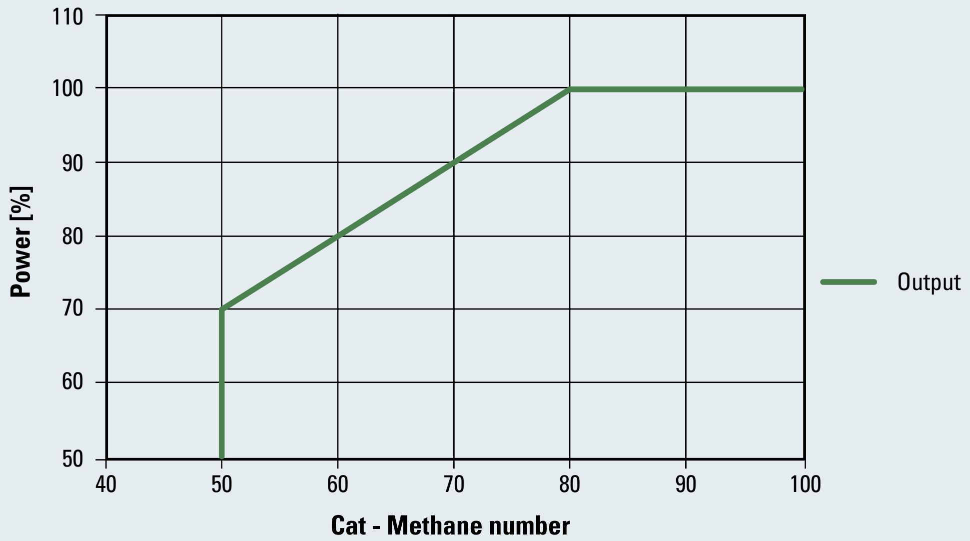

Fig. 3-10 Power as function of Cat-methane number

01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

4.1 Diesel, mechanical

4.1.1 Output 900 kW/Cyl. in HFO or MDO operation

Output 900 kW/Cyl. (HFO and MDO)		12 M 46 DF	16 M 46 DF
Performance data			
Maximum continuous rating acc. ISO 3046/1	[kW]	10,800	14,400
Speed	[rpm]	500/514	500/514
Minimum speed	[rpm]	300	300
Brake mean effective presure	[bar]	21.3/20.7	21.3/20.7
Charge air pressure	[bar]	3.55	3.55
Firing pressure (max. allowed, tolerance +/- 3%)	[bar]	190	190
Combustion air demand (ta=20°C)	[m³/h]	64,100	86,700
Max. load acceptance	[kW/s]	66	90
Specific fuel oil consumption diesel/gas			
n = const [1)] 100 %	[g/kWh] [kJ/kWh]	186/7,272	186/7,272
85 %	[g/kWh] [kJ/kWh]	185/7,417	185/7,417
75 %	[g/kWh] [kJ/kWh]	187/7,563	187/7,563
50 %	[g/kWh] [kJ/kWh]	192/8,088	192/8,088
Lube oil consumption [2)]	[g/kWh]	0.6	0.6
NO_x-emission (diesel) [6)]	[g/kWh]	10.0	10.0
NO_x-emission (gas) [6)]	[g/kWh]	2.6	2.6
Methane slip, sp. pilot oil injection			
100 %	[% kJ/kWh]	2.0/72	2.0/72
50 %	[% kJ/kWh]	2.1/96	2.1/96
15 %	[% kJ/kWh]	6.9/272	6.9/272
CO_2 100% (diesel/gas)	[%]	5.4/4.5	5.4/4.5
Turbocharger type		2 x ABB TPL71	2 x ABB TPL76
Fuel			
Engine driven booster pump	[m³/h] [bar]	–/–	–/–
Stand-by booster pump	[m³/h] [bar]	8.4/5	11.2/5
Mesh size MDO fine filter	[mm]	0.025	0.025
Mesh size HFO automatic filter	[mm]	0.010	0.010
Mesh size HFO fine filter	[mm]	0.034	0.034

Output 900 kW/Cyl. (HFO and MDO)		12 M 46 DF	16 M 46 DF
Lube oil			
Engine driven pump	[m³/h] [bar]	250/10	400/10
Independent pump	[m³/h] [bar]	200/10	270/10
Working pressure on engine inlet	[bar]	4 - 5	4 - 5
Engine driven suction pump	[m³/h] [bar]	–/–	–/–
Independent suction pump	[m³/h] [bar]	350/3	470/3
Priming pump	[m³/h] [bar]	30/5	40/5
Lube oil circulating tank / dry sump content	[m³]	16.3	21.8
Temperature at engine inlet	[°C]	60 - 65	60 - 65
Temperature controller NB	[mm]	200	200
Double filter NB	[mm]	200	200
Mesh size double filter	[mm]	0.08	0.08
Mesh size automatic filter	[mm]	0.03	0.03
Fresh water cooling			
Engine content	[m³]	2.8	4.0
Pressure at engine inlet min/max	[bar]	4.5/6.0	4.5/6.0
Header tank capacity	[m³]	1.5	2.0
Temperature at engine outlet	[°C]	80 - 90	80 - 90
Two circuit system			
Engine driven pump HT	[m³/h] [bar]	200/4.7	350/4.7
Independent pump HT	[m³/h] [bar]	200/3	350/3
HT-controller NB	[mm]	200	200
Water demand LT-charge air cooler	[m³/h]	100	130
Temperature LT-charge air cooler inlet	[°C]	38	38
Heat dissipation *)			
Specific jacket water heat	[kJ/kWh]	496	496
Specific lube oil heat	[kJ/kWh]	500	500
Lube oil cooler	[kW]	1,495	1,995
Jacket water	[kW]	1,490	1,985
Charge air cooler [3]	[kW]	–/–	–/–
Charge air cooler (HT-stage) [3]	[kW]	3,540	4,715
Charge air cooler (LT-stage) [3] (HT-stage before engine)	[kW]	1,000	1,330
Heat radiation engine	[kW]	510	670

*) NOTE: Tolerance for heat and exhaust flow +/- 10 %, tolerance of +10 % for rating coolers

01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

Output 900 kW/Cyl. (HFO and MDO)		12 M 46 DF	16 M 46 DF
Exhaust gas			
Silencer / spark arrestor NB	[mm]	1,200	1,500
Pipe diameter NB after turbine	[mm]	2 x 900	2 x 1,000
Exhaust gas temperature after turbine (intake air 25 °C, diesel) 5)	[°C)	345	335
Exhaust gas mass flow (intake air 25 °C, diesel) 5)	[kg/h]	79,025	105,360
Exhaust gas temperature after turbine (intake air 25 °C, gas) 5)	[°C]	385	375
Exhaust gas mass flow (intake air 25 °C, gas) 5)	[kg/h]	67,154	90,600
Maximum exhaust gas back pressure	[bar]	0.03	0.03
Starting air			
Maximum starting air pressure	[bar]	30	30
Minimum starting air pressure	[bar]	14	14
Air consumption per start 4)	[Nm^3]	3.0	3.5
Air consumption per slow turn maneuver 4)	[Nm^3]	6.0	7.0
Max. allowed crankcase pressure, ND ventilation pipe	[mmWs/mm]	15/200	15/200

1) Reference conditions: LCV = 42,700 kJ/kg, ambient temperature 25 °C, charge air coolant temperature 25 °C, tolerance 5 %, for engine driven oil pump +1% at 100%, 1.2% at 85%, 1.3% at 75%, 2% at 50%, 4% at 25%, for engine driven cooling water pump +0.4% at 100%, 0.47% at 85%, 0.53% at 75%, 0.8% at 50%, 1.6% at 25%, in propeller operation for engine driven oil pump +1% at 100%, 1.1% at 85%, 1.2% at 75%, 1.4% at 50%, 2% at 25%, for engine driven cooling water pump +0.4% at 100/85/75/50/25%, additions to fuel consumption must be considered before tolerance is taken into account. / 2) Standard value based on rated output, tolerance ± 0.3 g/kWh / 3) Charge air heat based on 45 °C ambient temperature / 4) Preheated engine / 5) Tolerance 10 %, relative air humidity 60 % / 6) Marpol 73/78, Annex VI, cycle E2, D

4.1.2 Output 965 kW/Cyl. in MDO operation only (preliminary)

4.1.2.1 Output 965 kW/Cyl. at 500 rpm (preliminary)

Output 965 kW/Cyl., 500 rpm (MDO only)			12 M 46 DF	16 M 46 DF
Performance data				
Maximum continuous rating acc. ISO 3046/1		[kW]	11,580	15,440
Speed		[rpm]	500	500
Minimum speed		[rpm]	300	300
Brake mean effective presure		[bar]	22.8	22.8
Charge air pressure		[bar]	4.0	4.0
Firing pressure (max. allowed, tolerance +/- 3%)		[bar]	190	190
Combustion air demand (ta=20°C)		[m³/h]	68,590	91,450
Max. load acceptance		[kW/s]	66	90
Specific fuel oil consumption diesel/gas				
n = const [1)]	100 %	[g/kWh] [kJ/kWh]	184/7,350	184/7,350
	85 %	[g/kWh] [kJ/kWh]	182/7,370	182/7,370
	75 %	[g/kWh] [kJ/kWh]	183/7,430	183/7,430
	50 %	[g/kWh] [kJ/kWh]	187/7,680	187/7,680
Lube oil consumption [2)]		[g/kWh]	0.6	0.6
NO_x-emission (diesel) [6)]		[g/kWh]	10.0	10.0
NO_x-emission (gas) [6)]		[g/kWh]	2.6	2.6
Methane slip, sp. pilot oil injection				
	100 %	[% kJ/kWh]	2.0/72	2.0/72
	50 %	[% kJ/kWh]	2.1/96	2.1/96
	15 %	[% kJ/kWh]	6.9/272	6.9/272
CO_2 100% (diesel/gas)		[%]	5.4/4.5	5.4/4.5
Turbocharger type			2 x ABB TPL71	2 x ABB TPL76
Fuel				
Engine driven booster pump		[m³/h] [bar]	–/–	–/–
Stand-by booster pump		[m³/h] [bar]	8.4/5	11.2/5
Mesh size MDO fine filter		[mm]	0.025	0.025
Mesh size HFO automatic filter		[mm]	0.010	0.010
Mesh size HFO fine filter		[mm]	0.034	0.034

Output 965 kW/Cyl., 500 rpm (MDO only)		12 M 46 DF	16 M 46 DF
Lube oil			
Engine driven pump	[m³/h] [bar]	250/10	400/10
Independent pump	[m³/h] [bar]	200/10	270/10
Working pressure on engine inlet	[bar]	4 - 5	4 - 5
Engine driven suction pump	[m³/h] [bar]	–/–	–/–
Independent suction pump	[m³/h] [bar]	350/3	470/3
Priming pump	[m³/h] [bar]	30/5	40/5
Lube oil circulating tank / dry sump content	[m³]	16.3	21.8
Temperature at engine inlet	[°C]	60 - 65	60 - 65
Temperature controller NB	[mm]	200	200
Double filter NB	[mm]	200	200
Mesh size double filter	[mm]	0.08	0.08
Mesh size automatic filter	[mm]	0.03	0.03
Fresh water cooling			
Engine content	[m³]	2.8	4.0
Pressure at engine inlet min/max	[bar]	4.5/6.0	4.5/6.0
Header tank capacity	[m³]	1.5	2.0
Temperature at engine outlet	[°C]	80 - 90	80 - 90
Two circuit system			
Engine driven pump HT	[m³/h] [bar]	200/4.7	350/4.7
Independent pump HT	[m³/h] [bar]	200/3	350/3
HT-controller NB	[mm]	200	200
Water demand LT-charge air cooler	[m³/h]	100	130
Temperature LT-charge air cooler inlet	[°C]	38	38
Heat dissipation *)			
Specific jacket water heat	[kJ/kWh]	480	480
Specific lube oil heat	[kJ/kWh]	482	482
Lube oil cooler	[kW]	1,550	2,065
Jacket water	[kW]	1,545	2,060
Charge air cooler [3)]	[kW]	–/–	–/–
Charge air cooler (HT-stage) [3)]	[kW]	3,995	5,325
Charge air cooler (LT-stage) [3)] (HT-stage before engine)	[kW]	1,055	1,405
Heat radiation engine	[kW]	550	730

*) NOTE: Tolerance for heat and exhaust flow +/- 10 %, tolerance of +10 % for rating coolers

Output 965 kW/Cyl., 500 rpm (MDO only)		12 M 46 DF	16 M 46 DF
Exhaust gas			
Silencer / spark arrestor NB	[mm]	1,200	1,500
Pipe diameter after turbine	[mm]	2 x 900	2 x 1,000
Exhaust gas temperature after turbine (intake air 25 °C, diesel) 5)	[°C)	336	335
Exhaust gas mass flow (intake air 25 °C, diesel) 5)	[kg/h]	84,780	113,035
Exhaust gas temperature after turbine (intake air 25 °C, gas) 5)	[°C]	366	365
Exhaust gas mass flow (intake air 25 °C, gas) 5)	[kg/h]	77,150	102,860
Maximum exhaust gas back pressure	[bar]	0.03	0.03
Starting air			
Maximum starting air pressure	[bar]	30	30
Minimum starting air pressure	[bar]	14	14
Air consumption per start 4)	[Nm³]	3.0	3.5
Air consumption per slow turn maneuver 4)	[Nm³]	6.0	7.0
Max. allowed crankcase pressure, ND ventilation pipe	[mmWs/mm]	15/200	15/200

1) Reference conditions: LCV = 42,700 kJ/kg, ambient temperature 25 °C, charge air coolant temperature 25 °C, tolerance 5 %, for engine driven oil pump +1% at 100%, 1.18% at 85%, 1.33% at 75%, 2% at 50%, 4% at 25%, for engine driven cooling water pump +0.4% at 100%, 0.47% at 85%, 0.53% at 75%, 0.8% at 50%, 1.6% at 25%, additions to fuel consumption must be considered before tolerance is taken into account. / **2)** Standard value based on rated output, tolerance ± 0.3 g/kWh / **3)** Charge air heat based on 45 °C ambient temperature / **4)** Preheated engine / **5)** Tolerance 10 %, relative air humidity 60 % / **6)** Marpol 73/78, Annex VI, cycle E2, D2

01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

4.1.2.2 Output 965 kW/Cyl. at 514 rpm (preliminary)

Output 965 kW/Cyl., 514 rpm (MDO only)		12 M 46 DF	16 M 46 DF
Performance data			
Maximum continuous rating acc. ISO 3046/1	[kW]	11,580	15,440
Speed	[rpm]	514	514
Minimum speed	[rpm]	300	300
Brake mean effective presure	[bar]	22.2	22.2
Charge air pressure	[bar]	3.83	3.83
Firing pressure (max. allowed, tolerance +/- 3%)	[bar]	190	190
Combustion air demand (ta=20°C)	[m³/h]	67,220	89,620
Max. load acceptance	[kW/s]	66	90
Specific fuel oil consumption diesel/gas			
n = const [1] 100 %	[g/kWh] [kJ/kWh]	185/7,350	185/7,350
85 %	[g/kWh] [kJ/kWh]	183/7,370	183/7,370
75 %	[g/kWh] [kJ/kWh]	184/7,430	184/7,430
50 %	[g/kWh] [kJ/kWh]	188/7,680	188/7,680
Lube oil consumption [2]	[g/kWh]	0.6	0.6
NO_x-emission (diesel) [6]	[g/kWh]	10.0	10.0
NO_x-emission (gas) [6]	[g/kWh]	2.6	2.6
Methane slip, sp. pilot oil injection			
100 %	[% kJ/kWh]	2.0/72	2.0/72
50 %	[% kJ/kWh]	2.1/96	2.1/96
15 %	[% kJ/kWh]	6.9/272	6.9/272
CO_2 100% (diesel/gas)	[%]	5.4/4.5	5.4/4.5
Turbocharger type		2 x ABB TPL71	2 x ABB TPL76
Fuel			
Engine driven booster pump	[m³/h] [bar]	–/–	–/–
Stand-by booster pump	[m³/h] [bar]	8.4/5	11.2/5
Mesh size MDO fine filter	[mm]	0.025	0.025
Mesh size HFO automatic filter	[mm]	0.010	0.010
Mesh size HFO fine filter	[mm]	0.034	0.034

Output 965 kW/Cyl., 514 rpm (MDO only)		12 M 46 DF	16 M 46 DF
Lube oil			
Engine driven pump	[m³/h] [bar]	250/10	400/10
Independent pump	[m³/h] [bar]	200/10	270/10
Working pressure on engine inlet	[bar]	4 - 5	4 - 5
Engine driven suction pump	[m³/h] [bar]	–/–	–/–
Independent suction pump	[m³/h] [bar]	350/3	470/3
Priming pump	[m³/h] [bar]	30/5	40/5
Lube oil circulating tank / dry sump content	[m³]	16.3	21.8
Temperature at engine inlet	[°C]	60 - 65	60 - 65
Temperature controller NB	[mm]	200	200
Double filter NB	[mm]	200	200
Mesh size double filter	[mm]	0.08	0.08
Mesh size automatic filter	[mm]	0.03	0.03
Fresh water cooling			
Engine content	[m³]	2.8	4.0
Pressure at engine inlet min/max	[bar]	4.5/6.0	4.5/6.0
Header tank capacity	[m³]	1.5	2.0
Temperature at engine outlet	[°C]	80 - 90	80 - 90
Two circuit system			
Engine driven pump HT	[m³/h] [bar]	200/4.7	350/4.7
Independent pump HT	[m³/h] [bar]	200/3	350/3
HT-controller NB	[mm]	200	200
Water demand LT-charge air cooler	[m³/h]	100	130
Temperature LT-charge air cooler inlet	[°C]	38	38
Heat dissipation *)			
Specific jacket water heat	[kJ/kWh]	480	480
Specific lube oil heat	[kJ/kWh]	482	482
Lube oil cooler	[kW]	1,550	2,065
Jacket water	[kW]	1,545	2,060
Charge air cooler [3]	[kW]	–/–	–/–
Charge air cooler (HT-stage) [3]	[kW]	3,995	5,325
Charge air cooler (LT-stage) [3] (HT-stage before engine)	[kW]	1,055	1,405
Heat radiation engine	[kW]	550	730

*) NOTE: Tolerance for heat and exhaust flow +/- 10 %, tolerance of +10 % for rating coolers

Output 965 kW/Cyl., 514 rpm (MDO only)		12 M 46 DF	16 M 46 DF
Exhaust gas			
Silencer / spark arrestor NB	[mm]	1,200	1,500
Pipe diameter after turbine	[mm]	2 x 900	2 x 1,000
Exhaust gas temperature after turbine (intake air 25 °C, diesel) [5)]	[°C)	336	335
Exhaust gas mass flow (intake air 25 °C, diesel) [5)]	[kg/h]	83,084	110,771
Exhaust gas temperature after turbine (intake air 25 °C, gas) [5)]	[°C]	366	365
Exhaust gas mass flow (intake air 25 °C, gas) [5)]	[kg/h]	75,606	100,800
Maximum exhaust gas back pressure	[bar]	0.03	0.03
Starting air			
Maximum starting air pressure	[bar]	30	30
Minimum starting air pressure	[bar]	14	14
Air consumption per start [4)]	[Nm³]	3.0	3.5
Air consumption per slow turn maneuver [4)]	[Nm³]	6.0	7.0
Max. allowed crankcase pressure, ND ventilation pipe	[mmWs/mm]	15/200	15/200

1) Reference conditions: LCV = 42,700 kJ/kg, ambient temperature 25 °C, charge air coolant temperature 25 °C, tolerance 5 %, for engine driven oil pump +1% at 100%, 1.18% at 85%, 1.33% at 75%, 2% at 50%, 4% at 25%, for engine driven cooling water pump +0.4% at 100%, 0.47% at 85%, 0.53% at 75%, 0.8% at 50%, 1.6% at 25%, additions to fuel consumption must be considered before tolerance is taken into account. / **2)** Standard value based on rated output, tolerance ± 0.3 g/kWh / **3)** Charge air heat based on 45 °C ambient temperature / **4)** Preheated engine / **5)** Tolerance 10 %, relative air humidity 60 % / **6)** Marpol 73/78, Annex VI, cycle E2, D2

5.1 MGO / MDO operation

General

MaK diesel engines are designed to burn a wide variety of fuels.
See the information on fuel requirements in section MDO / MGO and HFO operation or consult the Caterpillar Motoren technical product support.
For proper operation of MaK engines the minimum Caterpillar Motoren requirements for storage, treatment and supply systems have to be observed, as shown in the following sections.

5.1.1 Acceptable MGO / MDO characteristics

Two fuel oil product groups are permitted for MaK engines:

Pure distillates:	Gas oil, marine gas oil, diesel fuel
Distillate/mixed fuels:	Marine gas oil (MGO), marine diesel oil (MDO)

The difference between distillate/mixed fuels and pure distillates are higher density, sulfur content and viscosity.

Marine distillate fuels

Parameter	Unit	Limit	DMX	DMA	DMZ	DMB
Viscosity at 40 °C	[mm²/s]	max	5.5	6.0	6.0	11.0
Viscosity at 40 °C	[mm²/s]	min	1.4	2.0	3.0	2.0
Micro Carbon residue at 10 % residue	[% m/m]	max	0.3	0.0	0.3	–
Density at 15 °C	[kg/m³]	max	–	890	890	900
Micro Carbon residue	[% m/m]	max	–	–	–	0.3
Sulfur [a)]	[% m/m]	max	1.0	1.5	1.5	2.0
Water	[% V/V]	max	–	–	–	0.3 [b)]
Total sediment by hot filtration	[% m/m]	max	–	–	–	0.1 [b)]
Ash	[% m/m]	max	0.01	0.01	0.01	0.01
Flash point	[°C]	min	43	60	60	60
Pour point, summer	[°C]	max	–	0	0	6
Pour point, winter	[°C]	max	–	-6	-6	0
Cloud point	[°C]	max	-16	–	–	–
Calculated Cetane Index		min	45	40	40	35
Acid number	[mgKOH/g]	max	0.5	0.5	0.5	0.5
Oxidation stability	[g/m³]	max	25	25	25	25 [c)]
Lubricity, corrected wear scar diameter (wsd 1.4 at 60 °C) [d)]	[µm]	max	520	520	520	520 [c)]
Hydrogen sulfide [e)]	[mg/kg]	max	2.0	2.0	2.0	2.0
Appearance			clear & bright [f)]			[b), c)]

a) A Sulphur limit of 1.00 % m/m applies in the Emission Control Areas designated by the International Maritime Organization. As there may be local variations, the purchaser shall define the maximum Sulphur content according to the relevant statutory requirements, notwithstanding the limits given in this table. / **b)** If the sample is not clear and bright, total sediment by hot filtration and water test shall be required. / **c)** Oxidation stability and lubricity tests are not applicable if the sample is not clear and bright. / **d)** Applicable if Sulphur is less than 0.050% m/m. / **e)** Effective only from 1 July 2012. / **f)** If the sample is dyed and not transparent, water test shall be required. The water content shall not exceed 200 mg/kg (0.02% m/m)

5.1.2 Internal fuel oil system

General

The fuel injectors are utilized to deliver the correct amount of fuel to the cylinders precisely at the moment it is needed.
The diesel fuel supply system must ensure a permanent and clean supply of diesel fuel to the engine internal fuel oil system.
NOTE: In diesel mode operation the ignition fuel system is always active.

Fuel fine filter (duplex filter) DF1 (fitted)

Duplex change over type (mesh size of 25 µm) is fitted on the engine.

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5.1.3 External fuel oil system

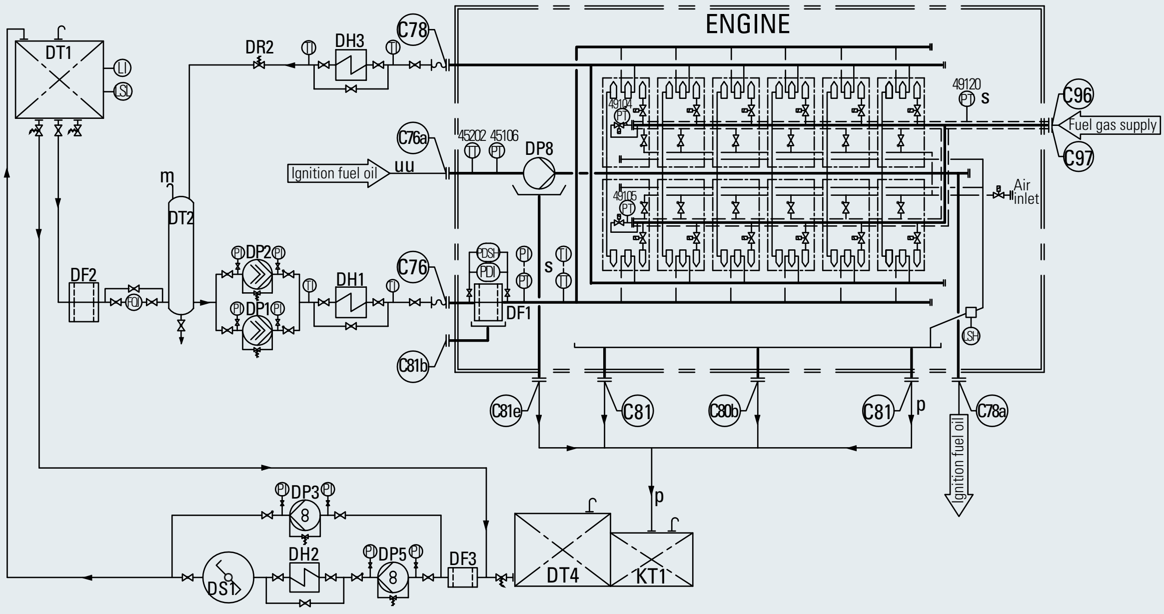


Fig. 5-1 External fuel oil system diagram with intermediate tank

DF1	Fuel fine filter (duplex filter)
DF2	Fuel primary filter (duplex filter)
DH3	Diesel oil cooler
DP1	Diesel oil feed pump
DP2	Diesel oil stand-by feed pump
DP8	Common rail high pressure pump
DR2	Fuel pressure regulating valve
DT1	Diesel oil day tank
DT2	Diesel oil intermediate tank
KT1	Drip fuel tank

C76	Duplex filter, inlet
C76a	Pilot fuel, inlet
C78	Fuel outlet
C78a	Ignition fuel, outlet
C80b	Drip fuel connection (sealing oil injection pump)
C81	Drip fuel connection
C81b	Drip fuel connection
C81e	Drip fuel connection, pilot fuel
C96	Gas inlet
C97	Flushing connection gas pipe (inert gas)

FQI	Flow quantity indicator
LI	Level indicator
LSH	Level switch high
LSL	Level switch low
PDI	Diff. pressure indicator
PDSH	Diff. pressure switch high
PI	Pressure indicator
PT	Pressure transmitter
TI	Temperature indicator
TT	Temperature transmitter (PT100)

m	Lead vent pipe beyond service tank level.
p	Free outlet required.
s	Please refer to the measuring point list regarding design of the monitoring devices.
uu	Only MDO fuel types DMA and DMZ acc. to ISO 8271 are to be used. For usage of DMB or DMX please consult Caterpillar Motoren in advance.

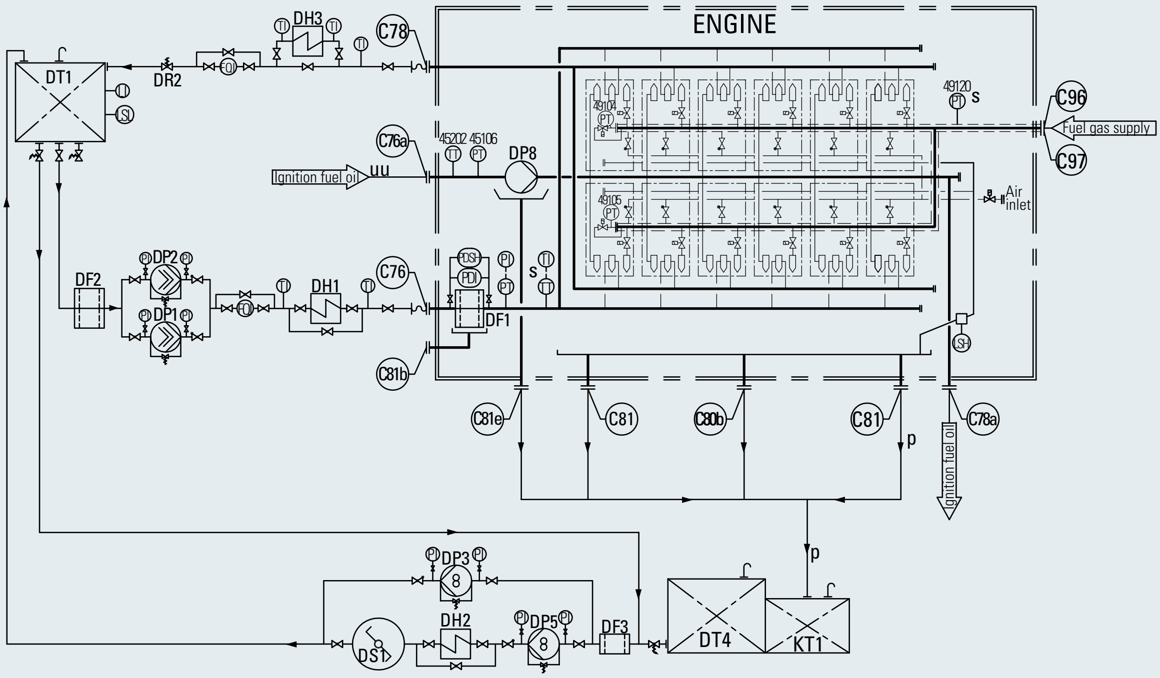


Fig. 5-2 External fuel oil system diagram without intermediate tank

DF1	Fuel fine filter (duplex filter)
DF2	Fuel primary filter (duplex filter)
DH3	Gas oil cooler
DP1	Diesel oil feed pump
DP2	Diesel oil stand-by feed pump
DP8	Common rail high pressure pump
DR2	Fuel pressure regulating valve
DS1	Diesel oil separator
DT1	Diesel oil day tank
DT4	Diesel oil storage tank
KT1	Drip fuel tank
FQI	Flow quantity indicator
LI	Level indicator
LSL	Level switch low
PDI	Diff. pressure indicator
PDSH	Diff. pressure switch high
PI	Pressure indicator
PT	Pressure transmitter
TI	Temperature indicator
TT	Temperature transmitter (PT100)

C76	Duplex filter, inlet
C76a	Pilot fuel, inlet
C78	Fuel outlet
C78a	Ignition fuel, outlet
C80b	Drip fuel connection (sealing oil injection pump)
C81	Drip fuel connection
C81b	Drip fuel connection
C81e	Drip fuel connection, pilot fuel
C96	Gas inlet
C97	Flushing connection gas pipe (inert gas)
p	Free outlet required.
s	Please refer to the measuring point list regarding design of the monitoring devices.
uu	Only MDO fuel types DMA and DMZ acc. to ISO 8271 are to be used. For usage of DMB or DMX please consult Caterpillar Motoren in advance.

General

The design of the fuel oil system may vary from ship to ship, the system itself has to provide sufficient, permanent and clean fuel oil of the required viscosity and pressure to each engine. Fuel storage, treatment, temperature and pressure control as well as sufficient circulation must be ensured.

Diesel oil storage tank DT4

The tank design, sizing and location are according to classification society requirements and based on ship application. No heating is necessary because all marine distillate fuels are suitable for pumping.

Diesel oil separator DS1

Depending on the fuel oil quality a diesel oil separator DS1 is recommended for the use of MGO and required for MDO by Caterpillar Motoren. Any fuel oil must always be considered as contaminated upon delivery and should therefore be thoroughly cleaned to remove solid and liquid contaminants before use.
Most of the solid contaminants in the fuel are rust, sand, dust.
Liquid contaminants are mainly water, i.e. fresh water or salt water.
Impurities in the fuel oil can result in

- damage to fuel injection pumps and injectors,
- increased cylinder liner wear,
- deterioration of the exhaust valve seats
- increased fouling of turbocharger blades.

If a diesel oil separator is installed a total diesel oil separator capacity of 100 % of the full load fuel consumption is recommended.
HT-water or electrical heating is normally used as heating medium.
The nominal capacity should be based on a separation time of 22h/day:

$V_{eff.}[l/h] = 0.28 \cdot P_{eng.}$ [kW]

$V_{eff.}$ = Volume effective [l/h]
$P_{eng.}$ = Power engine [kW]

Diesel oil day tank DT1

The day tank collects clean / treated fuel oil, compensates irregularities in the treatment plant and its standstill periods. Two day tanks are to be provided, each with a capacity according to classification rules. The tank should be provided with a sludge space including a sludge drain valve and an overflow pipe from the MDO/MGO service tank to the settling/storage tank. The level of the tank must ensure a positive static pressure on the suction side of the fuel feed pumps. Usually tank heating is not required.

Fuel primary filter (duplex filter) DF2

The fuel primary filter protects the fuel meter and feed pump from major solids.
A duplex change over type with mesh size of 320 µm is recommended.

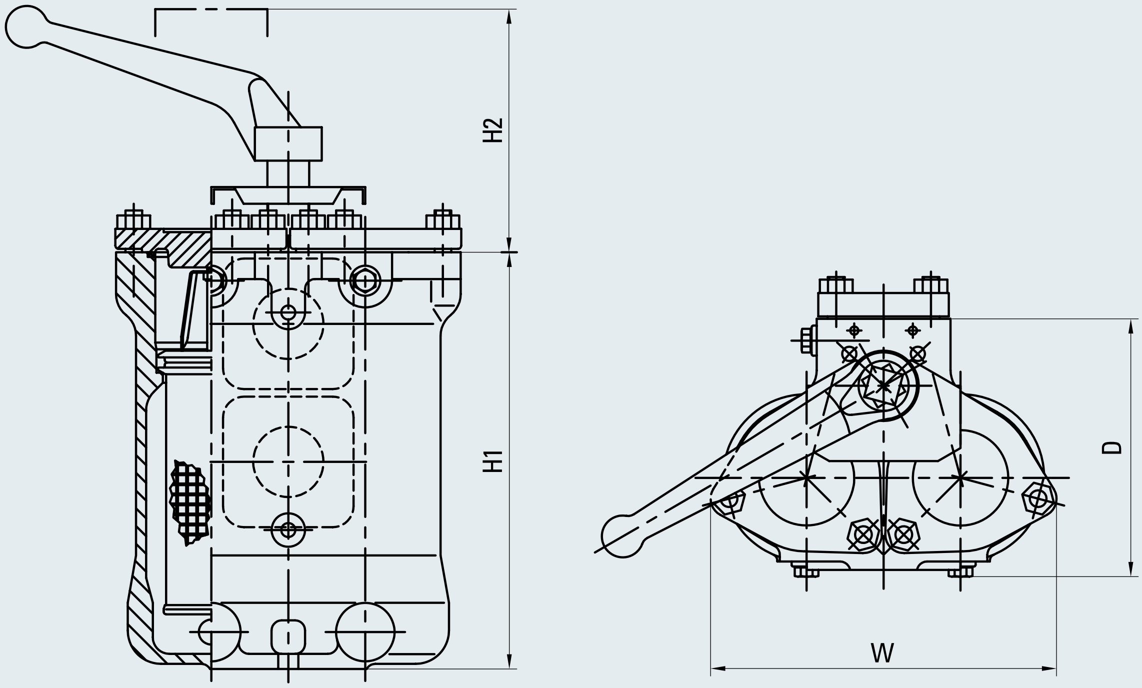


Fig. 5-3 Fuel primary filter DF2

Engine output	DN	Dimensions [mm]			
[kW]		H1	H2	W	D
≤ 20,000	80	690	700	370	430

Flow quantity indicator FQI

One fuel meter is sufficient if the return fuel from the engine is connected to the diesel intermediate tank DT2.
If the fuel return from engine is connected to the day tank, an additional fuel meter in the return line to day tank has to be provided.
A minimum static fuel pressure head of at least 0.2 bar has to be considered. The fuel may be provided by gravity flow from the day tank. The static pressure must exceed the back pressure of the flow meter and prefilter.

Diesel oil intermediate tank DT2

In the intermediate tank DT2 the warm return fuel from the engine mixes with the fuel from the day tank. The tank shall be vented as an open system, with the ventilation line guided to above the day tank level.

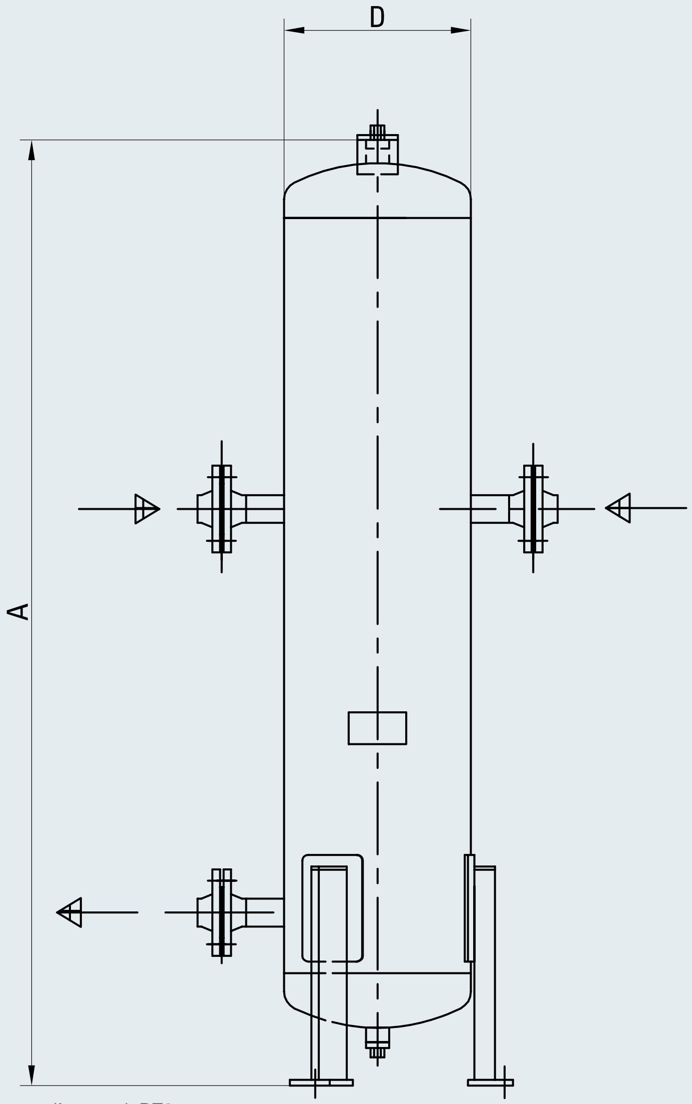


Fig. 5-4 Diesel oil intermediate tank DT2

Plant output	Volume	Dimensions [mm]		Weight
[kW]	l	A	D	[kg]
> 10,000	200	1,700	406	175

Diesel oil preheater DH1 (hot water)

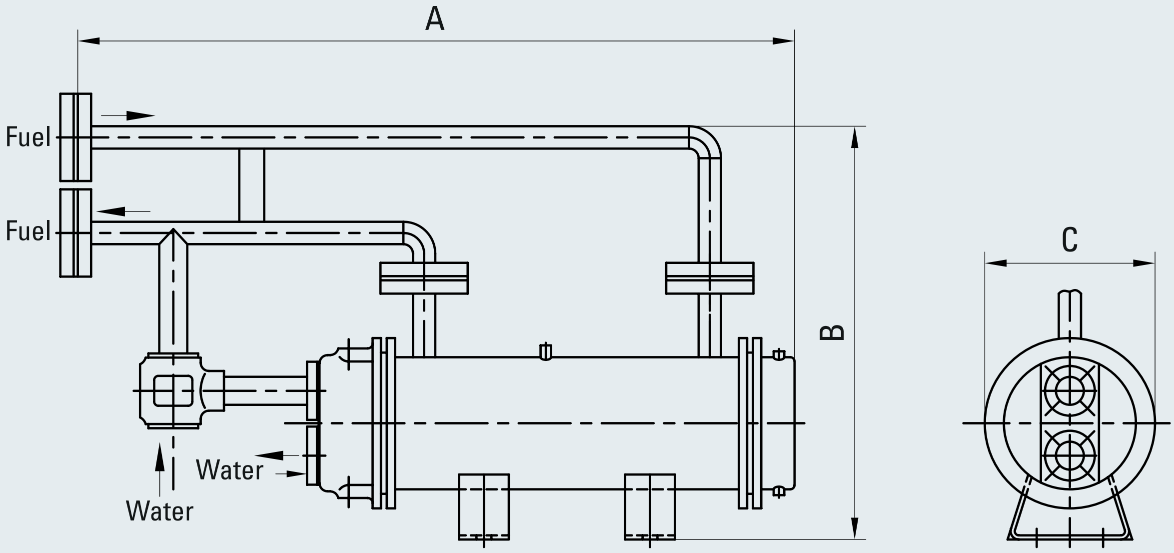


Fig. 5-5 Diesel oil preheater DH1

Engine	Dimensions [mm]		
	A	B	C
12/16 M 46 DF	1,995	655	Ø 270

The capacity of the MDO preheater is to determine on the required fuel temperature up to approx. 50 °C.

Heating capacity: $Q\,[kW] = \frac{P_{eng.}\,[kW]}{166}$

Q = Heating capacity [kW]

$P_{eng.}$ = Power engine [kW]

A diesel oil preheater is not required

- for gas oil operation.
- with preheated day tanks.

Feed pump DP1/DP2 (separate)

The feed pump DP1/DP2 delivers fuel through the filter DF1 to each injection pump.
The feed pump maintains the pressure at the injection pumps and circulates the fuel in the system.
The capacity is slightly oversized to transfer the heat, which occurs during the injection process, away from the fuel injection system.
A positive static pressure is required at the suction side of the pump.
Capacity see technical data.

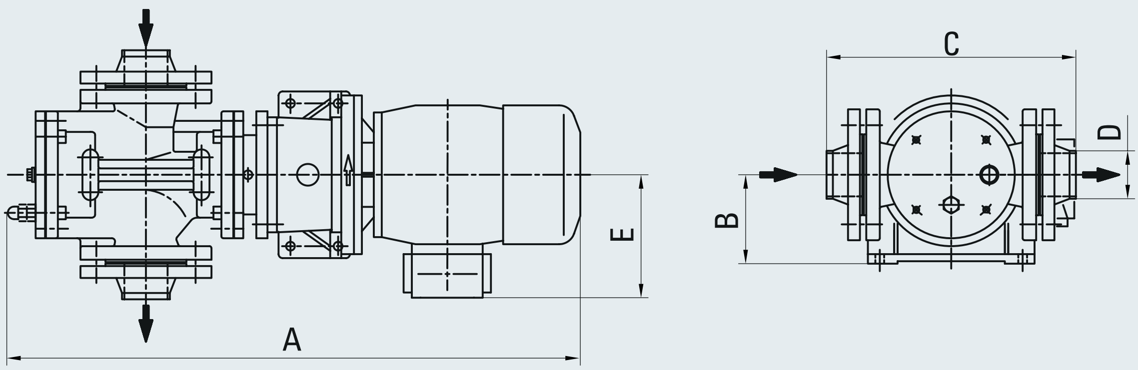


Fig. 5-6 Feed pump DP1/DP2

Engine	Dimensions [mm]					Weight	Voltage / Frequency
	A	B	C	D	E	[kg]	[V/Hz]
12 M 46 DF	940	132	354	88.9	166	92	400/50
12 M 46 DF	940	132	354	88.9	166	92	440/60
16 M 46 DF	980	160	354	88.9	210	126	400/50
16 M 46 DF	980	160	354	88.9	210	126	440/60

Fuel oil cooler DH3

To ensure a fuel oil temperature below 50 °C at any time a cooling of diesel oil may be required.
The need for a fuel cooler is system specific and depends on fuel circuit design and type of fuel oil. In case of more than one engine connected to the same fuel supply system, the MDO-cooler capacity has to be increased accordingly.
The heat transfer load into the diesel oil system is approx. 1.6 kW/cyl.
LT-water is normally used as cooling medium.

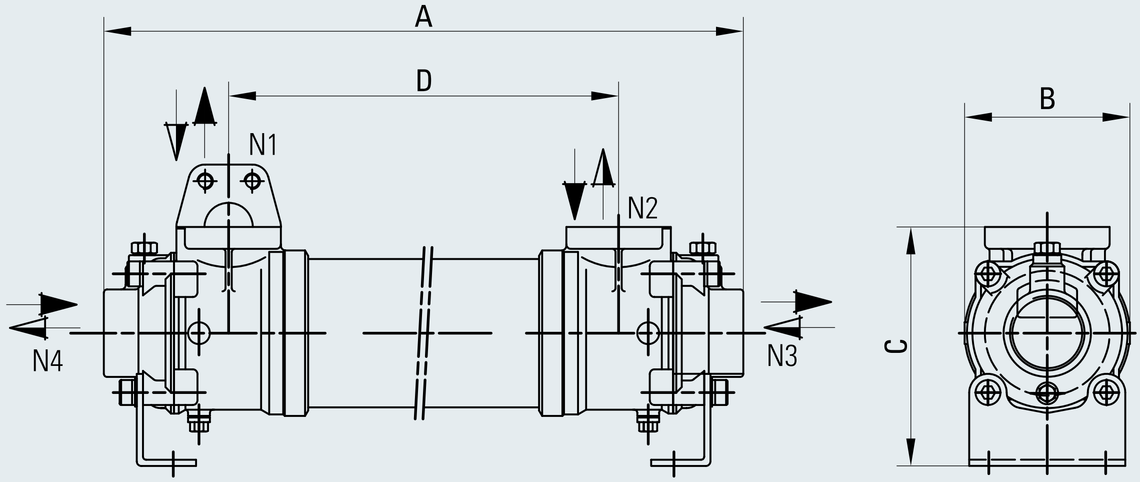


Fig. 5-7 Fuel oil cooler for MDO operation DH3

Engine	Dimensions [mm]						Weight
	A	B	C	D	N1 + N2	N3 + N4	[kg]
12 M 46 DF	1,140	148	225	1,098	DN50	1 ½" BSP	44
16 M 46 DF	1,640	148	225	1,598	DN50	1 ½" BSP	55

Fuel pressure regulating valve DR2

To ensure a sufficient diesel oil pressure at engine inlet, a fuel pressure regulating valve DR2 has to be installed and adjusted during commissioning of the engine.

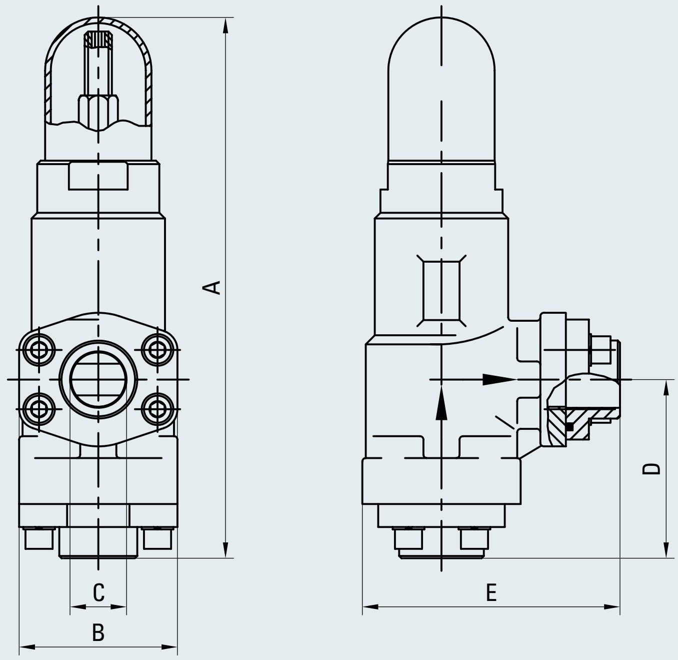


Fig. 5-8 Fuel pressure regulating valve

Plant output	Dimensions [mm]					Weight
[kW]	A	B	C	D	E	[kg]
≤ 16,000	279	94	Ø 38	109	150.5	8.4

01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

5.2 HFO operation

The following section is based on the experiences gained in the operation of heavy fuel installations.
Stable and correct viscosity of the fuel before injection pumps (see technical data) must be maintained at any time. Sufficient circulation through every engine connected to the same circuit must be ensured in all operating conditions.
The fuel treatment system should comprise at least one settling tank and two separators.
Correct dimensioning of HFO separators is of great importance, and therefore the recommendations of the separator manufacturer must be closely followed.
Poorly purified fuel is harmful to the engine. A high content of water may also damage the fuel feed system.
Injection pumps generate pressure pulses into the fuel feed and return piping. The fuel pipes between the feed unit and the engine must be clamped properly to rigid structures. The distance between the fixing points should be at close distance next to the engine. (See chapter piping design, treatment and installation.)

ATTENTION:
In multiple engine installations, where several engines are connected to the same fuel feed circuit, it must be possible to close the fuel supply and return lines connected to the engine individually. (This is a SOLAS requirement.)

NOTE:
It is further stipulated that the means of isolation shall not affect the operation of the other engines, and it shall be possible to close the fuel lines from a position that is not rendered inaccessible due to fire on any of the engines.

In HFO mode operation the ignition fuel system is always active.

Fuel oil system

A pressurized fuel oil system, as shown in Fig. 5-13, is necessary when operating on high viscosity fuels. When using high viscosity fuels requiring high preheating temperatures, the fuel oil from the engine fuel oil system to the return line will also have a relatively high temperature. The fuel oil pressure measured on the engine (at fuel pump level) should be about 5 bar. This maintains a pressure margin against gasification and cavitation in the fuel system, even at 150 °C preheating.
In order to ensure correct atomization, the fuel oil temperature must be adjusted according to the specific fuel oil viscosity used. An inadequate temperature can influence the combustion and could cause increased wear on cylinder liners and piston rings, as well as deterioration of the exhaust valve seats.
A too low heating temperature, i.e. too high viscosity, could also result in excessive fuel consumption.
Therefore, optimum injection viscosity of 10 – 12 cSt must be maintained at any rate and with all fuel grades.
Deviations from design recommendations are possible, however, they should be discussed with Caterpillar Motoren.
Trace heating for all heavy fuel pipes is recommended.

Viscosity temperature sheet

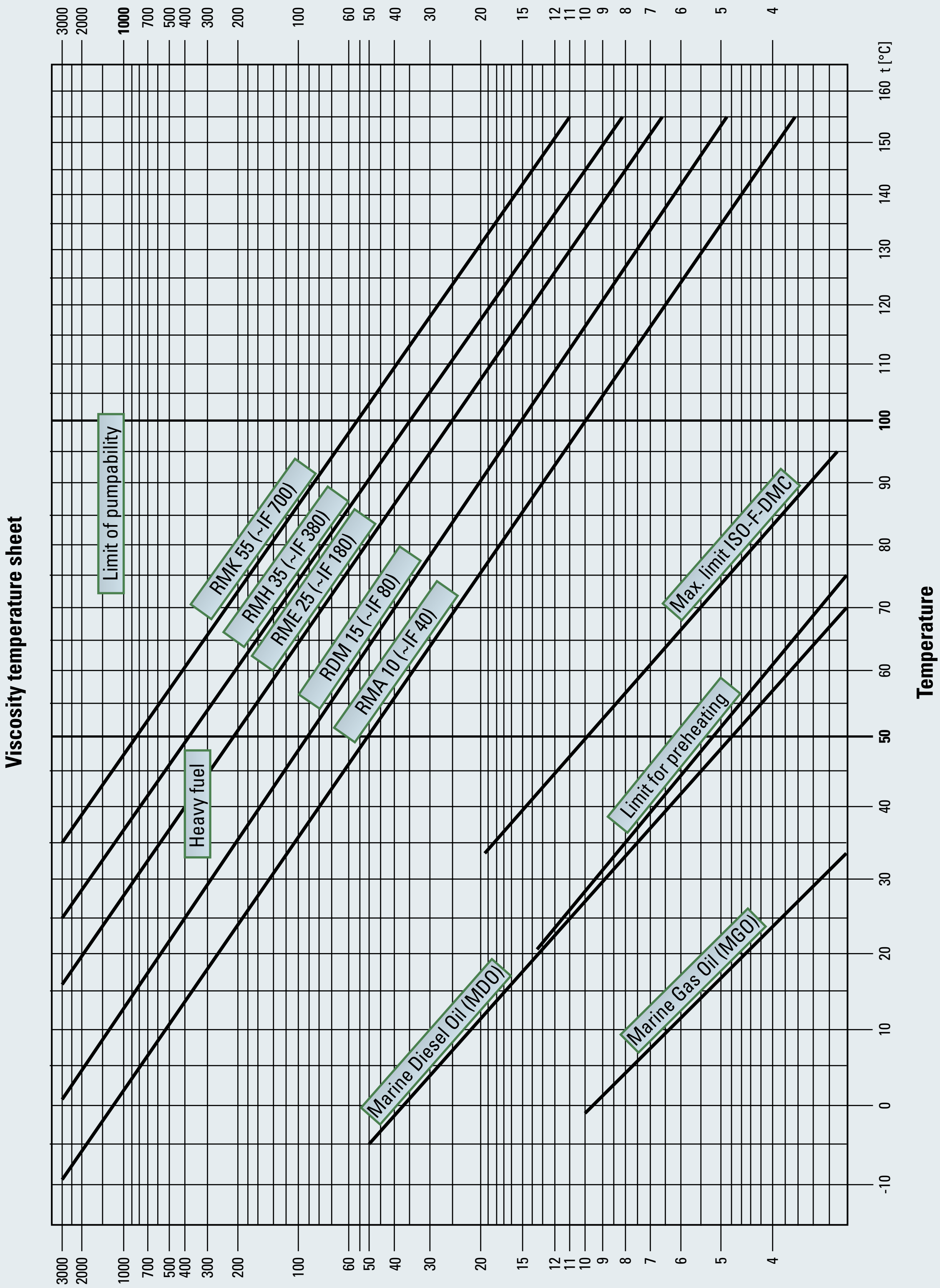


Fig. 5-9 Viscosity / temperature diagram

5.2.1 CIMAC – Requirements for residual fuels for diesel engines (as delivered)

- Fuel shall be free of used lube oil.
- Requirements for residual fuels for diesel engines please see table next page.

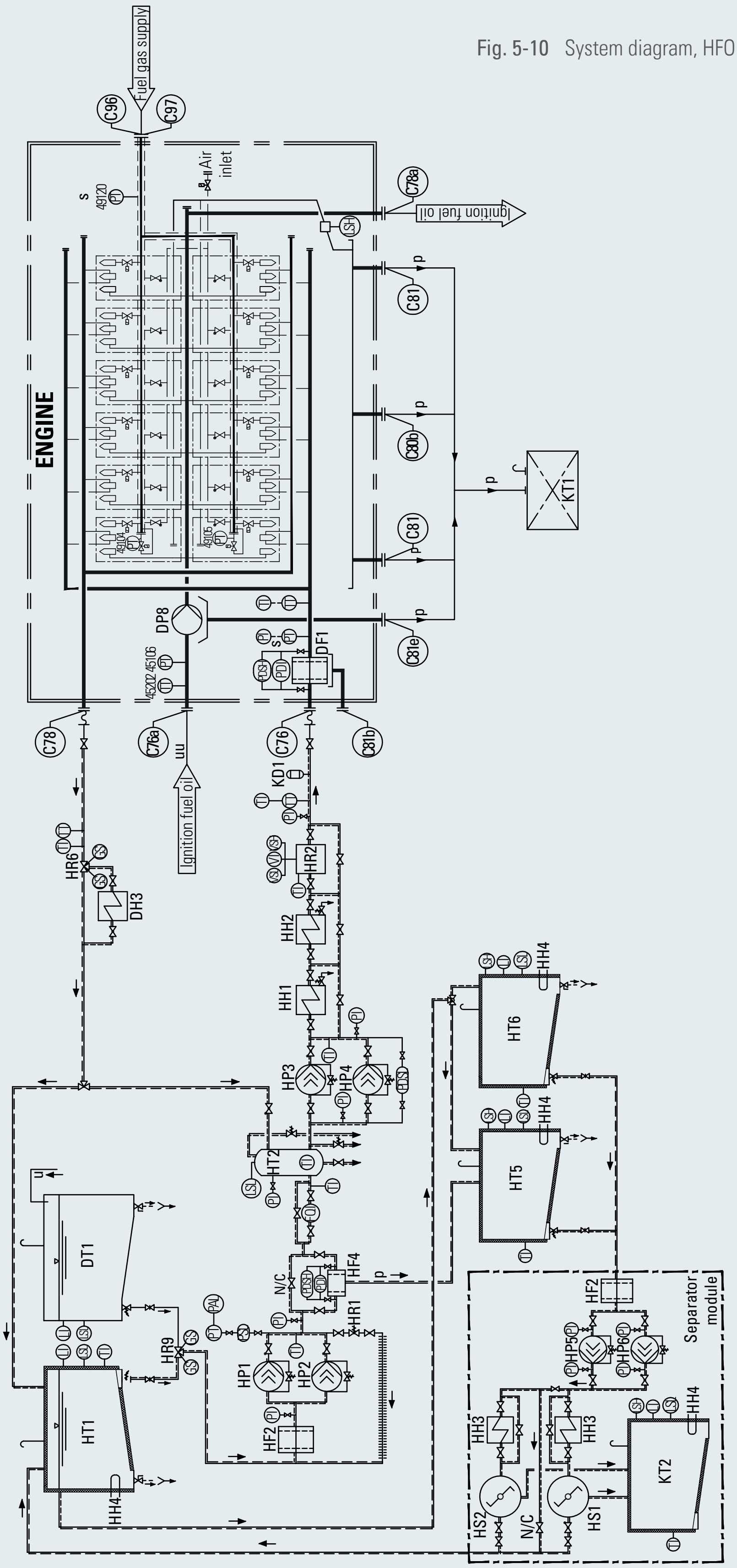
Characteristic	Designation		CIMAC A10	CIMAC B10	CIMAC C10	CIMAC D15	CIMAC E25	CIMAC F25	CIMAC G35	CIMAC H35	CIMAC K35	CIMAC H45	CIMAC K45	CIMAC H55	CIMAC K55
	Related to ISO8217 (12) F-		RMA 30	RMB 30	RMC 30	RMD 80	RME 180	RMF 180	RMG 380	RMH 380	RMK 380	RMH 500	RMK 500	RMH 700	RMK 700
	Dim.	Limit													
Density at 15°C	kg/m³	max	950 2)	975 3)		980 4)	991		991		1,010	991	1,010	991	1,010
Kin. viscosity at 100°C	cSt. 1)	max	10			15	25		35			45		55	
Kin. viscosity at 100°C	cSt. 1)	min	6 5)				15 5)								
Flash point	°C	min	60			60	60		60			60		60	
Pour point winter	°C	max	0												
Pour point summer	°C	max.	6		24	30	30		30			30		30	
Carbon residue	% (m/m)	max	12 6)		14	14	15	20	18	22		22		22	
Ash	% (m/m)	max	0.10			0.10	0.10	0.15	0.15	0.15		0.15		0.15	
Total sedim. after ageing	% (m/m)	max	0.10			0.10	0.10		0.10			0.10		0.10	
Water	% (V/V)	max	0.5			0.5	0.5		0.5			0.5		0.5	
Sulphur	% (m/m)	max	3.5			3.5	3.5		3.5			3.5		3.5	
Vanadium	mg/kg	max	150		300	150	150	500	350	350	450	450		450	
Aluminum + Silicon	mg/kg	max	40			40	50		60			60		60	
Zink	mg/kg	max	15			15	15		15			15		15	
Phosphor	mg/kg	max	15			15	15		15			15		15	
Calcium	mg/kg	max	30			30	30		30			30		30	

1) An indication of the approximate equivalents in kinematic viscosity at 50°C and Redw. I sec 100°F is given below:

Kinematic viscosity at 100°C [mm²/s] (cSt.)	7	10	15	25	35	45	55
Kinematic viscosity at 50°C [mm²/s] (cSt.)	30	40	80	180	380	500	700
Kinematic viscosity at 100°F Redw. [I sec.]	200	300	600	1,500	3,000	5,000	7,000

2) ISO: 960 / **3)** ISO: 960 / **4)** ISO: 975 / **5)** ISO: not limited / **6)** ISO: carbon residue 10

Fig. 5-10 System diagram, HFO operation



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General

For location, dimensions and design (e.g. flexible connection) of the disconnecting points see engine installation drawing.
No valve fittings with loose cone must be installed by the shipyard in admission and return lines.

DF1	Fuel fine filter (Duplex filter)
DH3	Gas oil cooler
DP8	Common rail high pressure pump
DT1	Diesel oil day tank
HF2	Primary filter (duplex filter)
HF4	Self cleaning filter
HH1	Heavy fuel final preheater
HH2	Stand-by final preheater
HH3	Heavy fuel preheater (separator)
HH4	Heating coil
HP1	Fuel pressure pump
HP2	Fuel stand-by pressure pump
HP3	Fuel circulating pump
HP4	Stand-by circulating pump
HP5/6	Heavy fuel transfer pump (separator)
HR1	Fuel pressure regulating valve
HR2	Viscosimeter
HR6	Change over valve
HR9	Fuel change over main valve
HS1/2	Heavy fuel separator
HT1	Heavy fuel day tank
HT2	Mixing tank
HT5/6	Settling tank
KD1	Pressure absorber
KT1	Drip fuel tank
KT2	Sludge tank

FQI	Flow quantity indicator
GS	Limit switch
LI	Level indicator
LSH	Level switch high
LSL	Level switch low
PAL	Pressure alarm low
PDI	Diff. pressure indicator
PDSH	Diff. pressure switch high
PDSL	Diff. pressure switch low
PI	Pressure indicator
PSL	Pressure switch low
PT	Pressure temp.
TI	Temperature indicator
TT	Temperature transmitter (PT100)
VI	Viscosity indicator
VSH	Viscosity control switch high
VSL	Viscosity control switch low

C76	Duplex filter, inlet
C76a	Pilot fuel, inlet
C78	Fuel outlet
C78a	Ignition fuel, oulet
C80b	Drip fuel connection (sealing oil injection pump)
C81	Drip fuel connection
C81b	Drip fuel connection
C81e	Drip fuel connection, pilot fuel
C96	Gas inlet
C97	Flushing connection gas pipe (inertgas)

All heavy fuel pipes have to be insulated.

------	Heated pipe
‖‖‖‖‖‖‖	Fintube heat exchanger

p	Free outlet required
s	Please refer to the measuring point list regarding design of the monitoring devices.
u	Fuel from separator or from transfer pump
uu	Only MDO fuel types DMA and DMZ acc. to ISO 8271 are to be used. For usage of DMB or DMX please consult Caterpillar Motoren in advance.

Storage tanks

The tank design, sizing and location must comply with classification society requirements and are based on ship application.
Heating coils are necessary and are to be designed so that the HFO temperature is at least 10K above the pour point to ensure a pumping viscosity below 1,000 cSt.
Heating is possible by steam, thermal oil, electrical current or hot water.

Settling tanks HT5, HT6

The tank design, sizing, location must comply with classification society requirements and are based on ship application. Two settling tanks are to be provided.
Its function is to remove water and solids by gravity due to higher fuel oil temperature and reduced turbulences. Provide constant oil temperature and avoid interruption of treatment system, due to overflow from HFO day tank.Thermal insulation of the settling tanks is recommended to avoid heat losses.

In order to ensure a sufficient settling effect, the following settling tank designs are permitted:

- 2 settling tanks, each with a capacity sufficient for 24 hours full load operation of all consumers or
- 1 settling tank with a capacity sufficient for 36 hours full load operation of all consumers and automatic filling

Settling tank temperature shall be 70 - 80 °C; the charging level shall be 70 - 90 %.

Heavy fuel preheater (separator) HH3

Heavy fuel oil needs to be heated up to a certain temperature before separating.
The most common heaters on board of ships are steam heaters. Other fluid heating sources are hot water, thermal oil or electrical heaters. Overheating of the fuel may cause fuel cracking. Thus the maximum electric load on the heater element should not exceed 1 Watt/cm².
In a cleaning system for HFO the usual processing temperature is 98 °C.
The separator manufacturer's guidelines have to be observed.

Heavy fuel transfer pumps (separator) HP5, HP6

The separator feed pumps shall be installed as close as possible to the settling tanks.
The separator manufacturer's guidelines have to be observed.

Heavy fuel separators HS1, HS2

Any fuel oils whether heavy fuel oil, diesel oil or crude oil must always be considered as contaminated upon delivery and should therefore be thoroughly cleaned before use.
Therefore self-cleaning types should be selected.
The purpose of any fuel treatment system is to clean the fuel oil by removal of water, solids, and suspended matter to protect the engine from excessive wear and corrosion.
Liquid contaminants are mainly water, i.e. either fresh water or salt water.
Impurities in the fuel can cause damage to fuel injection pumps and injectors, and can result in increased cylinder liner wear and deterioration of the exhaust valve seats as well as increased fouling of turbocharger blades.
Two separators with independent electrically driven pumps must be provided.

Separator sizing:

The correct sizing of the separators is based on the max. fuel oil consumption at maximum continuous rating (MCR) of the engines. The following formula can be used:
(The fuel consumption of auxiliary engines and boilers, if there are any, must be included)

$V_{eff.} = 0.28\ P\ (l/h)$

$V_{eff.}$ = Volume effective [l/h]
$P_{eng.}$ = Power engine [kW]

The cleaning capacity of the separator must always be higher than the entire fuel consumption of the plant, incl. aux. equipment.

ATTENTION:
The separator outlet pressure is limited, so the pressure in the pipe line between separator outlet and day tank must be observed carefully. Follow the separator manufacturer's guidelines.

Heavy fuel day tank HT1

The tank design, sizing and location must comply with classification society requirements based on ship application. Two day tanks are to be provided. Each day tank capacity must be designed for full load operation of all consumers according to classification requirements. An overflow system into the settling tanks is required.HFO day tanks shall be provided with heating coils and sufficient insulation.
Heating is possible by steam, thermal oil or hot water. The day tank temperature shall be above 90 °C.

5.2.2 Fuel booster and supply system

The booster system shall provide a pre-pressure to the mixing tank of approx. 4 - 5 bar. The circulating system provides sufficient flow of the required viscosity to the injection pumps. The circulation flow rate is typically 3.5 - 4 times the fuel consumption at MCR to prevent overheating of the fuel injection system and thus avoiding evaporation in the injection pumps.

Fuel change over main valve HR9

A manually operated three-way valve for changing over from MDO/MGO to HFO operation and back to MDO/MGO equipped with limit switches is necessary.

Primary filter (duplex filter) HF2

A protection strainer with a mesh size 320 µm has to be installed before fuel pressure pumps to prevent any large particles entering the pump.

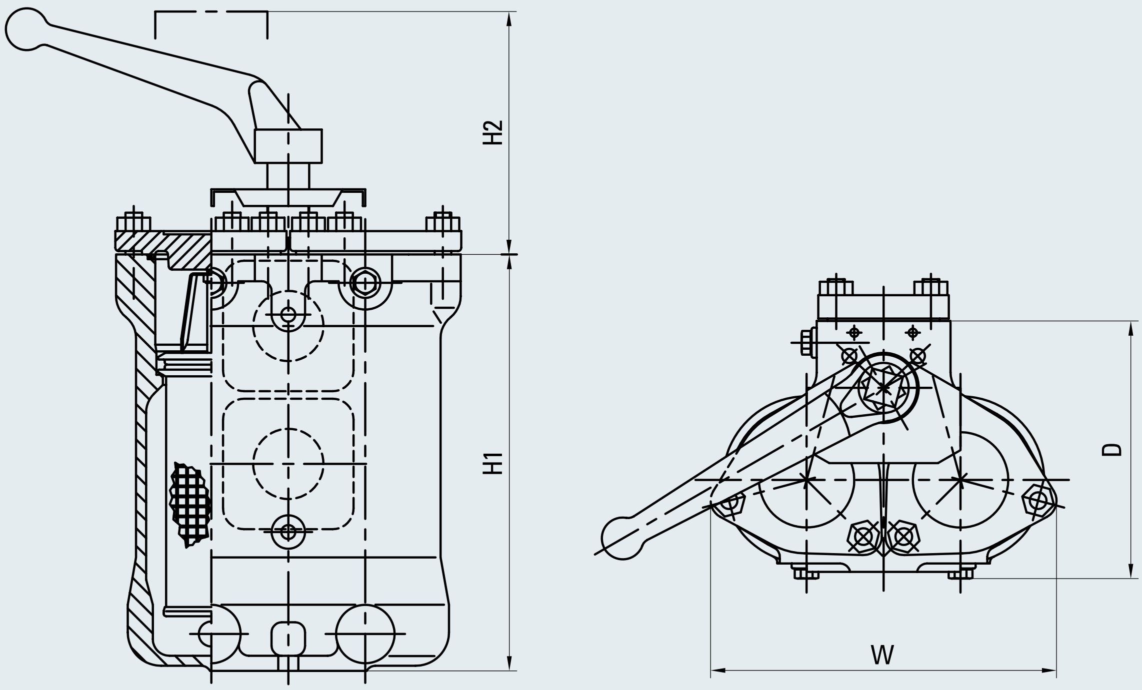

Fig. 5-11 Primary filter HF2

Engine output [kW]	DN	Dimensions [mm]			
		H1	H2	W	D
≤ 10,000	40	330	300	250	210
≤ 20,000	65	523	480	260	355
> 20,000	80	690	700	370	430

Fuel pressure pump HP1, fuel stand-by pressure pump HP2

Two supply pumps in parallel are recommended, one in operation and one on stand-by.
The capacity of the pump must be sufficient to prevent pressure drop during flushing of the automatic filter.
A suction strainer with a mesh size of 320 µm should be installed before each pump.

- Screw type pump with mechanical seal.
- Vertical or horizontal installation is possible.
- Delivery head 5 bar.

Capacity $V\,[m^3/h] = 0.4 \cdot \frac{P_{eng.} \cdot [kW]}{1{,}000}$

V = Volume [m³/h]
$P_{eng.}$ = Power engine [kW]

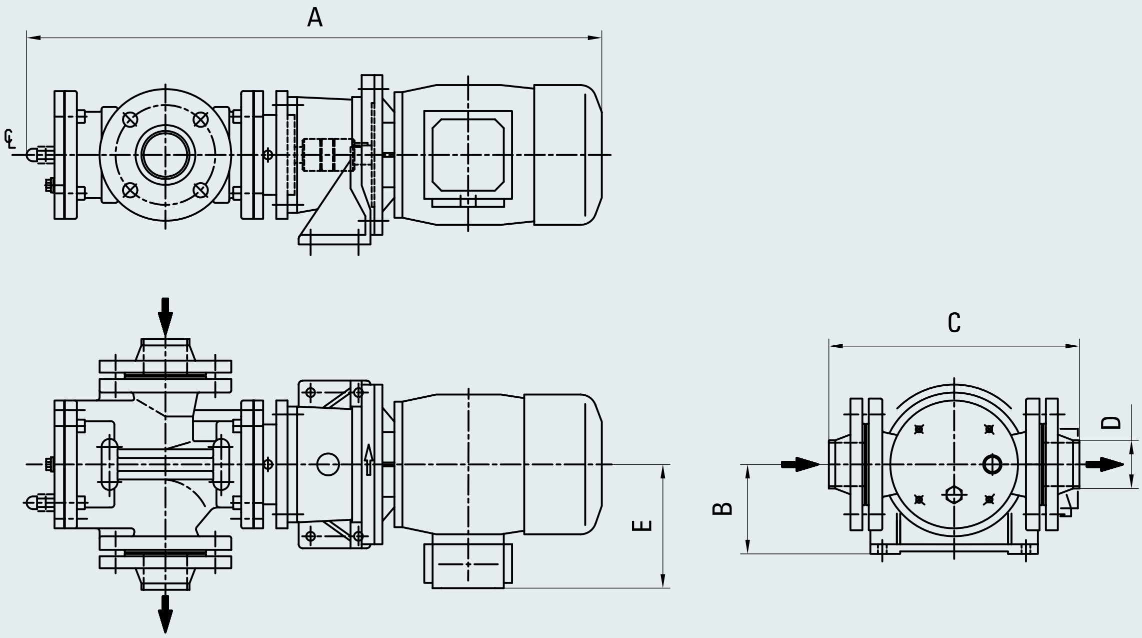

Fig. 5-12 Fuel pressure pump HP1; fuel stand-by pressure pump HP2

Plant output	Dimensions [mm]					Weight	Voltage / frequency
[kW]	A	B	C	D	E	[kg]	[V/Hz]
10,800 - 11,580	805	132	314	60.3	180	72	400/50
14,400 - 15,440	980	160	354	88.9	210	124	400/50

Plant output	Dimensions [mm]					Weight	Voltage / frequency
[kW]	A	B	C	D	E	[kg]	[V/Hz]
10,800 - 11,580	805	132	314	60.3	180	70	440/60
14,400 - 15,440	820	132	314	60.3	180	80	440/60

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Fuel pressure regulating valve HR1

This valve is installed for adjusting a constant and sufficient pressure at engine fuel inlet. Due to the overcapacity of the pressure pumps HP1/HP2 the valve provides a nearly constant pressure under all operating conditions - from engine stop to maximum engine consumption. For MDO/MGO operation the pipes of the fuel return line must be equipped with sufficient fincoolers to reduce the generated heat.

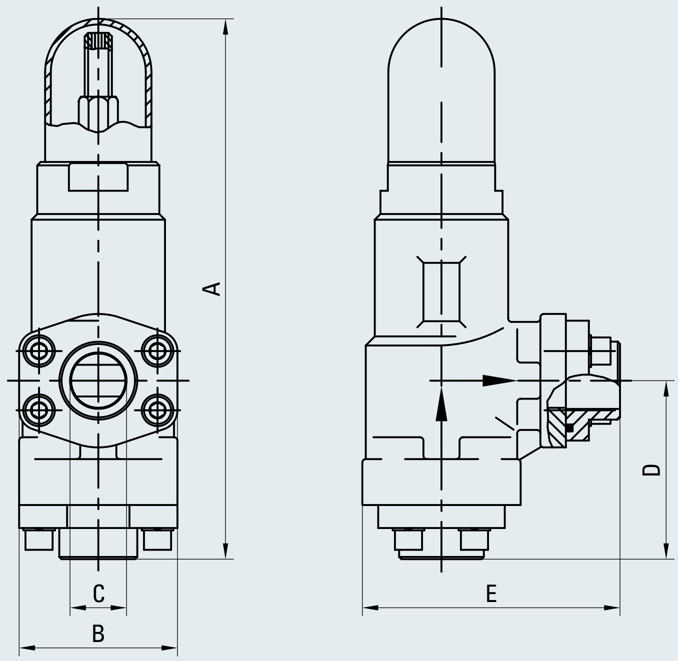

Fig 5-13 Fuel pressure regulating valve

Plant output	Dimensions [mm]					Weight
[kW]	A	B	C	D	E	[kg]
≤ 8,400	248	70	Ø 25	88	122.5	3.6
≤ 32,000	279	94	Ø 38	109	150.5	8.4

HFO automatic filter HF4

An automatic filter with a mesh size 10 µm (absolute) is required to remove cat fines from the fuel oil. The filter is installed between day tank and mixing tank.

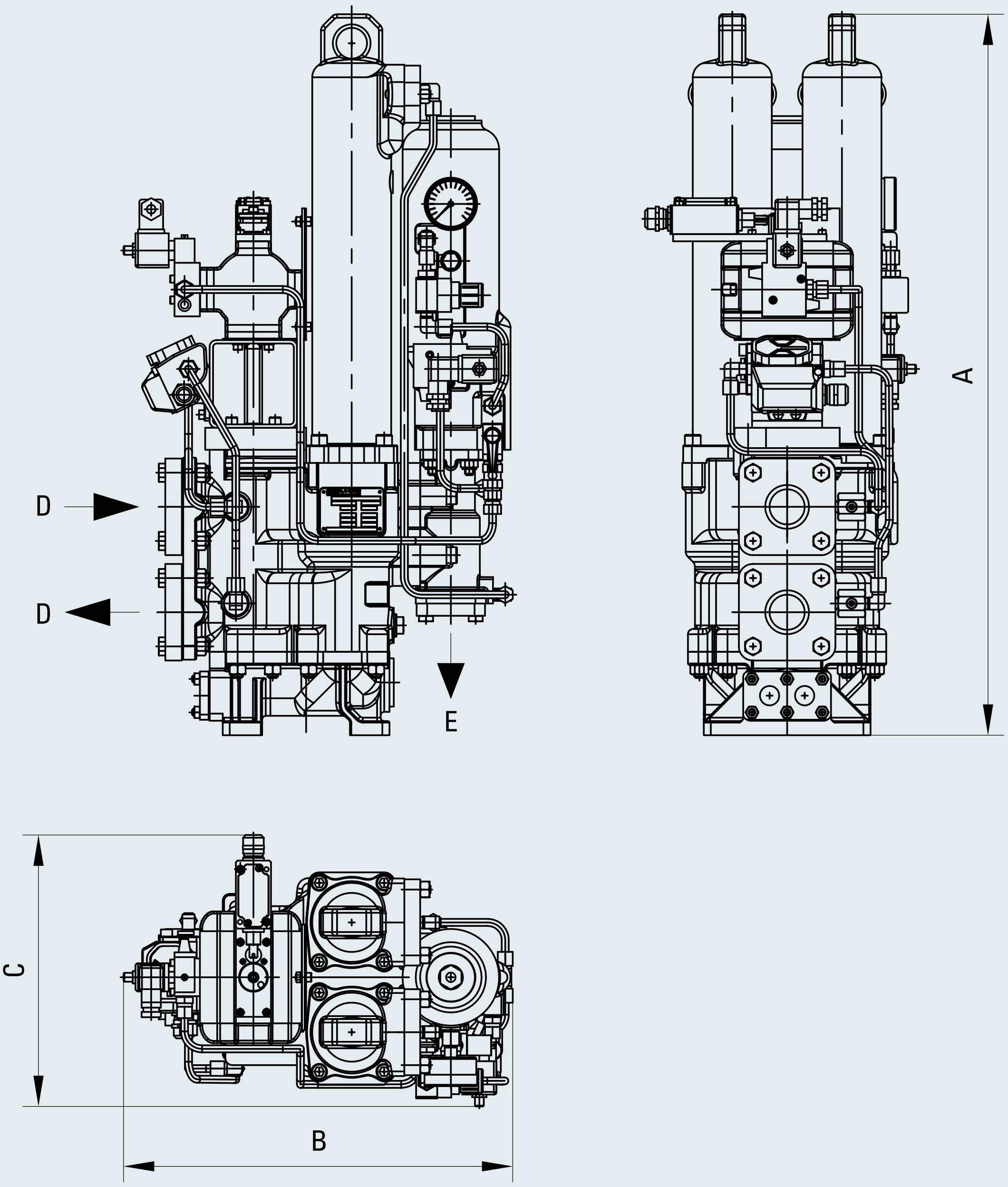

Fig. 5-14 HFO automatic filter HF4

Plant output	Dimensions [mm]				
[kW]	A	B	C	D	E
≤ 12,000	890	520	335	DN 65	DN 50
≤ 19,800	975	590	410	DN 80	DN 65

Flow quantity indicator FQ1

The fuel meter has to be installed between feed pumps and mixing tank HT2.
Independent fuel consumption measurements for individual engines can be provided by installing two flow meters per engine, one at the feed line and one at the return line.

Mixing tank HT2

The mixing tank acts as a buffer for fuel viscosity and/or fuel temperature, when changing over from HFO to diesel oil and vice versa. In the mixing tank the warm return fuel from the engine is mixed with the fuel delivered from the day tank.
Venting to the day tank is required, if level switch is activated, due to accumulated air or gases in the mixing tank.

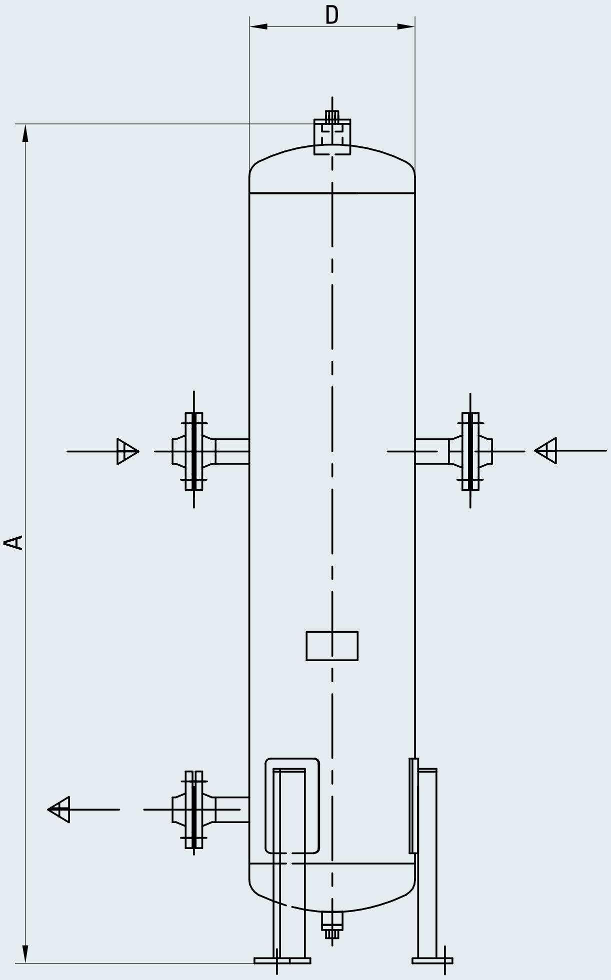

Fig. 5-15 Mixing tank HT2

Plant output	Volume	Dimensions [mm]		Weight
[kW]	[l]	A	D	[kg]
> 10,000	200	1,700	406	175

Fuel circulating pump HP3, stand-by circulating pump HP4

Two fuel circulating pumps in parallel are recommended, one in operation and one on stand-by.
The circulating pumps maintain the required fuel circulation through the engine's fuel injection system.

- Screw type pump with mechanical seal
- Vertical or horizontal installation is possible
- Delivery head 5 bar

Capacity $V\,[m^3/h] = 0.7 \cdot \frac{P_{eng.} \cdot [kW]}{1{,}000}$

$V =$ Volume [m³/h]
$P_{eng.} =$ Power engine [kW]

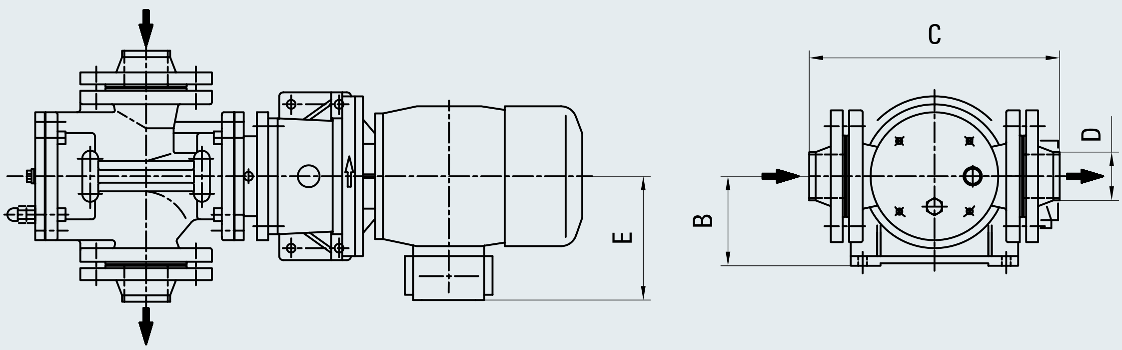

Fig. 5-16 Fuel circulating pump HP3, Stand-by circulating pump HP4

Plant output	Dimensions [mm]					Weight	Voltage / frequency
[kW]	A	B	C	D	E	[kg]	[V/Hz]
10,800 - 11,580	980	160	354	88.9	210	124	400/50
14,400 - 15,440	1,020	160	354	88.9	210	139	400/50

Plant output	Dimensions [mm]					Weight	Voltage / frequency
[kW]	A	B	C	D	E	[kg]	[V/Hz]
10,800 - 15,440	980	160	354	8.9	210	124	440/60

Heavy fuel final preheater HH1, stand-by final preheater HH2

The capacity of the final preheater shall be determined based on the injection temperature at the nozzle, to which 4 K must be added to compensate for heat losses in the piping.
The piping for both heaters shall be arranged for separate and series operation.
Parallel operation with half the flow must be avoided due to the risk of sludge deposits.
The arrangement of only one preheater may be approved where it is ensured that the operation with fuel oil which does not need preheating can be temporarily maintained.
NOTE:
Safe return to port requirement, maneuverability must be ensured.

- Two mutually independent final preheaters have to be installed.
- The arrangement of only one preheater may be approved where it is ensured that the operation with fuel oil which does not need preheating can be temporarily maintained.

Heating media:

- Electric current (max. surface power density 1.1 W/cm²)
- Steam
- Thermal oil

Temperature at engine inlet max. 150 °C

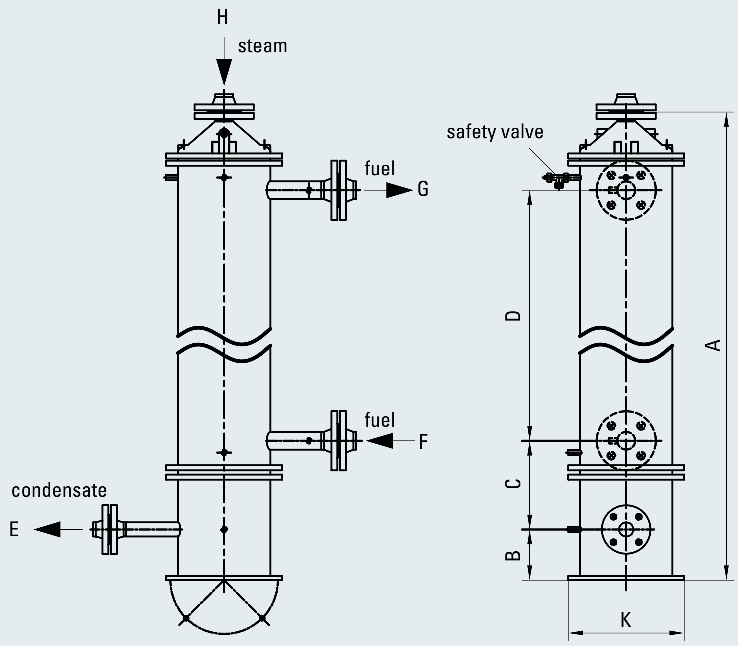

Fig. 5-17 Heavy fuel final preheater HH1, stand-by final preheater HH2 (steam heated)

Plant output	Dimensions [mm]									Weight
[kW]	A	B	C	D	E	F	G	H	K	[kg]
up to 14,000	1,630	130	235	1,035	DN 40	DN 50	DN 50	DN 50	Ø 390	265
up to 21,000	2,170	130	235	1,555	DN 40	DN 65	DN 65	DN 50	Ø 390	339

Viscosimeter HR2

The viscosimeter is regulating in conjunction with the final preheater the required fuel injection viscosity. This device automatically regulates the heating of the final preheater depending on the viscosity of the bunkered fuel oil, so that the fuel will reach the nozzles with the viscosity required for injection.

Pressure absorber KD1 (optional)

During the injection phases of fuel from the supply line, compression and injection as well as the release of unused fuel into the return line, cyclic pressure pulsations may result. The requirement of installing fuel dampers in the external pipe system depends on the design of the external fuel pipe work and its ability to absorb such pulsations sufficiently. Just in case of enhanced damping requirements additional dampers have to be installed.

Bypass overflow valve HV (optional)

If more than one engine is connected to the fuel booster and supply system a bypass overflow valve between the feed line and the return line can be required.
It serves to secure and stabilize the pressure in the fuel feed line under all circumstances and operation conditions.
The overflow valve must be differential pressure operated.
The opening differential pressure should be 2 bar.

Duplex filter HF1 (fitted)

The fuel duplex filter is installed at the engine.
The two filter chamber construction allows continuous operation without any shut downs for cleaning the filter elements.
The drain connection of the filter is provided with a valve and must be routed to the leak oil tank.
If the filter elements are removed for cleaning, the filter chamber must be emptied. This prevents the dirt particles remaining in the filter casing from migrating to the clean oil side of the filter.

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Fuel oil cooler DH3

To ensure a fuel oil temp. below 50 °C a cooling of diesel oil may be required.
The need for fuel cooler is system specific and depends on fuel circuit design and type of fuel oil.
In case of more than one engine are connected to the same fuel supply system, the MDO-cooler capacity has to be increased accordingly. The diesel oil coolers are always installed in the fuel return line (engine connection C78). The heat transfer load into the diesel oil system is approx. 1.6 kW/cyl.
LT-water is normally used as cooling medium.

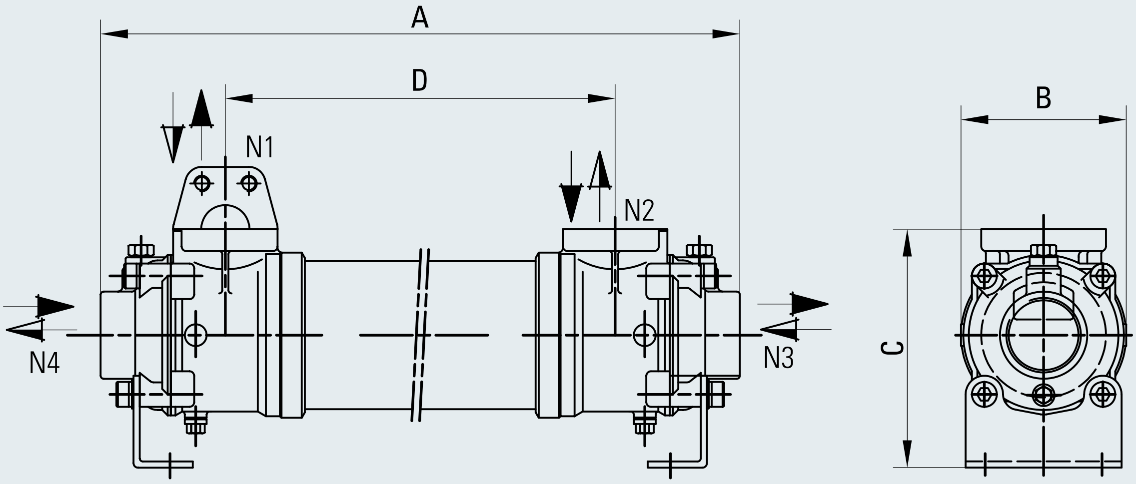

Fig. 5-18 Fuel oil cooler for MDO operation DH3

Engine	Dimensions [mm]						Weight
	A	B	C	D	N1 + N2	N3 + N4	[kg]
12 M 46 DF	1,140	148	225	1,098	DN50	1 ½" BSP	44
16 M 46 DF	1,640	148	225	1,598	DN50	1 ½" BSP	55

5.2.3 Fuel booster and supply module

A complete fuel conditioning module, designed for HFO up to 700 cSt / 50 °C, can be supplied.

Caterpillar Motoren standard modules consist of the following components

- Three-way change over valve
- Booster pumps
- Automatic filter
- Pressure regulating valve
- Fuel flow meter
- Mixing tank
- Circulating pumps
- Fuel preheater (steam, thermal oil or electric)
- Viscosity control
- Diesel oil cooler
- Control cabinet
- Alarm panel

Built on one frame, they include all piping, wiring and trace heating.

01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

Module controlled automatically with alarms and starters

- Pressure pump starters with stand-by automatic
- Circulating pump starters with stand-by automatic
- PI-controller for viscosity controlling
- Starter for the viscosimeter
- Analog output signal 4 - 20 mA for viscosity

Alarms

- Pressure pump stand-by start
- Low level in the mixing tank
- Circulating pump stand-by start
- Self-cleaning fine filter clogged
- Viscosity alarm high/low
- The alarms with potential free contacts
- Alarm cabinet with alarms to engine control room and connection interface for remote start/stop and
- indicating lamp of fuel pressure and circulating pumps

Size, weight and dimensions

The whole module is tubed and cabled up to the terminal strips in the electric switch boxes which are installed on the module. All necessary components like valves, pressure switches, thermometers, gauges etc. are included. The fuel oil pipes are equipped with trace heating (steam, thermal oil or electrical) where necessary.

NOTE:
The module will be tested hydrostatical and functional in the workshop without heating and not connected to the engine.

Fuel oil standard module

Module size	Capacity [kW]	Module size (LxWxH) [mm]	Module weight [kg]
Size 7	≤ 11,600	2,600 x 1,400 x 2,100	3,400
Size 8	≤ 13,100	3,600 x 1,400 x 2,100	3,400
Size 9	≤ 15,900	4,200 x 1,600 x 2,100	3,800
Size 10	≤ 19,800	5,000 x 1,700 x 2,100	4,600
Size 11	≤ 26,000	6,000 x 2,000 x 2,100	5,600
Size 12	≤ 31,000	8,000 x 2,500 x 2,500	6,600

NOTE:
Customized modules are possible on request.

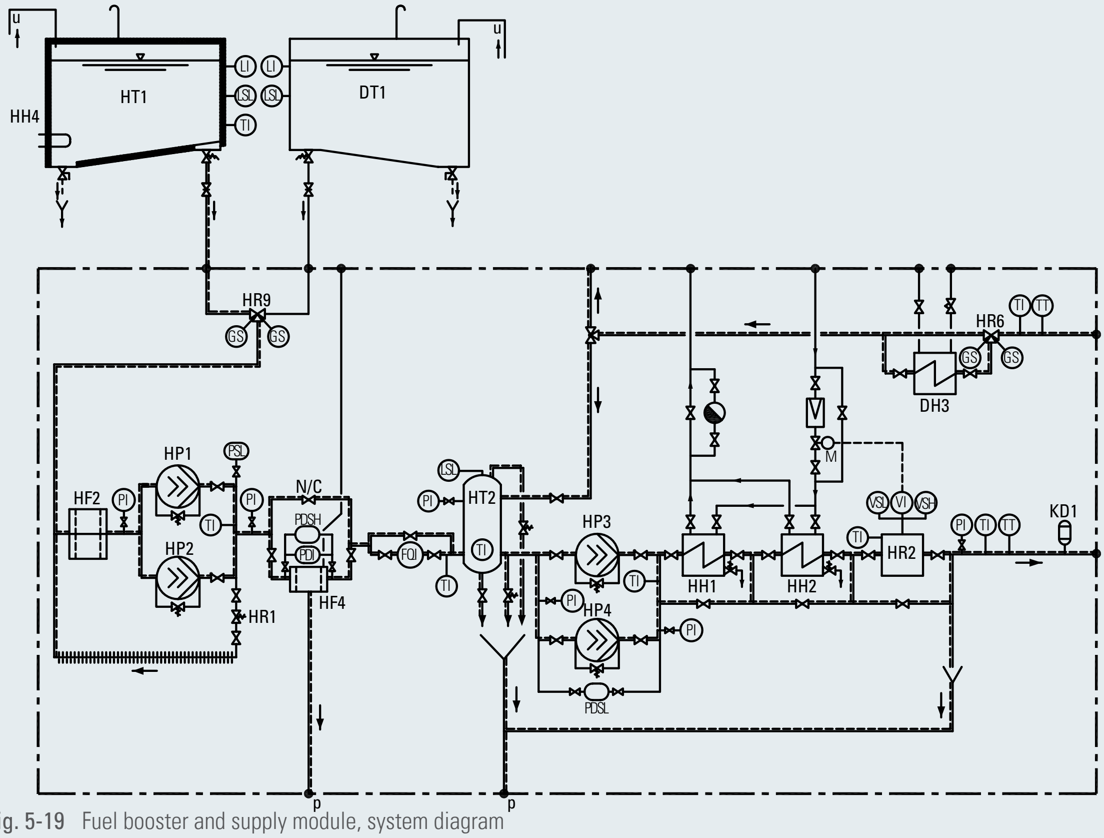

Fig. 5-19 Fuel booster and supply module, system diagram

DH3	Fuel oil cooler for MDO operation	KD1	Pressure absorber
DT1	Diesel oil day tank	FQI	Flow quantity indicator
HF2	Primary filter (duplex filter)	GS	Limit switch
HF4	HFO automatic filter	LI	Level indicator
HH1	Heavy fuel final preheater	LSL	Level switch low
HH2	Stand-by final preheater	PDI	Diff. pressure indicator
HH4	Heating coil	PDSH	Diff. pressure switch high
HP1	Fuel pressure pump	PDSL	Diff. pressure switch low
HP2	Fuel stand-by pressure pump	PI	Pressure indicator
HP3	Fuel circulating pump	PSL	Pressure switch low
HP4	Stand-by circulating pump	TI	Temperature indicator
HR1	Fuel pressure regulating valve	TT	Temperature transmitter (PT100)
HR2	Viscosimeter	VI	Viscosity indicator
HR6	Change over valve (HFO/diesel oil) 3-way-valve	VSH	Viscosity control switch high
		VSL	Viscosity control switch low
HR9	Fuel change over main valve		
HT1	Heavy fuel day tank	p	Free outlet required
HT2	Mixing tank	u	Fuel separator or from transfer pump

All heavy fuel pipes have to be insulated.

-------- Heated pipe

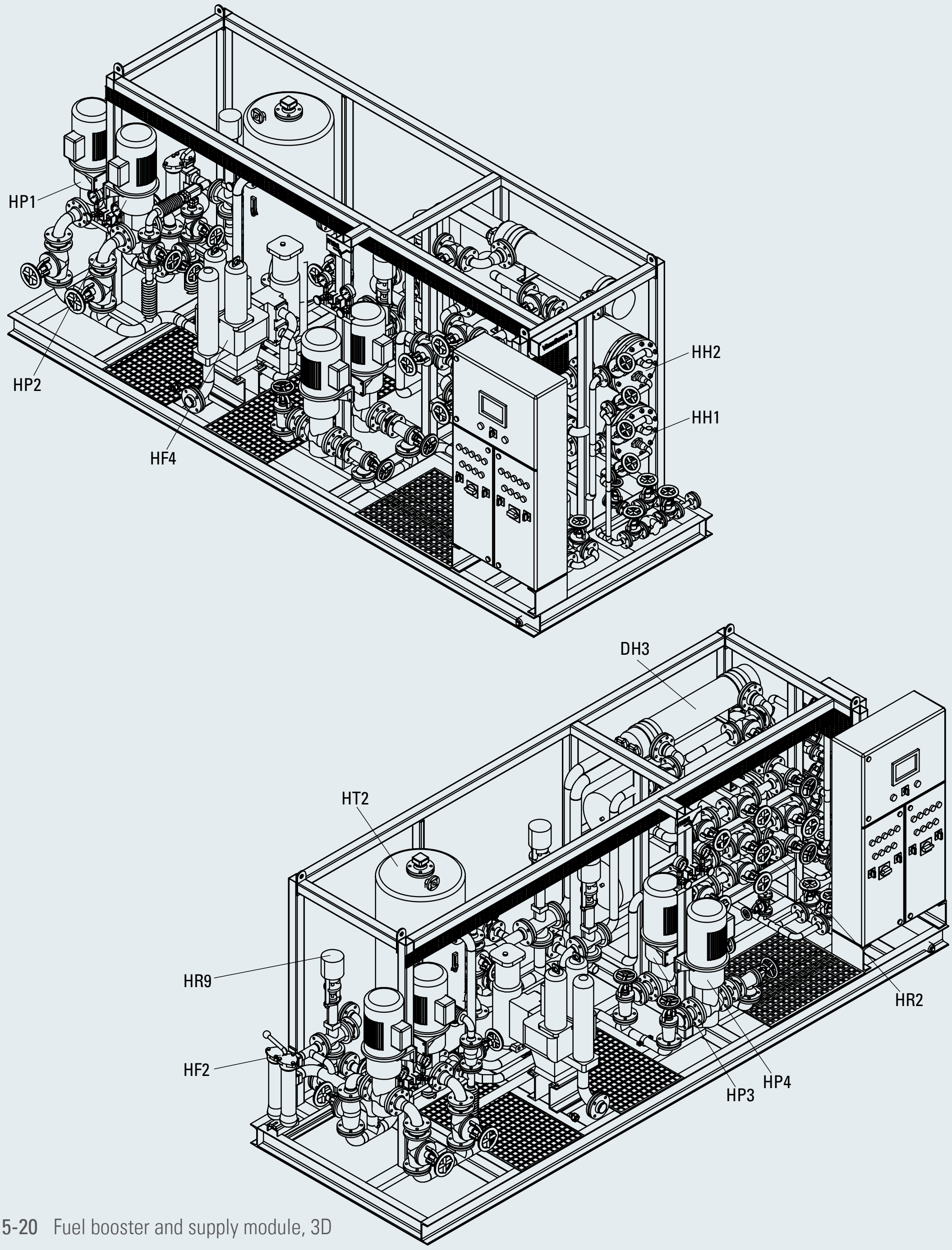

Fig. 5-20 Fuel booster and supply module, 3D

DH3	Fuel oil cooler for MDO operation	HP1	Fuel pressure pump
HF2	Primary filter (duplex filter)	HP2	Fuel stand-by pressure pump
HF3	Coarse filter	HP3	Fuel circulation pump
HF4	HFO automatic filter	HP4	Stand-by circulation pump
HH1	Heavy fuel final preheater	HR9	Fuel change over main valve
HH2	Stand-by final preheater	HT2	Mixing tank

5.3 Switching over from HFO to diesel oil

Continuous operation with HFO is recommended for engines designed for running mainly on HFO.
Starting and stopping the engine on HFO (Pier to Pier) can be provided if a sufficient preheating of the fuel oil system is ensured.
The circulating pumps have to be permanently in service, so that a continuous circulation of warm/hot fuel oil through the engine is ensured.

A frequent change over from HFO to diesel oil is only recommended when necessary for flushing purposes, emergencies, special sea area emission requirements, etc.

Changing the fuel oil too quickly and too often may cause high risk of plunger seizure (thermal shock), fuel injection pump leakages, etc. in the fuel injection pump.
Only a slow switch over will attenuate that effect.

Typical switch over characteristics (HFO to diesel)

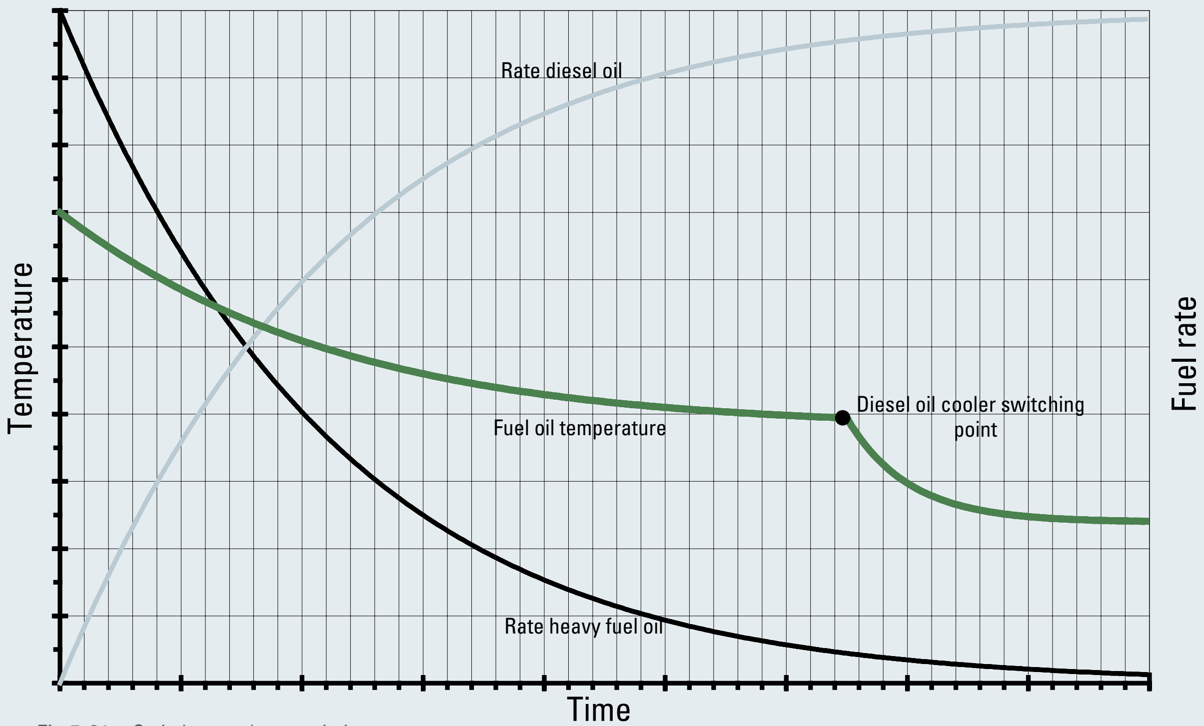

Fig 5-21 Switch over characteristics

6.1 General

The gas system provides the fuel gas from the Gas Valve Unit (GVU) to the gas admission valves on the engine.

The complete gas manifold on the engine is double walled and leak detected to comply with the gas safe machinery space requirements. A leakage location system to decrease the maintenance effort is available as an option.

The fuel gas will be port injected by solenoid gas valves, these gas valves are integrated in the cylinder head design.

The GVU is part of the Caterpillar Motoren standard scope of supply. One individual GVU per engine has to be provided. A maximum pipe length of 10 m between the GVU and the engine must not be exceeded.
For applications, where the GVU is located directly in the machinery space, a gas-proof cover is available as an option to comply with the gas safe machinery space requirements.

6.1.1 Gas fuel quality requirements

Gas fuel to be complied with the Caterpillar gas fuel specification VD8768 for dual fuel engines.

Gas specification VM 46 DF		
Gas temperature before engine inlet	[°C]	0 - 60
Gas pressure before fuel regulating skid	[bar (g)]	6.5 - 9
Maximum gas pressure fluctuation	[mbar/s]	+/- 80
Minimum lower heat value	[MJ/m³]	28
Minimum Cat - Methane number (without power derate)	[MN]	80
Maximum Sulphur as H_2S	[mg/m³]	20
Maximum Ammonia (NH_4)	[mg/m³]	25
Maximum Fluorines	[mg/m³]	Σ = 50
Maximum Chlorine	[mg/m³]	Σ = 50
Maximum oil content	[mg/m³]	50
Maximum particles content	[mg/m³]	50
Maximum particles size	[µm]	5
Maximum tar content	[mg/m³]	10
Maximum Silicium	[mg/m³]	10
Maximum water		Saturated fuel or water and condensates at gas control unit are not allowed

6.1.2 Inert gas quality requirements

Inert gas to be complied with the Caterpillar inert gas specification VD8836 for dual fuel engines.

Gas specification VM 46 DF		
Gas temperature range at interfaces to engine	[°C]	0 - 60
Minimum pressure difference (min. inert gas - max. fuel gas)	[bar(g)]	1
Maximum inert gas pressure	[bar(g)]	10
Allowed gases		Nitrogen ≥ 95 % Carbon Dioxid 2.5
Maximum Sulphur as H_2S	[%]	0.05 (= 770 mg/mn³)
Maximum Ammonia (NH_3)	[mg/m³]	25
Maximum Fluorines	[mg/m³]	Σ = 50
Maximum Chlorine	[mg/m³]	Σ = 50
Maximum oil content	[mg/m³]	50
Maximum particles content	[mg/m³]	50
Maximum particles size	[µm]	5
Maximum dew point	[°C]	-20

6.2 Gas system overview

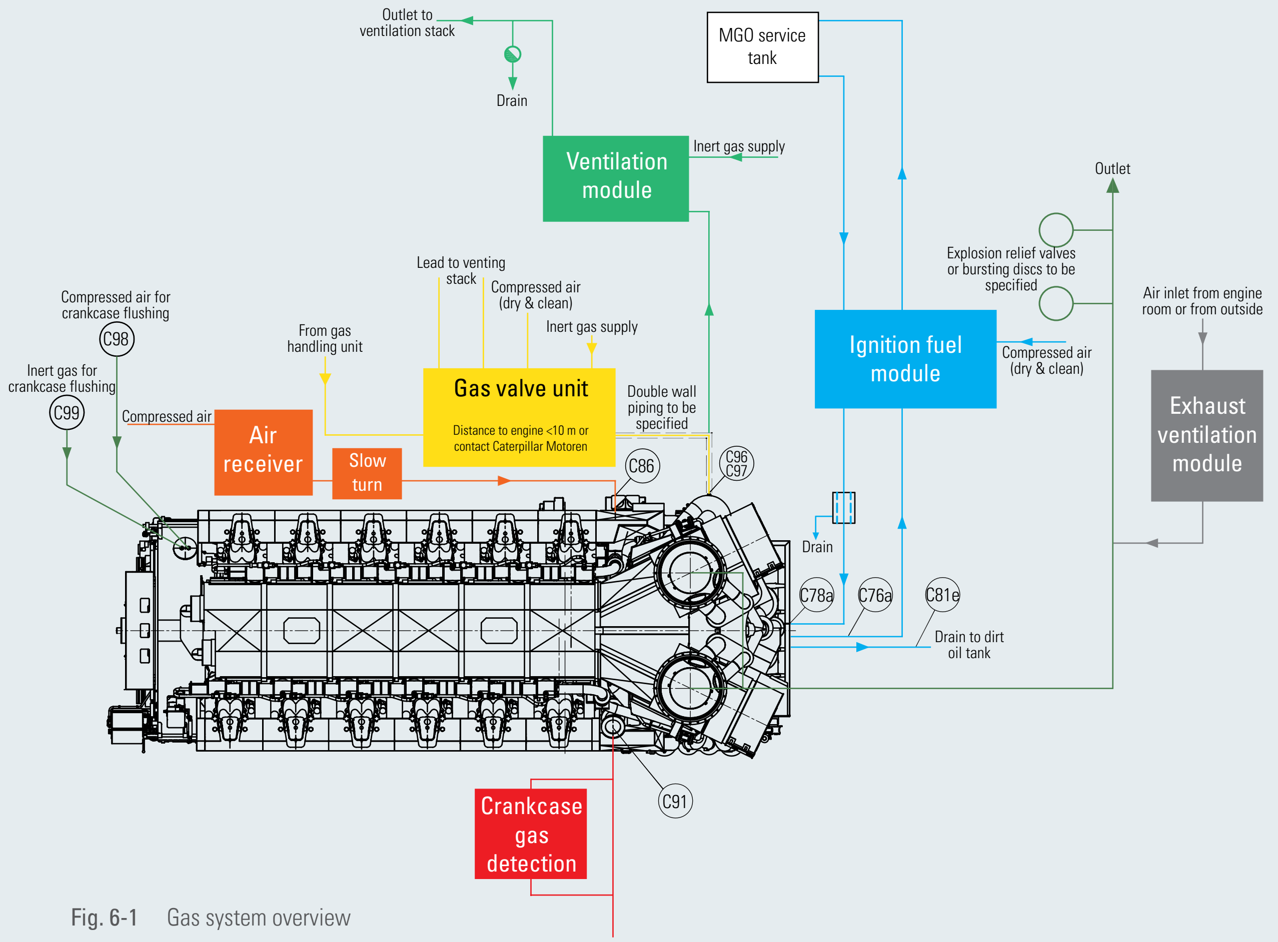

Fig. 6-1 Gas system overview

6.2.1 Gas valve unit (GVU)

The gas valve unit provides the engine with the desired fuel gas pressure and fuel gas quantity.
It is controlled by the engine's control and monitoring system and the engine's speed governor. The maximum distance between the GVU and the engine is 10 m. If more distance is requested please contact Caterpillar Motoren.
It has several features to safely cut the engine from the gas train and to remove the gas fuel from the piping system (flushing). In case of flushing the gas fuel is pushed by inert gas over the engine via the GVU towards the ship's vent system.

The shown GVU's are an example. GVU's can be supplied in horizontal and vertical design, as U-type and also mounted within an enclosure.
The gas valve unit is an off-engine component. GVU is single walled designed and needs to be installed in an ESD compliant machinery space or within an enclosure.
The GVU is optionally available with a gas fuel flow meter.

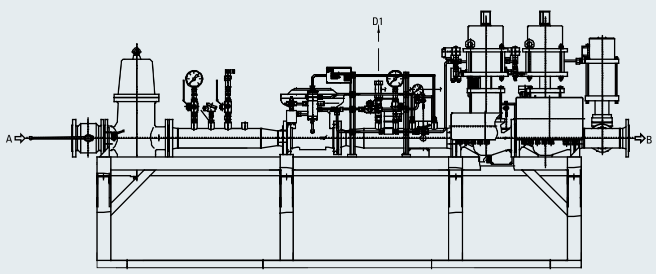

Fig. 6-2 Gas valve unit

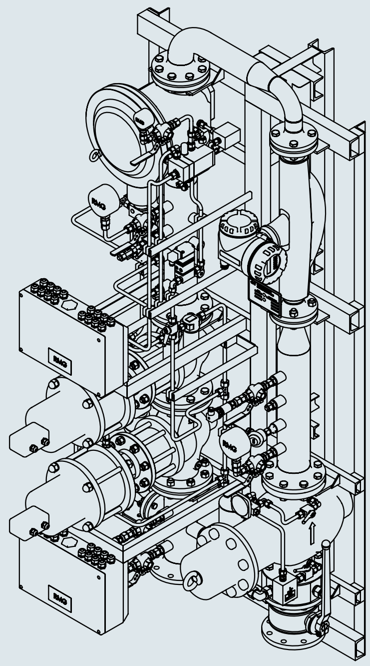

Fig. 6-3 Gas valve unit, U-form vertical

6.2.2 Ignition fuel system

The MaK dual fuel engine is equipped with an ignition fuel system to ignite the gas fuel / air mixture in the combustion chamber. This ignition system is a common rail system which injects only a small amount of MDO fuel.
Ignition fuel is to be used also during operation with liquid fuel, for cooling of injector needles. To achieve the cleanliness of the ignition fuel a filtering system is required.

6.2.2.1 Ignition fuel quality requirements

Only MDO fuel types DMA and DMZ acc. to ISO 8271 are to be used. For usage of DMB or DMX please consult Caterpillar Motoren in advance.
A filter module to provide the required ignition fuel cleanliness is part of MaK standard scope of supply.

6.2.2.2 Ignition fuel components

Ignition fuel module

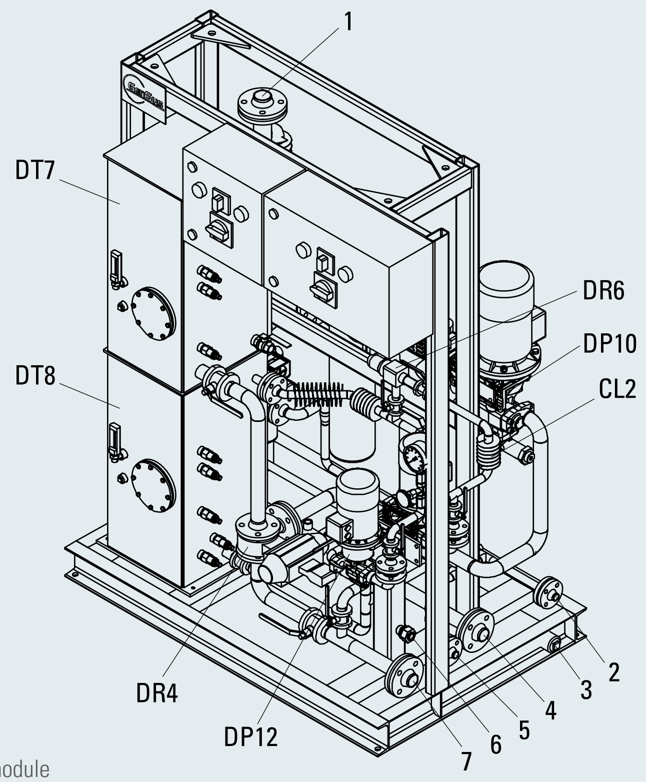

Fig. 6-4 Ignition fuel module

1	Vent to the top of day tank	CL2	Fin cooler
2	Return fuel from engine	DP10	Gear pump
3	Drain module	DP12	Gear pump
4	Drain filter and tank	DR4	Change over valve
5	DF to pilot injection system engine	DR6	Pressure regulating valve
6	Supply compressed air (dry & clean)	DT7	Mixing tank
7	DF from diesel oil day tank	DT8	Mixing tank

Ignition fuel fine filter

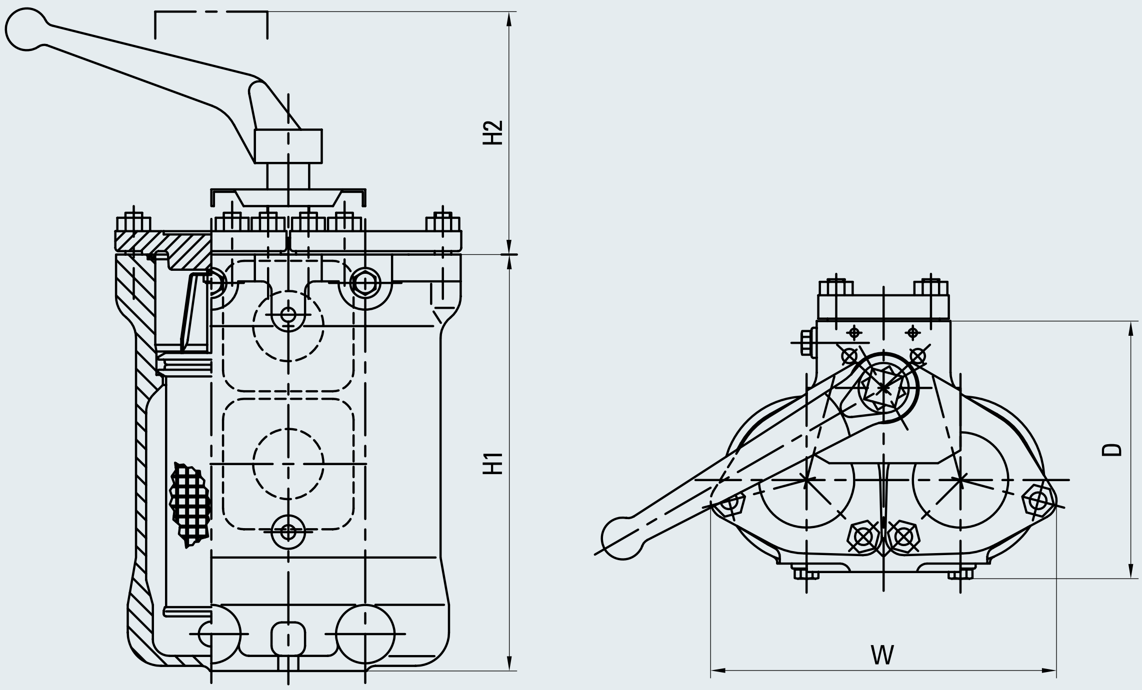

Fig. 6-5 Ignition fuel fine filter

Engine	DN	Dimensions [mm]			
		H1	H2	W	D
12/16 M 46 DF	25	200	170	206	ca. 150

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Ignition fuel injector

Weight: 5.9 kg
The ignition fuel injector enables the injection of pressurized fuel directly into the cylinder.

The injector design is simple and compact, the key features are:

- Electronically controlled
- Flexible injection timing and duration
- Flow limiter

Fig. 6-6 Ignition fuel injector

High pressure pump

Weight: 36 kg
One high pressure pump delivers the required amount of ignition fuel to the injectors and provides the desired pressure in closed loop control. The pump itself is based on a proved design.

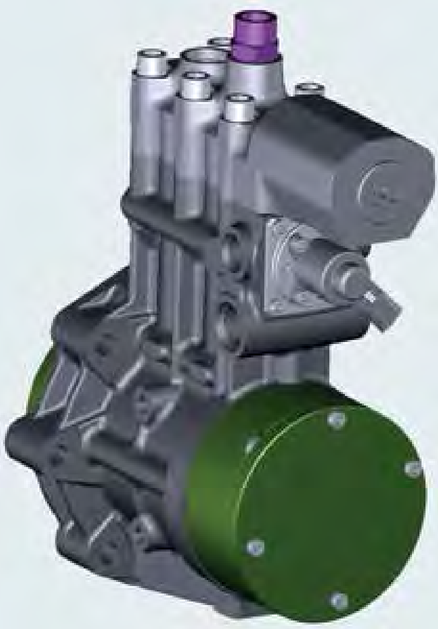

Fig. 6-7 High pressure pump

6.2.3 Engine ventilation system

The ventilation module supplies permanent ventilation for continuous monitoring / leakage detection by vacuum pump and gas sensor. This pump is able to handle any kind of ignitable gases.
Nitrogen connection on the module, for flushing of the annular space of the double walled piping system and fuel gas supply line of the engine.
Depending on class requirements redundant equipment might be requested.
The standard design is for the use in an inherent safe engine room and is therefore of non-hazardous type.
The ventiltaion module shall be installed in the engine room as close as possible to the gas valve unit.

6.2.4 Engine ventilation module

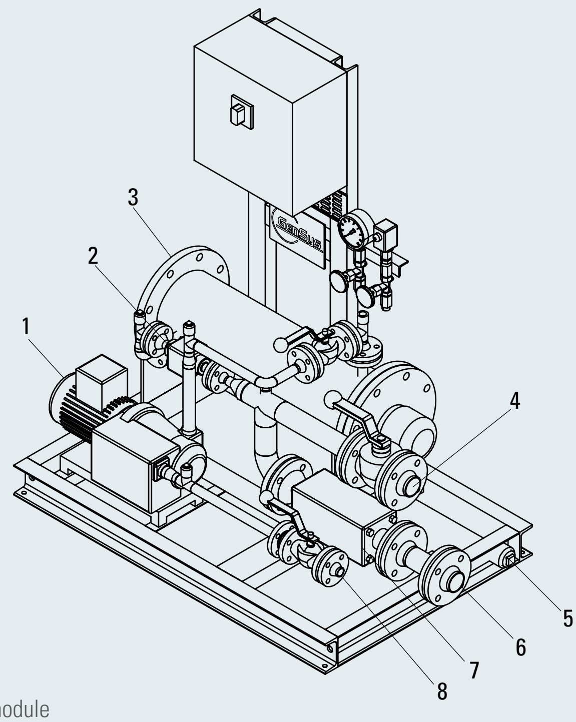

Fig. 6-8 Engine ventilation module

1	Vacuum pump	5	Drain module
2	Electro-magnetic valve	6	Nitrogen, inlet
3	Gas sensor	7	Electro-magnetic valve
4	Jacketed pipe system, inlet Nitrogen, outlet	8	Outlet to drain

6.2.5 Exhaust gas ventilation system

The exhaust gas ventilation module is installed to ventilate the ship side exhaust gas system after an emergency stop of the engine in gas mode. The module consists of a ventilation fan, a separated butterfly valve and exhaust gas compensator for the connection to the exhaust gas system. The butterfly valve separates the exhaust gas system under all conditions to protect the engine room against exhaust gas inrush except the case of a stop of the engine in gas mode. The ventilator is sized to remove the total volume of the exhaust gas system, incl. silencer, stack, boiler and duct three times. The engine start is blocked, if the valve is not completely closed, monitored by a position switch.

6.2.6 Exhaust gas ventilation module

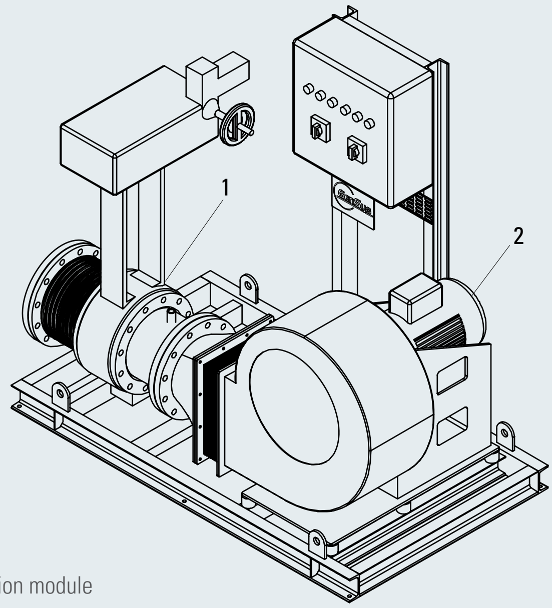

Fig. 6-9 Exhaust gas ventilation module

1 Isolation valve
2 Exhaust fan

6.2.7 Crankcase gas detection

The crankcase needs several protection devices to provide a reliable and safe operation of the dual fuel engine. Due to the normal blow-by special care needs to be taken to detect fuel gas before it reaches an explosive concentration.

This system detects an abnormal amount of fuel gas in the crankcase. The gas sensor will sense for fuel gas and will monitor the actual fuel gas concentration in percent of the lower explosion limit (% LEL). Before the LEL is reached an alarm will be triggered and without recovery of the LEL within a certain time, latest before the concentration of fuel gas will reach 100 % LEL, the engine will switch back to fuel oil to ensure that an explosive atmosphere will not occur due to fuel gas blow-by.

If abnormal blow-by occurs the pressure sensor will trigger an alarm, showing that at least one of the piston rings has worn and the switch over to fuel oil might occur soon.

A gas detection system might also be required to detect fuel gas in HT expansion tank and lube oil circulating tank, depending on authority.

6.2.8 Explosion relief valves for exhaust gas system

Exhaust gas piping in which explosive atmosphere can accumulate is routed steadily ascending to avoid gas accumulations. Additionally it is protected against overpressure by explosion pressure relief valves. These relief valves discharge the overpressure in case of any explosion within the exhaust gas system. The positioning and amount of explosion relief vavles must be adjusted according to the design and layout of the existing exhaust gas system.

In case of an explosion in the exhaust gas system the explosion relief valves open quickly. This reduces explosion overpressure inside the exhaust gas system to a safe level without any flame transmission to the surrounding area. After the explosion pressures subsides, the valves reseal, so that the engine could be restarted or further operated.

6.2.9 Slow turn

The slow turn module can turn the engine automatically in predefined intervals with pressure reduced starting air. This air supply is limited in such a way that the ignition engine speed will not be reached. A fuel injection will be disabled during this process. If the crankshaft will only start to oscillate during slow turning and will not come to a continuous rotation it must be assumed that water has accumulated in one of cylinders. In that case a starting interlock will be set
For more information, please see also chapter 9.5

6.3 Gas system – GVU inside gas safe machinery room

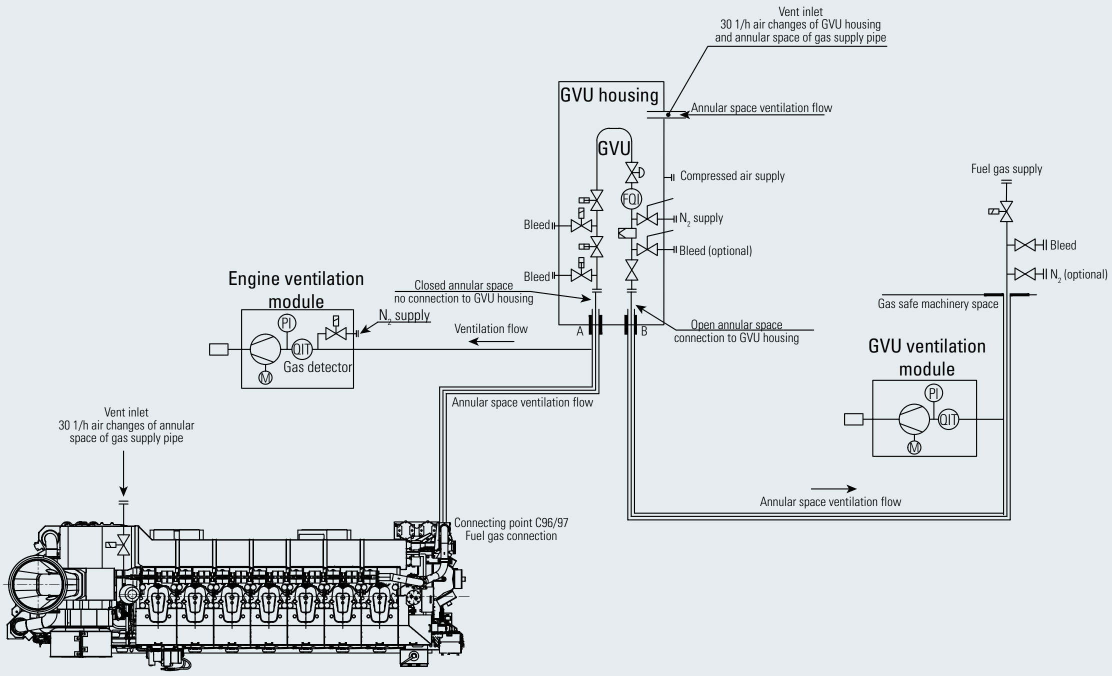

Fig. 6-10 Gas valve unit inside machinery room

6.3.1 GVU housing

In case of installing the GVU inside the machinery room and to ensure its definition as a safe machinery room the GVU needs to be encased and the gas pipe needs to be of double wall pipe.
The GVU housing is seen as an extension of the annular space of double wall fuel gas pipe in front of the GVU.

6.3.2 GVU ventilation module

Similar to the engine ventilation module the GVU ventilation module is used for permanent ventilation of the GVU housing and its double walled pipe inside machinery space.
The vent flow will be through the GVU housing and the annular space of the double wall fuel gas line by an explosion proofed fan. A gas detector will be installed close to the exhaust fans inside the extraction flow. The GVU housing is always connected to open atmosphere by the annular space and hereby not considered as a pressure vessel.

General

The lube oil performs several basic functions:

- It cleans the engine by carrying dirt and wear particles until the filters can extract and store them.
- It cools the engine by carrying heat away from the piston, cylinder walls, valves and cylinder heads to be dissipated in the engine oil cooler.
- It cushions the engines bearings from the shocks of cylinder firing.
- It lubricates the wear surfaces, reducing friction.
- It neutralizes the corrosive combustion products.
- It seals the engines metal surfaces from rust.
- It lubricates the turbocharger bearings.
- It cools the injection nozzles.

7.1 Lube oil requirements

NOTE:
The viscosity class SAE 40 is required.

Wear and tear and thus the service life of the engine depend on the lube oil quality.
Therefore high requirements are made for lubricants:

- Constant uniform distribution of the additives at all operating conditions
- Perfect cleaning (detergent effect) and dispersing power, prevention of deposits from the combustion process in the engine
- Sufficient alkalinity in order to neutralize acid combustion residues
- The TBN (total base number) must be 30 KOH/g at HFO operation
  The TBN is 12 - 20 KOH/g for MDO operation depending on Sulfur content

Manufacturer	Diesel oil / MDO operation	I	II	HFO operation	I	II
AGIP	DIESEL SIGMA S		X	CLADIUM 300 S	X	
	CLADIUM 120		X	CLADIUM 400 S	X	
BP	ENERGOL HPDX 40	X				
	VANELLUS C3		X			
CAT	DEO	X				
CHEVRON, CALTEX, TEXACO	DELO 1000 MARINE	X		TARO 30 DP	X	
	DELO SHP	X		TARO 40 XL	X	
	TARO 12 XD	X		TARO 40 XLX	X	
	TARGO 16 XD	X				
	TARGO 20 DP	X				
	TARGO 20 DPX	X				
CASTROL	MARINE MLC	X		TLX PLUS 304	X	
	MHP 154	X		TLX PLUS 404	X	
	TLX PLUS 204	X				
CEPSA	KORAL 1540		X			
ESSO	EXXMAR 12 TP	X		EXXMAR 30 TP	X	
	EXXMAR CM+		X	EXXMAR 30 TP PLUS	X	
	ESSOLUBE X 301		X	EXXMAR 40 TP		X
				EXXMAR 40 TP PLUS	X	
MOBIL	MOBILGARD 412	X		MOBILGARD M430	X	
	MOBILGARD ADL	X		MOBILGARD M440	X	
	MOBILGARD M430	X		MOBILGARD M 50	X	
	MOBILGARD 1-SHC [1)]		X			
	DELVAC 1640	X				
SHELL	GADINIA	X		ARGINA T	X	
	GADINIA AL	X		ARGINA X	X	
	ARGINA S	X				
	ARGINA T	X				
TOTAL LUBMARINE	RUBIA FP		X	AURELIA TI 4030	X	
	DISOLA M 4015	X		AURELIA TI 4040	X	
	AURELIA TI 4030	X				
	CAPRANO M40	X				
LUKOIL	NAVIGO 12/40	X		NAVIGO TPEO 30/40	X	
	NAVIGO 15/40	X		NAVIGO TPEO 40/40	X	
GULF				SEA POWER 4030	X	
				SEA POWER 4040	X	

I Approved in operation / II Permitted for controlled use. When these lube oils are used, Caterpillar Motoren GmbH & Co. KG must be informed because at the moment there is insufficient experience available for engines. Otherwise the warranty is invalid. / **1)** Synthetic oil with a high viscosity index (SAE 15 W/40). Only permitted if the oil inlet temperatures can be decreased by 5 - 10 °C.

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7.2 Lube oil system

General

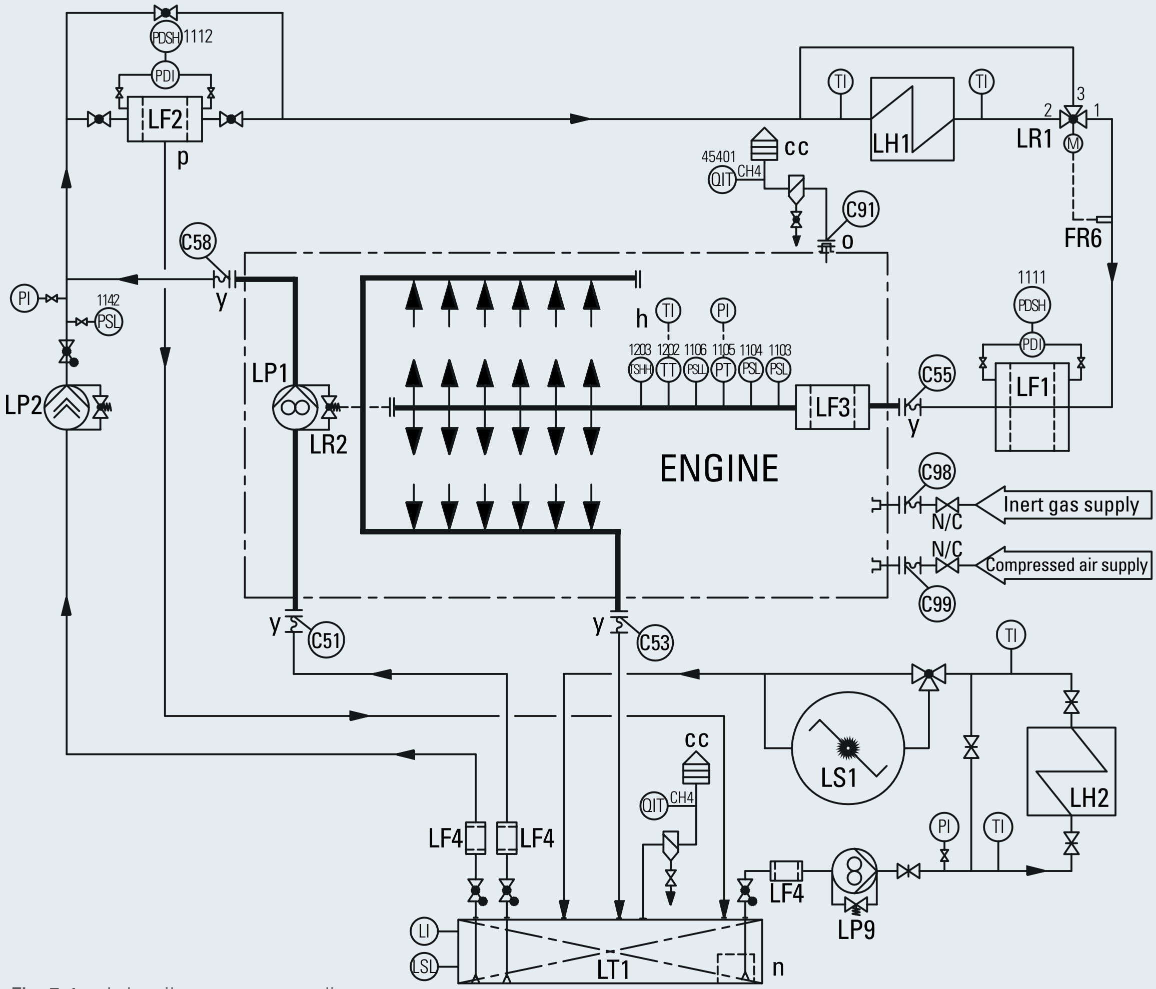

Fig. 7-1 Lube oil system, system diagram

- FR6 Sensor for temperature control valve
- LF1 Duplex lube oil filter
- LF2 Self cleaning lube oil filter
- LF3 Protective strainer
- LF4 Suction strainer
- LH1 Lube oil cooler
- LH2 Lube oil preheater
- LP1 Lube oil force pump
- LP2 Lube oil stand-by force pump
- LP9 Transfer pump (separator)
- LR1 Lube oil temperature control valve
- LR2 Oil pressure regulating valve
- LS1 Lube oil separator
- LT1 Lube oil sump tank

- LI Level indicator
- LSL Level switch low
- PDI Diff. pressure indicator
- PDSH Diff. pressure switch high
- PI Pressure indicator
- PSL Pressure switch low
- PT Pressure transmitter
- QIT Gas indicator and transmitter
- TI Temperature indicator
- TSHH Temperature switch high
- TT Temperature transmitter (PT100)

C51	Force pump, suction side
C53	Lube oil discharge
C55	Lube oil inlet, lube oil protective filter
C58	Force pump, delivery side
C91	Crankcase ventilation to stack
C98	Flushing connection crankcase (inertgas)
C99	Flushing connection crankcase (air)

cc	Flame arrestor must be provided.
h	Please refer to the measuring point list regarding design of the monitoring devices.
n	See "arrangement of the flushing oil pipe into the lube oil circulating tank" 4-A-10691.
o	See "crankcase ventilation installation instructions" 4-A-9570.
p	Free outlet required.
y	Provide an expansation joint.
N/C	Normally closed.

Lube oil force pump LP1 (fitted)

The lube oil force pump is a screw pump, fitted on the engine and mechanically driven by the crankshaft. The lube oil force pump provides the lube oil from the circulating tank LT1 to the engine.
It is designed to provide a sufficient amount of lube oil at the required pressure to the engine even when running at the designed minimum engine speed. Capacity, see technical data.

Duplex filter LF1 (separate)

The duplex filter shall indicate a failure of the self-cleaning filter LF2. Mesh size: 80 µm (absolute)
One chamber of the duplex filter is in operation, while the second chamber is in stand-by.
Change over can be done during engine operation. Weight (empty): 585 kg

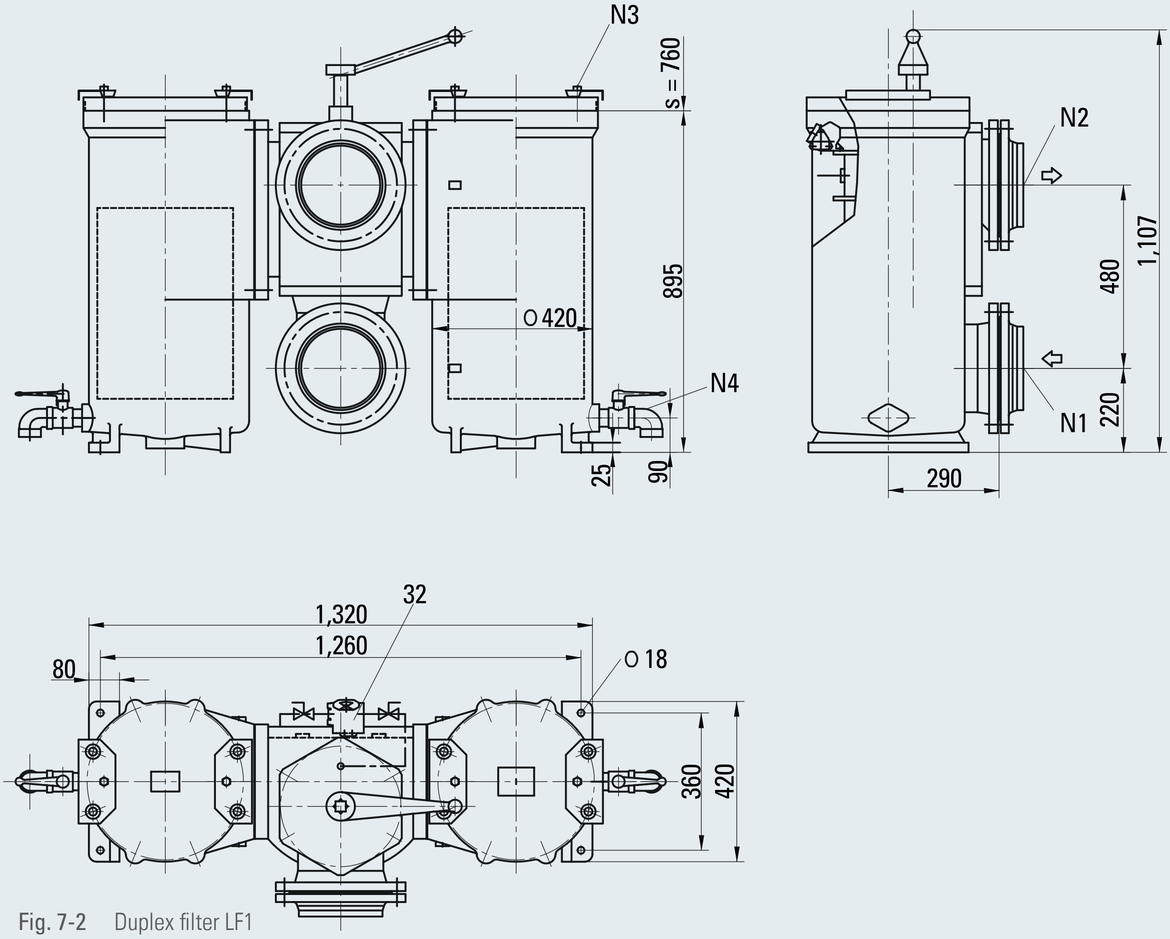

Fig. 7-2 Duplex filter LF1

N1	Filter inlet	N4	Drain
N2	Filter outlet	s	Dismounting of the filter element
N3	Air escape		

Back flushing filter LF2 (separate)

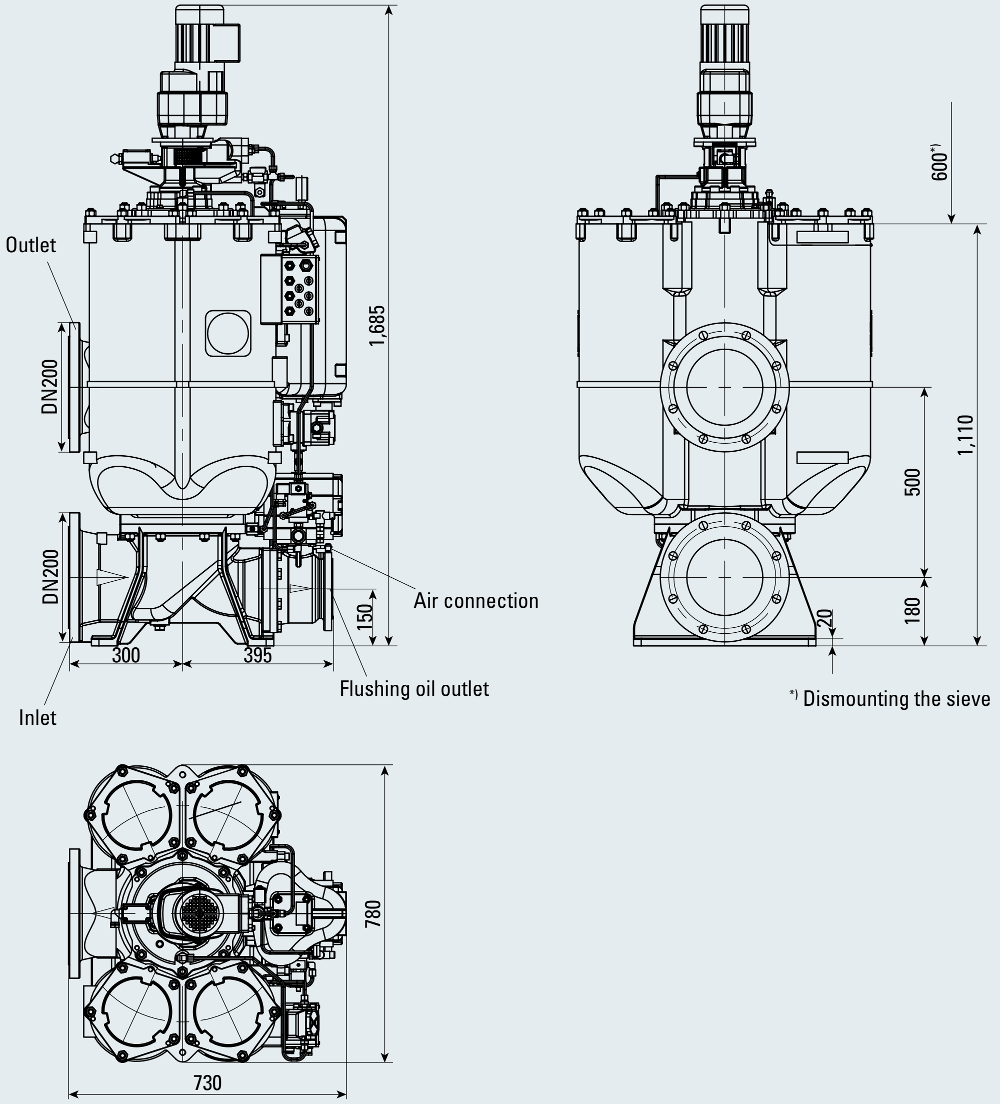

Fig. 7-3 Back flushing filter LF2

The back flushing filter protects the engine from dirt particles which may accumulate in the circulating tank LT1.
Mesh size: 30 µm (absolute)
The filter is continuously flushing into the circulating tank without flushing oil treatment, without bypass filter.
Weight: 784 kg

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Lube oil stand-by force pump LP2 (separate)

This pump is a stand-by to the force pump LP1.

It is a gear or screw type pump.
It is a requirement of the classification societies for single-engine plants.
This pump will also be used for prelubricating.

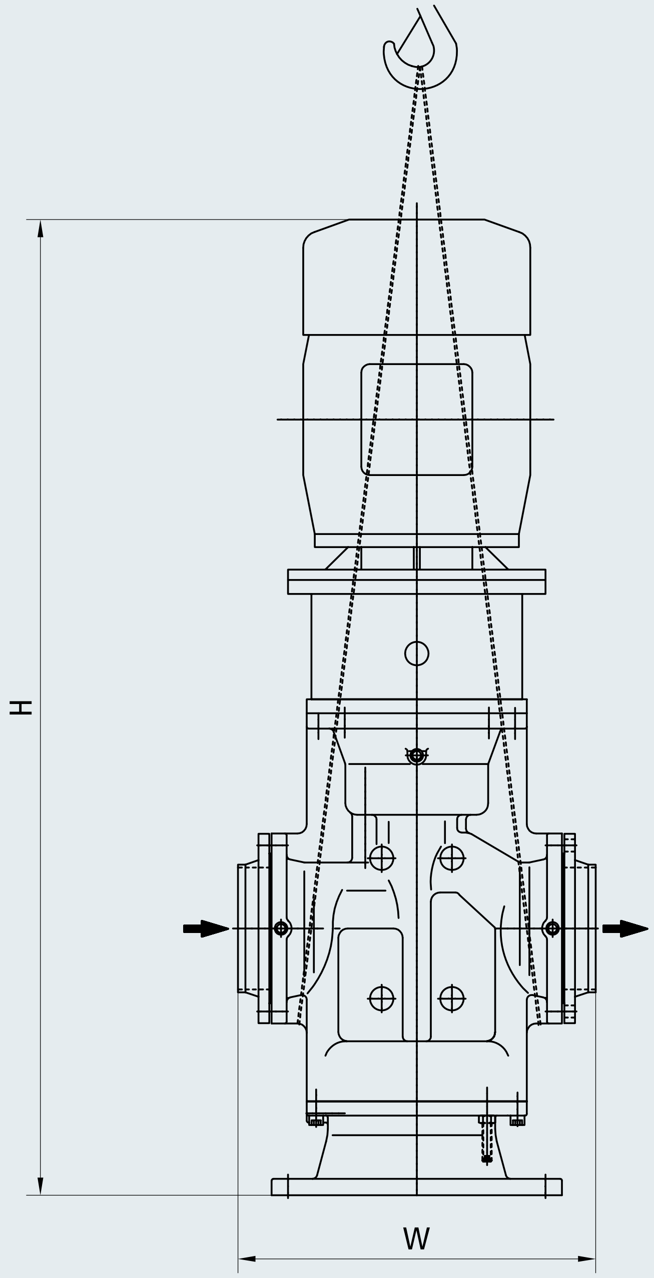

Fig. 7-4 Lube oil stand-by force pump LP2

		Capacity [m³/h]	Motor power [kW]	W [mm]	H [mm]	Weight [kg]
12 M 46 DF	400 V / 50 Hz	200	110	880	2,420	1,791
	440 V / 60 Hz	200	108	880	2,235	1,487
16 M 46 DF	400 V / 50 Hz	270	132	968	2,567	2,314
	440 V / 60 Hz	270	132	968	2,537	2,224

Prelubricating pump LP5 (separate)

This pump can be installed instead of a stand-by force pump in multiple engines plants.
This pump can only be used for prelubricating, not as stand-by for the force pump.
Capacity see technical data.

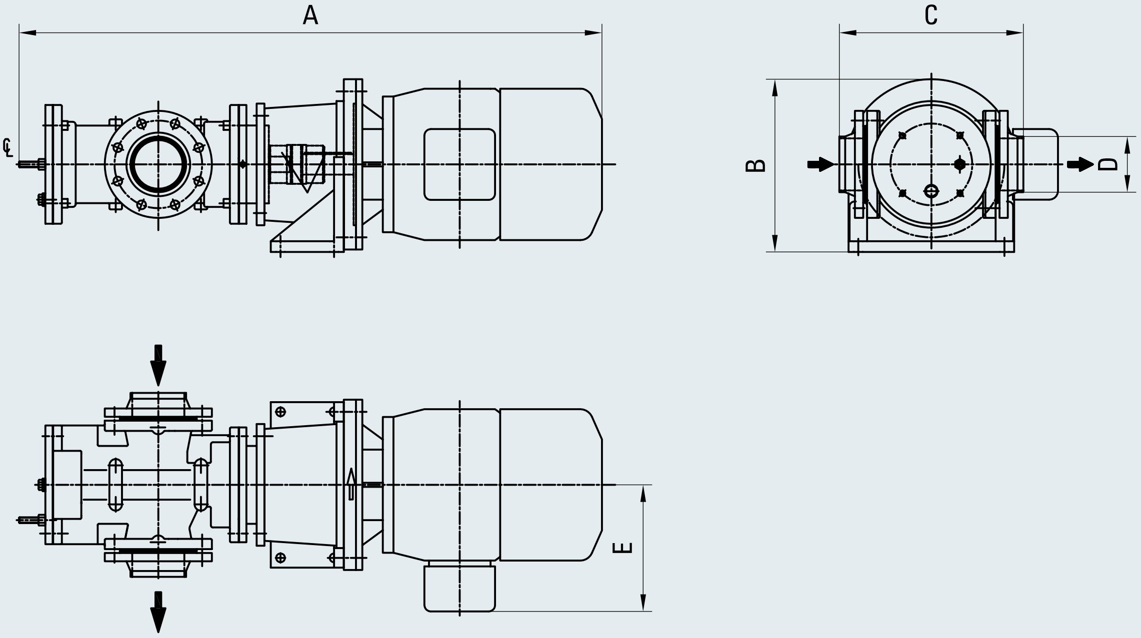

Fig. 7-5 Prelubricating pump LP5

		Dimensions [mm]					Motor power	Weight
		A	B	C	D	E	[kW]	[kg]
12 M 46 DF	400 V / 50 Hz	1,878	405	538	DN 150	260	15.0	370
	440 V / 60 Hz	1,871	405	534	DN 150	260	18.0	370
16 M 46 DF	400 V / 50 Hz	1,408	405	534	DN 150	275	18.5	405
	440 V / 60 Hz	1,408	405	534	DN 150	275	22.0	405

The pumps can be installed in horizontal or vertical position.

Suction strainer LF4 (separate)

This strainer shall only protect the pumps.
It is not in the Caterpillar Motoren scope of supply.
Mesh size 2 – 3 mm.

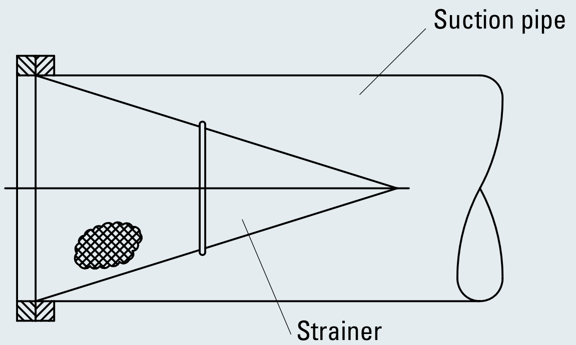

Fig. 7-6 Suction strainer LF4

Oil pressure regulating valve LR2 (fitted)

The pressure control valve controls the lube oil pressure at engine inlet by giving only the adequate oil flow to the engine. Excessive oil flow will be led back into the engine oil pan.

Lube oil cooler LH1 (separate)

A plate cooler with plates of stainless steel will be used to dissipate the heat to the LT fresh water system.

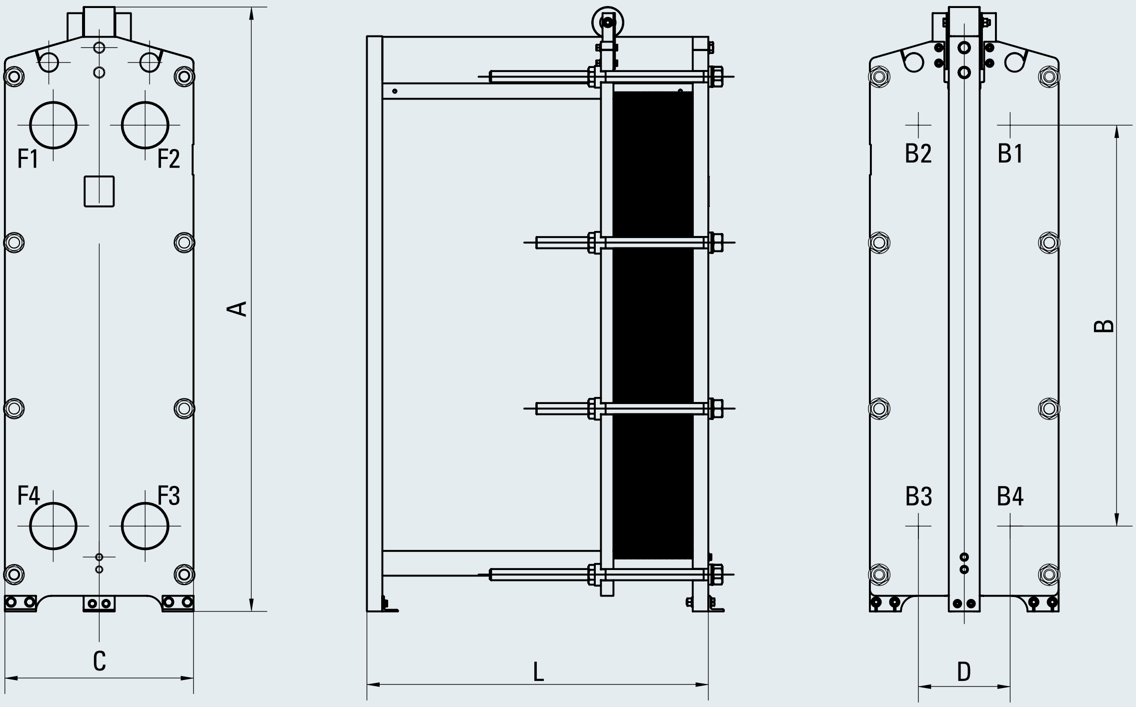

Fig. 7-7 Lube oil cooler LH1

	Dimensions					Weight
	A	B	C	D	L	
	[mm]	[mm]	[mm]	[mm]	[mm]	[kg]
12 M 46 DF	1,948	1,292	608	296	1,400	1,385
16 M 46 DF	1,948	1,292	608	296	1,600	1,498

Lube oil temperature control valve LR1 (electric driven valve)

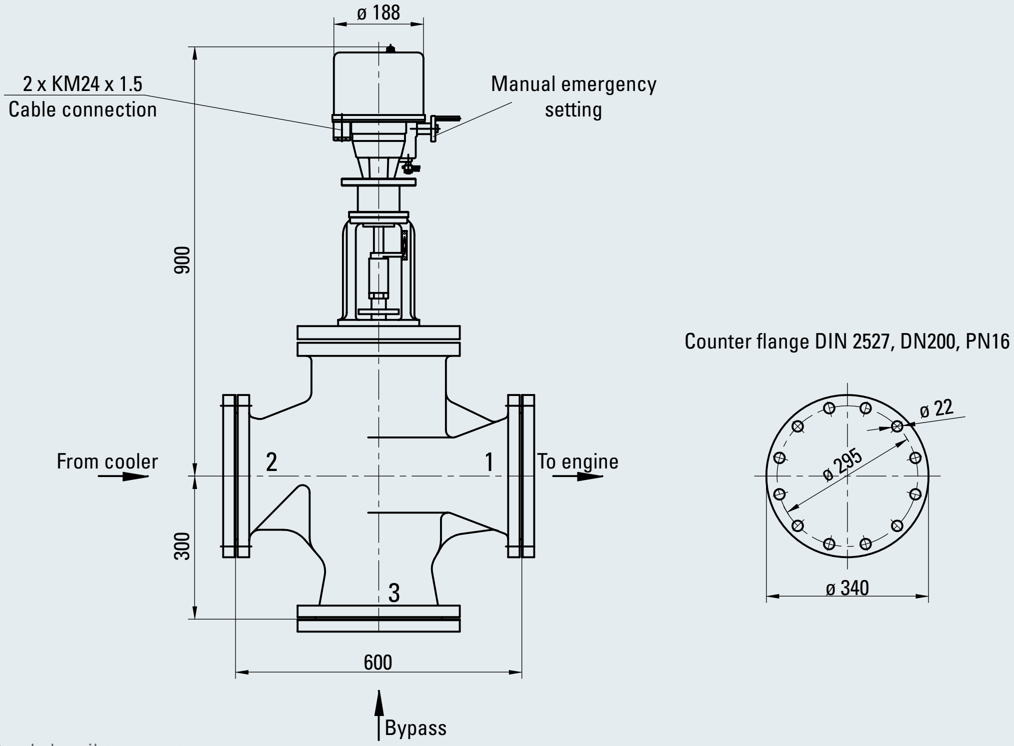

Fig. 7-8 Lube oil temperature control valve LR1 (electric driven valve)

Lube oil separator LS1 (separate)

The most effective cleaning of lube oil is carried out by means of separation.
Separation is mandatory for HFO driven plants and highly recommended for MGO/MDO operation.

Layout for MGO/MDO and gas operation
Automatic self-cleaning separator; Operating temperature 85 - 95 °C

$V\,[l/h] = 0.18 \cdot P_{eng}\,[kW]$ P_{eng} = Power engine [kW]

Layout for HFO and gas operation
Automatic self-cleaning separator; Operating temperature 95 °C

$V\,[l/h] = 0.29 \cdot P_{eng}\,[kW]$ P_{eng} = Power engine [kW]

For the layout of separators, please follow the separator manufacturer's guidelines.

7.3 Circulating tanks and components

7.3.1 Lube oil drain piping

The oil drain bend is provided separately. In general the oil drain connecting point is located at the driving end of the engine. If the engine is aligned with inclination to the free end, the oil drain bend can be mounted to the free end of the engine. The oil drain piping should be as short as possible.
There should be a compensator between the end of the oil drain bend and the circulating tank.

7.3.2 Circulating tank layout

Circulating tank LT1

The circulating tank contains the engine lube oil. The recommended volume of the circulating tank is calculated as follows:

$$V[m^3] = \frac{1.7 \cdot P_{eng}\,[kW]}{1{,}000} \qquad P_{eng} = \text{Power engine [kW]}$$

On request lower capacities are possible, please contact Caterpillar Motoren. The nominal oil level is at 80 % of circulating tank volume. At 60 % of circulating tank volume there should be a low level switch with monitoring by the MACS.
To make sure, that the engine is provided with lube oil, the lube oil suction pipe should be aligned inside the circulating tank in a position, that is filled with lube oil under any condition.
To avoid any stress to the structure of the engine as well as the circulating tank, the circulating tank should be located below the engine in its total length and width to make sure that the foundation is warmed up equally. In plants with separators the content of the circulating tank should be clarified permanently.
The preheater in the separator should be able to keep the lube oil temperature at min. 40 °C even when then engine is not running.

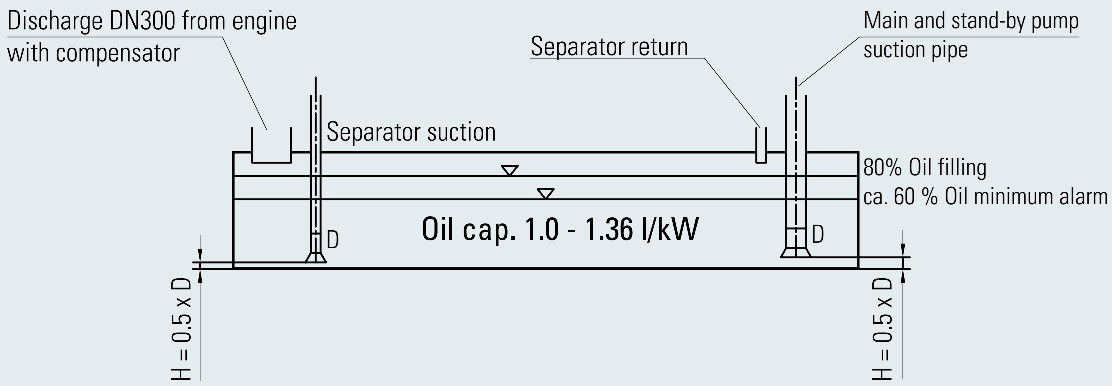

Fig. 7-9 Sump tank LT1

7.4 Crankcase ventilation system

7.4.1 Crankcase ventilation pipe dimensions

- The crankcase ventilation connecting point is DN 80.
- The engine main ventilation line must be at least DN 125.

7.4.2 Crankcase ventilation pipe layout

- The pipes should run upwards.
- Free ventilation under all trim conditions is required.
- To avoid backflow of condensate, a permanent drain of the ventilation pipe is required.

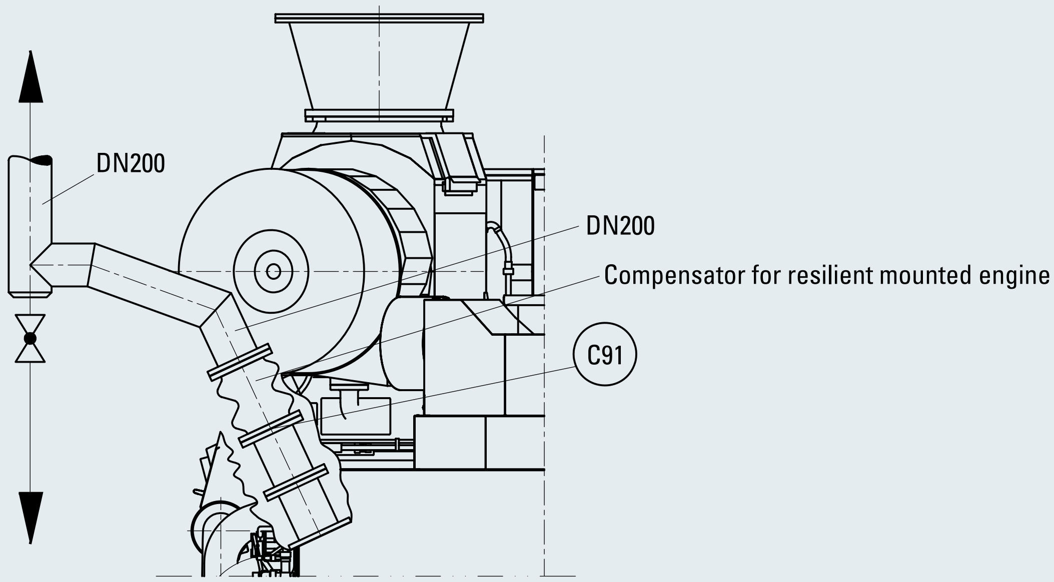

Fig. 7-10 Crankcase ventilation

C91 Crankcase ventilation to stack

7.4.3 Gas detection sensor

A gas detection sensor has to be installed in the crankcase vent pipe.

7.5 Recommendation for flushing of lube oil system

Required conditions

- The required flow velocity for flushing purposes is minimum 2.0 m/s.
- There should be an external flushing oil filter (30/34 µm mesh size) with differential pressure indicator (0.2 bar) installed on the end of the flushing circuit.
- Lube oil separator must be in operation.

Lube oil temperature min. 40 °C (140 cSt.), if possible use low-viscosity flushing oil.

Flushing the system from circulation tank to circulation tank

- The flushing oil pump takes the oil from the lube oil circulation tank and presses into the lube oil system.
- During the flushing process the automatic lube oil filter is bypassed.
- Before engine inlet the system is to be disconnected and the flushing oil is to be conducted via a flexible pipe through a crankcase door (near to the oil drain) into the circulating tank.

Flushing time

- Each system is to be flushed for at least 8 hours.
- The main flushing is completed when there is no more differential pressure at the flushing oil filter.
- After the main flushing is completed, re-install all filter inserts and flush the system one more hour with all filters in place not using bypasses.
- Inspect all filters and continue flushing until all filters and inserts stay clean.
- After flushing, all not flushed pipes and filters (e.g. stand-by pump lines, opened pipes) to be cleaned separately.

8.1 General

MaK engines are cooled by two cooling circuits:

- A high temperature (HT) and
- A low temperature (LT) cooling circuit

The cooling water needs to be treated according to Caterpillar Motoren requirements for MaK engines.

8.1.1 Two circuit cooling system

In this system arrangement, the two cooling systems are designed as two separate water circuits.
Each circuit needs to be fitted with a header tank and a fresh water cooler.

8.1.2 Secondary circuit cooling system

In the "secondary circuit cooling system", HT and LT cooling circuits are combined in sequence to one water circuit.
In order to use the different temperature levels, the HT suction side is connected to the LT delivery side.
The HT circuit uses an amount of warm LT water and further heats it up by cooling the engine. The amount of LT water, that is used by the HT system, depends on the current temperature and engine power. The overrun of the fixed flow of the fresh water pump (fitted on engine) HT (FP1) circulates via bypass line from the temperature control valve HT (FR1) to the suction side as usual.
The advantage of the secondary circuit system is it's simplicity. It uses just one water circuit and there is only one header tank and one fresh water cooler instead of two.
In addition also the amount of piping is reduced.

8.2 Water quality requirements

8.2.1 General

The engine cooling water must be carefully selected, treated and controlled.
The use of untreated cooling water will cause corrosion, erosion and cavitation on the surfaces of the cooling system. Deposits can impair the heat transfer and may result in thermal overload on components to be cooled.
Therefore the treatment with an anti-corrosion agent has to be effected before the very first commissioning of the plant.

8.2.2 Requirements

The characteristic of the untreated cooling water must be within the following limits:

- Distillate or freshwater free from foreign matter (no seawater or waste water)
- A total hardness of max. 10° dH
- pH-value 6.5 – 8
- Chloride ion content of max. 50 mg/l

8.2.3 Supplementary information

Distillate:
If a distillate or fully desalinated water is available, this should preferably be used as engine cooling water.
Hardness:
Water with more than 10° dGH (German total hardness) must be mixed with distillate or softened.

8.2.4 Treatment before operating the engine for the first time

Treatment with an anti-corrosion agent must be done before the engine is operated for the first time to prevent irreparable initial damage.

8.3 Recommendation for cooling water system

8.3.1 Pipes and tanks

Galvanized material should not be used in tanks and pipes, it can cause zinc attack in the engine.

8.3.2 Drain tank with filling pump

It is recommended to collect the treated water in a separate drain tank when carrying out maintenance work (to be installed by the yard).

8.3.3 Electric motor driven pumps

Pumps should be applicable for use in fresh water as well as sea water circuits, vertical design.

Rough calculation of power demand for the electric balance:

$$p = \frac{\rho \cdot H \cdot \dot{V}}{367 \cdot \eta} \text{ [kW]}$$

P =	Power [kW]
P_M =	Power of electr. motor [kW]
V =	Flow rate [m³/h]
$\dot{H}$ =	Delivery head [m]
ρ =	Density [kg/dm³]
η =	Pump efficiency, 0.70 for centrifugal pumps

P_M =	1.5 · P	< 1.5 kW
P_M =	1.25 · P	1.5 - 4 kW
P_M =	1.2 · P	4 - 7.5 kW
P_M =	1.15 · P	7.5 - 40 kW
P_M =	1.1 · P	> 40 kW

8.4 Cooling water system

General note: The following system diagrams should be regarded as typical examples. Their purpose is to explain the general function of the engine's systems. Numerous other variants and arrangements are possible and can be discussed and developed with the mechanical MaK A&I department.

8.4.1 General

The high temperature (HT) system provides the HT side of the charge air cooler and the engine's cylinder heads and cylinder liner water rings with cooling water. In order to reduce the thermal tension in water-cooled engine parts, it is important to keep the drop in temperature low and therefore the flow high. Therefore the fresh water pump (fitted on engine) HT (FP1) delivers its full flow over the engine. The HT outlet temperature of 90 °C is controlled by the temperature control valve HT (FR1). In case the temperature decreases, the valve delivers more water to the bypass (connection B for mechanical, connection 3 for electrical driven valves) back to the HT pump's suction side.
In order to use the thermal energy of the HT circuit, a heat recovery can be installed as shown in the cooling water diagrams (FH3). For heat recoveries, especially for fresh water generators a high flow over the heat consumer (FH3) is recommended. This can be achieved by using a flow temperature control valve HT (FR3). This valve raises the HT flow temperature and therefore reduces the amount of water that is circulated over the bypass of FR1 and increases the flow through the heat recovery heat consumer (FH3) and the fresh water cooler HT (FH1).

The low temperature (LT) cooling circuit provides cooling for the LT stage of the charge air cooler, the lube oil and the diesel oil coolers and possible other consumers like e.g. gearbox and generator coolers.
The LT flow temperature is controlled by FR2. The cooling system is laid out for 38°C under tropical conditions and full engine load. For better performance, the LT temperature is to be controlled to 32°C.
Caterpillar Motoren can deliver mechanic P-controllers with a set point range of 20 to 30°C or electric driven valves with electronic controllers, which must be set to 32°C.
Depending on the plant design the HT fresh cooling water pump can be fitted on the engine or be supplied separately with an electrical drive.

Cooling water system diagram, two circuit cooling, turbocharger at free end

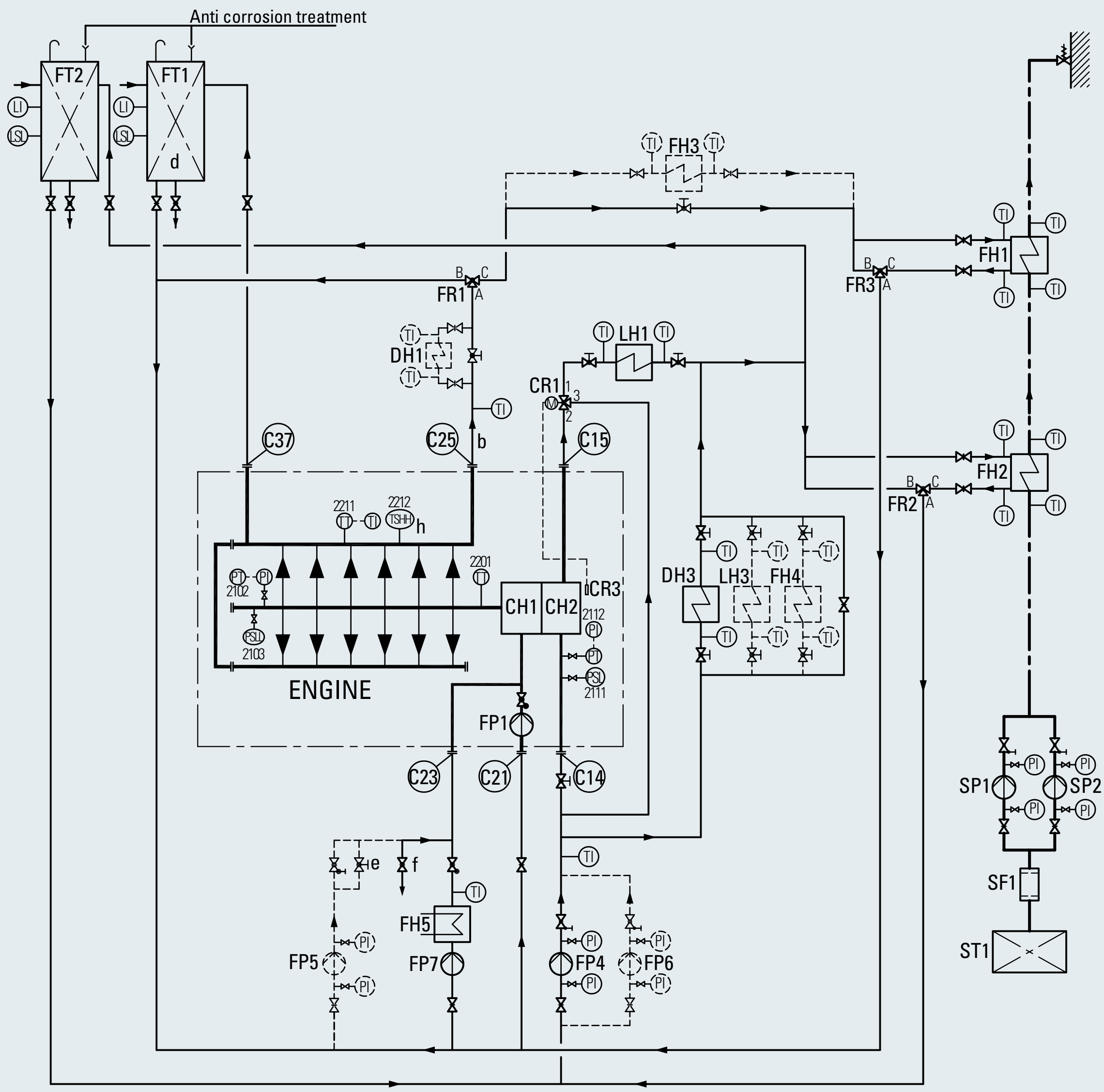

Fig. 8-1 Cooling water system, two circuit cooling, turbocharger at free end

In plants with skin or box coolers not required: Seawater system (SP1, SP2, SF1, ST1)

CH1	Charge air cooler HT
CH2	Charge air cooler LT
CR1	Charge air temperature control valve
CR3	Sensor for charge air temperature control valve
DH1	MDO preheater
DH3	Fuel oil cooler for MDO operation
FH1	Fresh water cooler HT
FH2	Fresh water cooler LT
FH3	Heat consumer
FH4	Heat exchanger gen.
FH5	Fresh water preheater
FP1	Fresh water pump (fitted on engine) HT
FP4	Fresh water pump (separate) LT
FP5	Fresh water stand-by pump HT
FP6	Fresh water stand-by pump LT
FP7	Preheating pump
FR1	Temperature control valve HT
FR2	Temperature control valve LT
FR3	Flow temperature control valve HT
FT1	Compensation tank HT
FT2	Compensation tank LT
LH1	Lube oil cooler
LH3	Gear box / generator cooler
SF1	Seawater filter
SP1	Seawater pump
SP2	Seawater stand-by pump
ST1	Sea chest

LI	Level indicator
LSL	Level switch low
PI	Pressure indicator
PSL	Pressure switch low
PSLL	Pressure switch low
PT	Pressure transmitter
TI	Temperature indicator
TSHH	Termperature switch high
TT	Temperature transmitter (PT100)

C14	Charge air cooler LT, inlet
C15	Charge air cooler LT, outlet
C21	Fresh water pump HT, inlet
C23	Stand-by pump HT, inlet
C25	Cooling water, engine outlet
C37	Vent

b	Measurement min. 2.0 m distance to C25.
d	Min. 4 m and max. 12 m above engine center.
e	Bypass DN12
f	Drain
h	Please refer to the measuring point list regarding design og the monitoring devices.

Cooling water system diagram, two circuit cooling with HT in LT heat exchanger

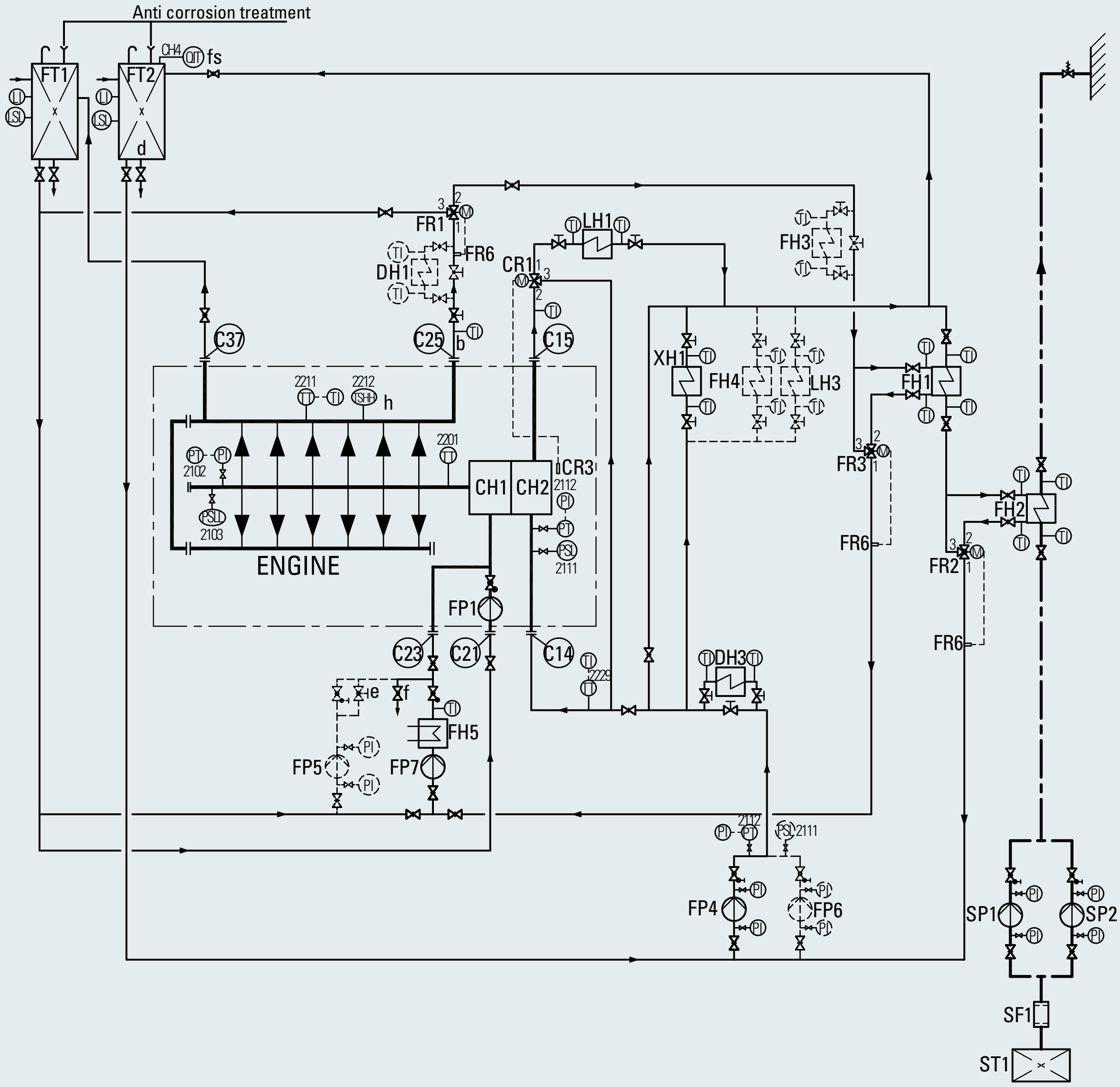

Fig. 8-2 Cooling water system, system diagram with HT in LT heat exchanger, turbocharger at free end

CH1	Charge air cooler HT
CH2	Charge air cooler LT
CR1	Charge air thermostat
CR3	Sensor for charge air temperature control valve
DH1	MDO preheater
DH3	Gas oil cooler
FH1	Fresh water cooler HT
FH2	Fresh water cooler LT
FH3	Heat consumer
FH4	Heat exchanger gen.
FH5	Fresh water preheater
FP1	Fresh water pump (fitted on engine) HT
FP4	Fresh water pump (separate) LT
FP5	Fresh water stand-by pump HT
FP6	Fresh water stand-by pump LT
FP7	Preheating pump
FR1	Temperature control valve HT
FR2	Temperature control valve LT
FR3	Flow temperature control valve HT
FR6	Sensor for temperature control valve
FT1	Compensation tank HT
FT2	Compensation tank LT
LH1	Lube oil cooler
LH3	Gear box / generator cooler
SF1	Seawater filter
SP1	Seawater pump
SP2	Seawater stand-by pump
ST1	Sea chest
XH1	Generator cooler

LI	Level indicator
LSL	Level switch low
PI	Pressure indicator
PSL	Pressure switch low
PSLL	Pressure switch low
PT	Pressure transmitter
QIT	Gas indicator and transmitter
TI	Temperature indicator
TSHH	Temperature switch high
TT	Temperature transmitter

C14	Charge air cooler LT, inlet
C15	Charge air cooler LT, outlet
C21	Fresh water pump, inlet
C23	Stand-by pump HT, inlet
C25	Cooling water, engine outlet
C37	Vent

b	Measurement min. 2.0 m distance to C25.
d	Min. 4 m and max. 12 m above engine center.
e	Bypass DN12
f	Drain
fs	Depending on classification society.
h	Please refer to the measuring point list regarding design of the monitoring devices.

Secondary circuit cooling system with turbocharger at free end

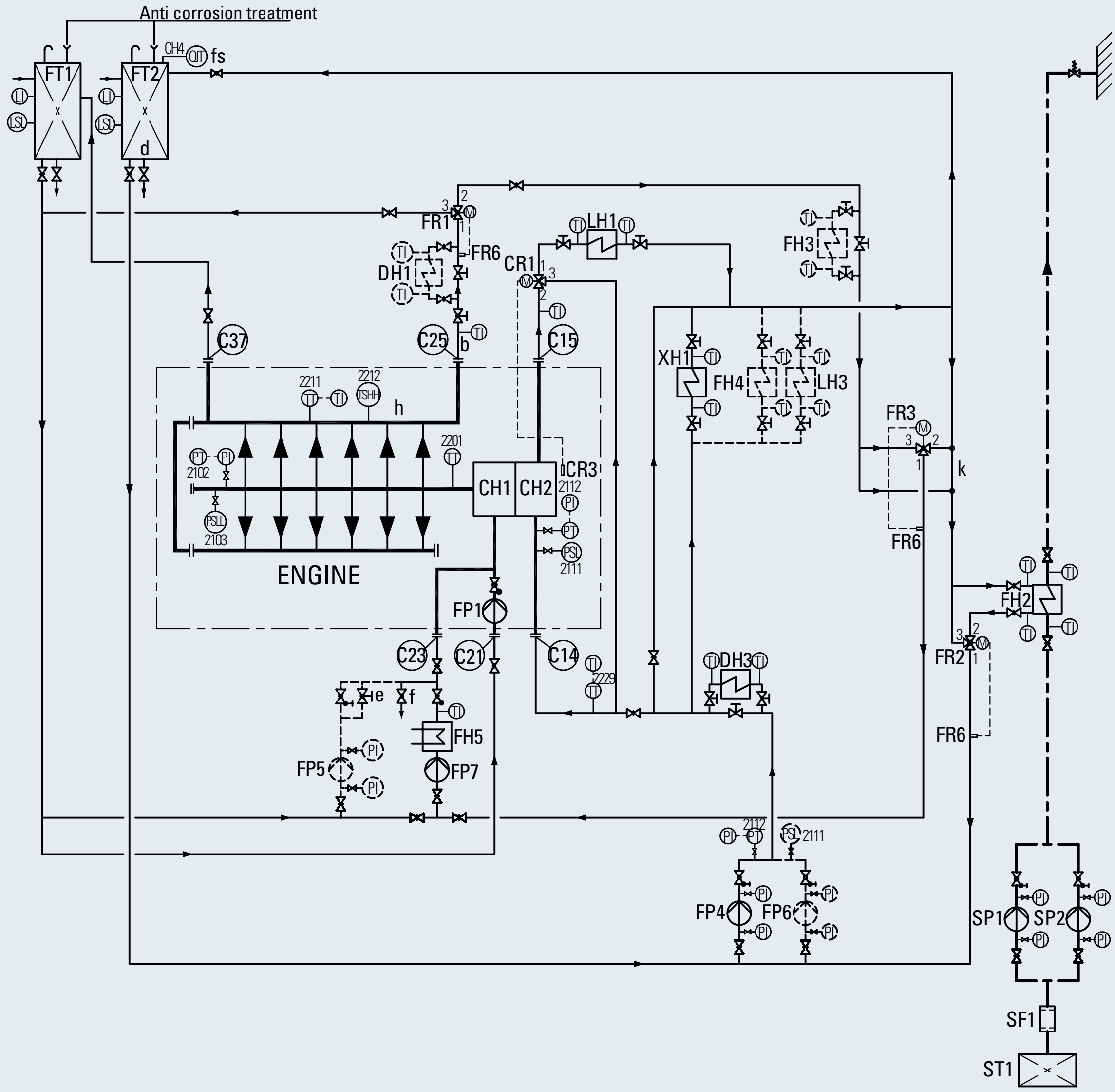

Fig. 8-3 Secondary circuit cooling system, system diagram, turbocharger at free end

CH1	Charge air cooler HT
CH2	Charge air cooler LT
CR1	Charge air thermostat
CR3	Sensor for charge air temperature control valve
DH1	MDO preheater
DH3	Gas oil cooler
FH1	Fresh water cooler HT
FH2	Fresh water cooler LT
FH3	Heat consumer
FH4	Heat exchanger gen.
FH5	Fresh water preheater
FP1	Fresh water pump (fitted on engine) HT
FP4	Fresh water pump (separate) LT
FP5	Fresh water stand-by pump HT
FP6	Fresh water stand-by pump LT
FP7	Preheating pump
FR1	Temperature control valve HT
FR2	Temperature control valve LT
FR3	Flow temperature control valve HT
FR6	Sensor temperature control valve LT
FT1	Compensation tank HT
FT2	Compensation tank LT
LH1	Lube oil cooler
LH3	Gear box / generator cooler
SF1	Seawater filter
SP1	Seawater pump
SP2	Seawater stand-by pump
ST1	Sea chest
XH1	Generator cooler

LI	Level indicator
LSL	Level switch low
PI	Pressure indicator
PSL	Pressure switch low
PSLL	Pressure switch low
PT	Pressure transmitter
QIT	Gas indicator and transmitter
TI	Temperature indicator
TSHH	Temperature switch high
TT	Temperature transmitte (PT100)

C14	Charge air cooler LT, inlet
C15	Charge air cooler LT, outlet
C21	Fresh water pump, inlet
C22	Fresh water pump HT, inlet
C23	Stand-by pump HT, inlet
C25	Cooling water, engine outlet
C37	Vent

b	Measurement min. 2.0 m distance to C25.
d	Min. 4 m and max. 12 m above engine center.
e	Bypass DN 12
f	Drain
h	Please refer to the measuring point list regarding design of the monitoring devices.
fs	Depends on classification society.
k	Distance min. 1 m.

8.4.2 Components

Freshwater cooler LT FH2 (separate)

Plate type, size depending on the total heat to be dissipated.
Most ship cooling systems dump the engines' waste heat in seawater cooled fresh water coolers. Caterpillar Motoren offers standardized titanium plate heat exchangers for this purpose. The size of these coolers will always be individually calculated for the heat dissipation demand of the respective systems.
Alternatively box coolers, radiators and other heat exchanger arrangements and any kind of combined cooling systems can be laid out and delivered.

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Compensation tank HT FT1 / LT FT2

- Arrangement: Min. 4 / max. 16 m above crankshaft center line (CL).
- Size according to technical engine data.
- All continuous vents from engine are to be connected.

Main functions of the cooling water header tank:

- It produces static pressure for the cooling water pumps in order to prevent cavitation. Therefore it has to be connected to each pump suction side or in case of a combined system to the suction side of the central cooling water pump.
- The vent lines continuously deliver a small water flow to the header tank. In this flow, air bubbles are carried away and the system gets de-aerated.
  - Vent lines should also be installed in the highest points of the circuits in order to get rid of all air bubbles that accumulate there.
  - Vent lines may not be too large in order to keep the flow over the header tank low. DN 20 is recommended and also valves for adjusting the flow must be installed.
- The flow of the vent lines gradually heats up the header tank by means of the constantly delivered hot water. This flow returns to the system via the pump suction side. As this circulation is very small in relation to the flow of the pump (if adjusted correctly), the temperature rise in the system will not be noticeable.
- The header tanks water volume balances the entire system volume, which changes due to thermal expansion and possibly due to leakages.

NOTE: Some marine classification societies require the HT compensation tank to be equipped with a gas sensor.

Electric driven charge air temperature control valve CR1 (separate)

	Dimensions [mm]					Weight
	DN	A	B	C	D	[kg]
12 M 46 DF	125	400	717	200	170	110
16 M 46 DF	200	600	900	300	188	278
–	250	730	948	455	188	380

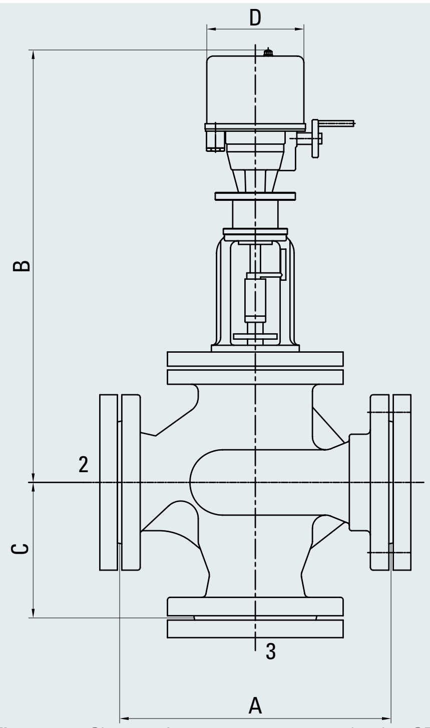


Fig. 8-4 Charge air temperature control valve CR1

01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

Fresh water pump (separate) HT FP3/FP5 and LT FP4/FP6

Capacity: acc. to heat balance.

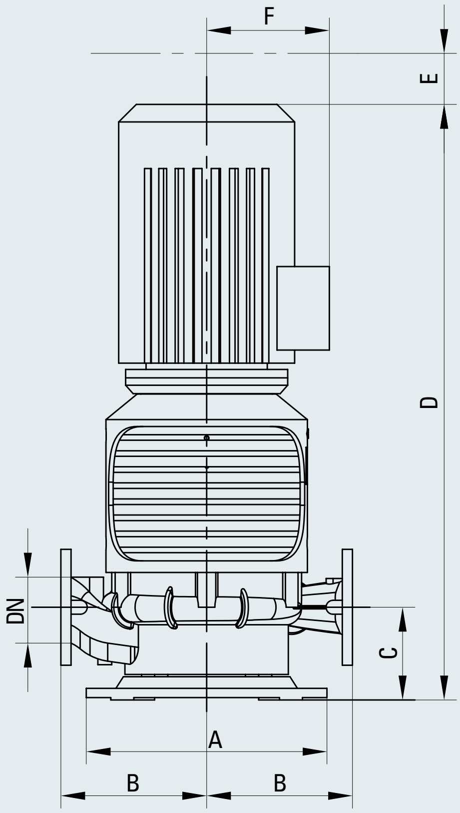


Fig. 8-5 Fresh water pump

Flow	Pressure	Dimensions [mm]							Weight
[m³/h]	[bar]	DN	A	B	C	D	E	F	[kg]
280	3.0	200	520	450	280	1,500	140	345	468
320	3.0	200	520	450	315	1,515	140	335	612

Temperature control valve HT FR1 / LT FR2 / HT flow FR3

P-controller with manual emergency adjustment (basis).
Option: PI-controller with electric drive. See charge air temperature control valve (CR1).

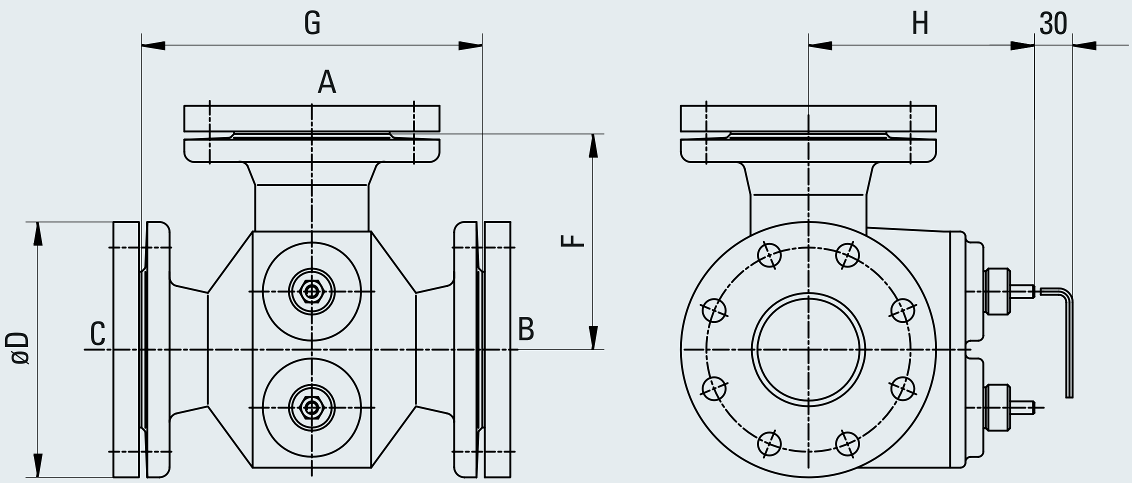


Fig. 8-6 Temperature control valve HT FR1

		Dimensions [mm]					Weight
		DN	D	F	G	H	[kg]
12 M 46 DF	HT	150	285	254	489	200	80
12 M 46 DF	LT	150*)	285	254	489	200	80
16 M 46 DF	HT	200[1)]	–	–	–	–	–
16 M 46 DF	LT	200[1)*)]	–	–	–	–	–

[1)] Not available. Use PI-controller with electric drive. See charge air temperature control valve (CR1).

*) Minimum depending on total cooling flow.

8.5 System diagrams heat balance

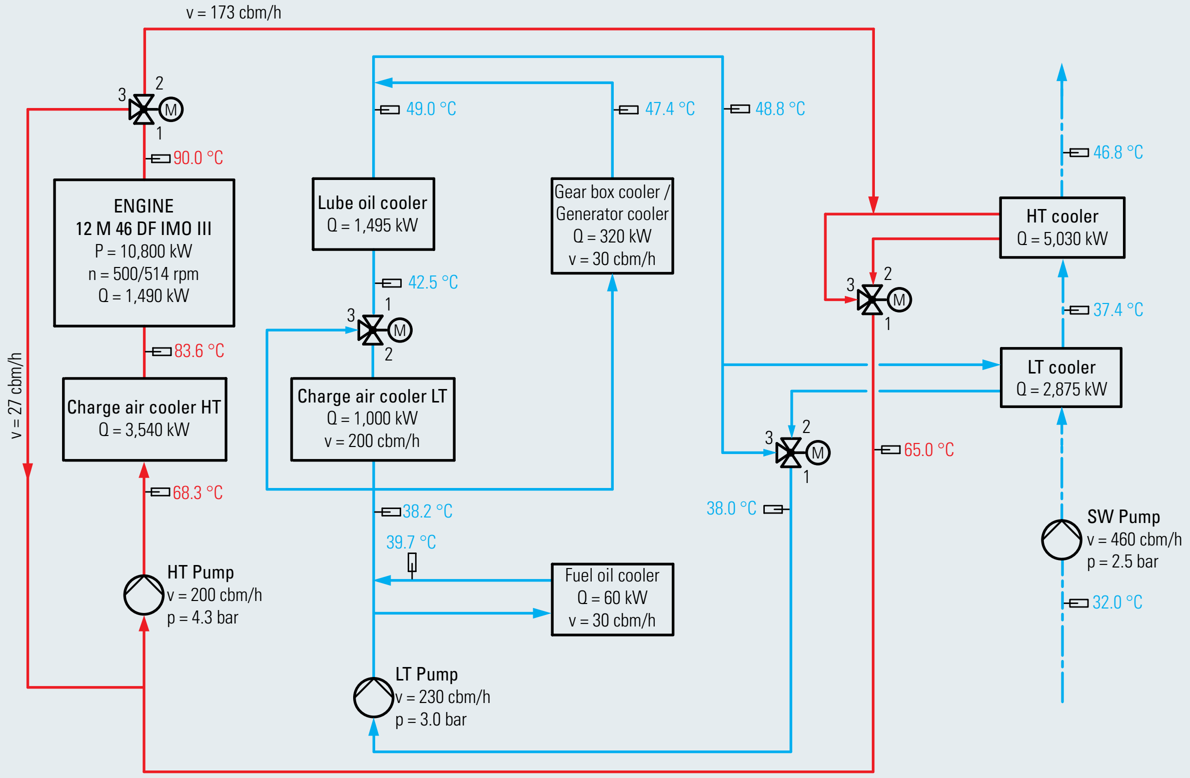


Fig. 8-7 Heat balance, system diagram 12 M 46 DF, 900 kW/Cyl.

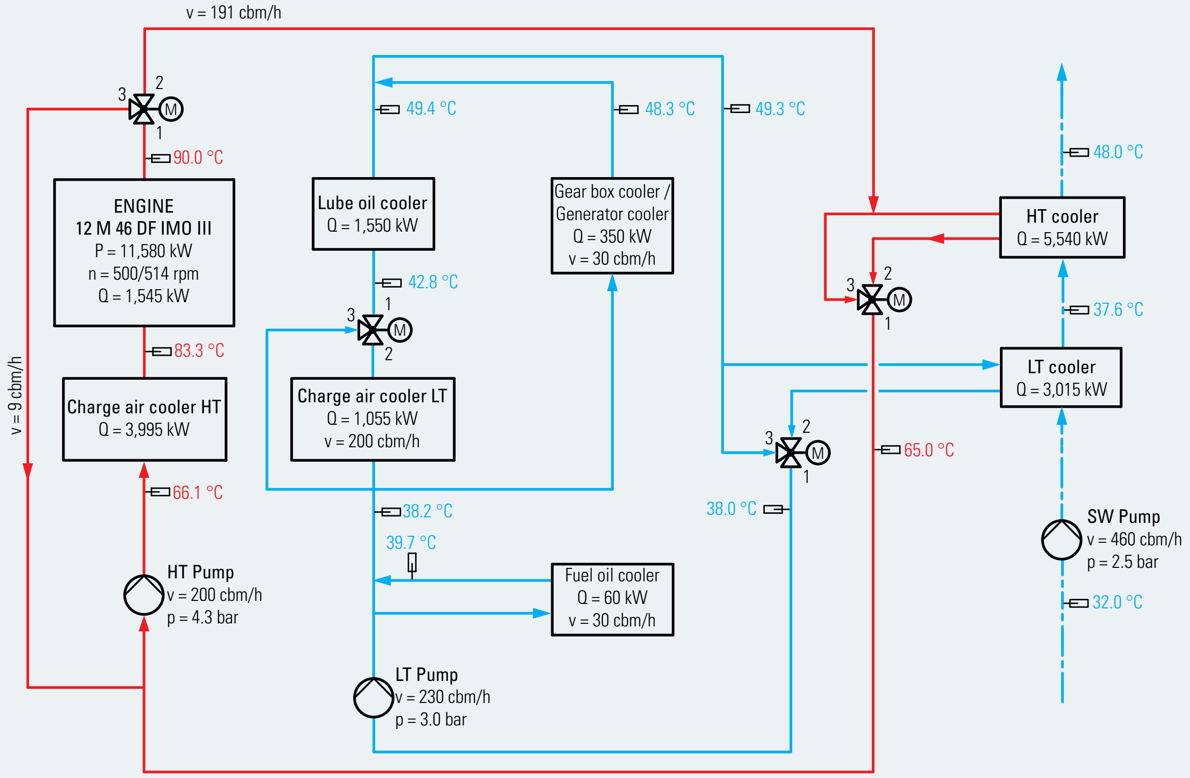


Fig. 8-8 Heat balance, system diagram 12 M 46 DF, 965 kW/Cyl.

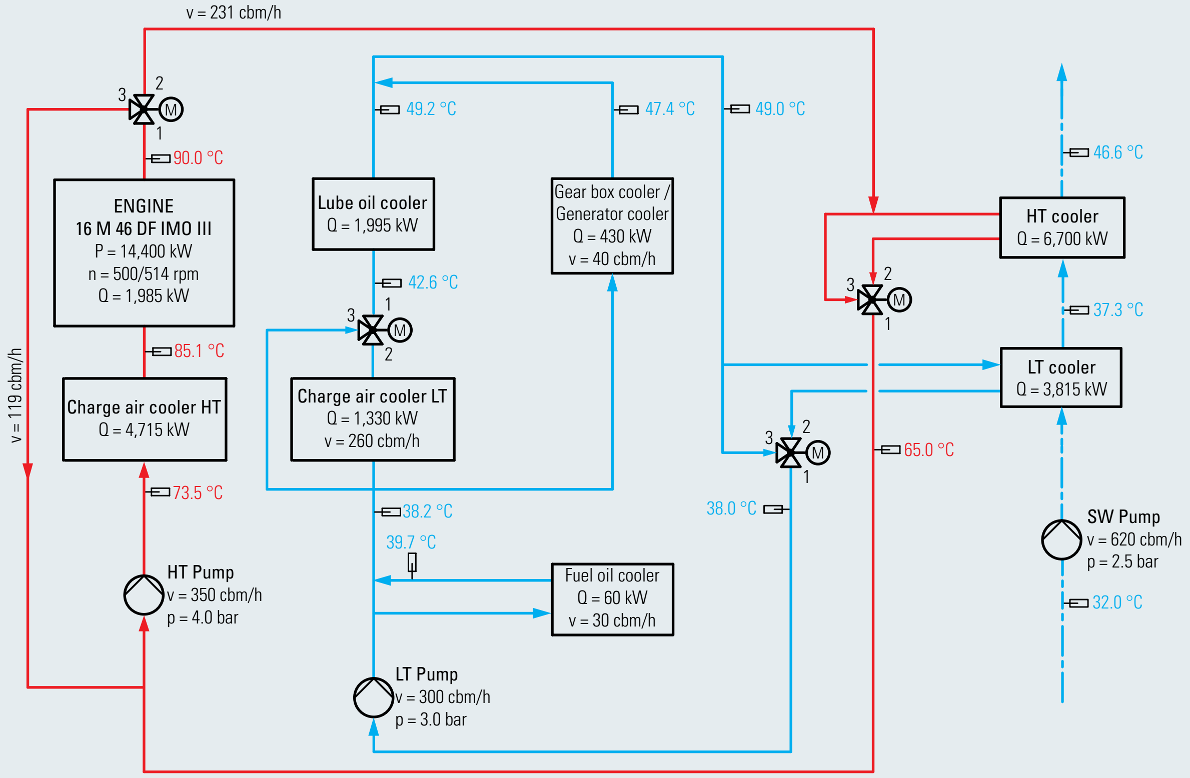


Fig. 8-9 Heat balance, system diagram 16 M 46 DF, 900 kW/Cyl.

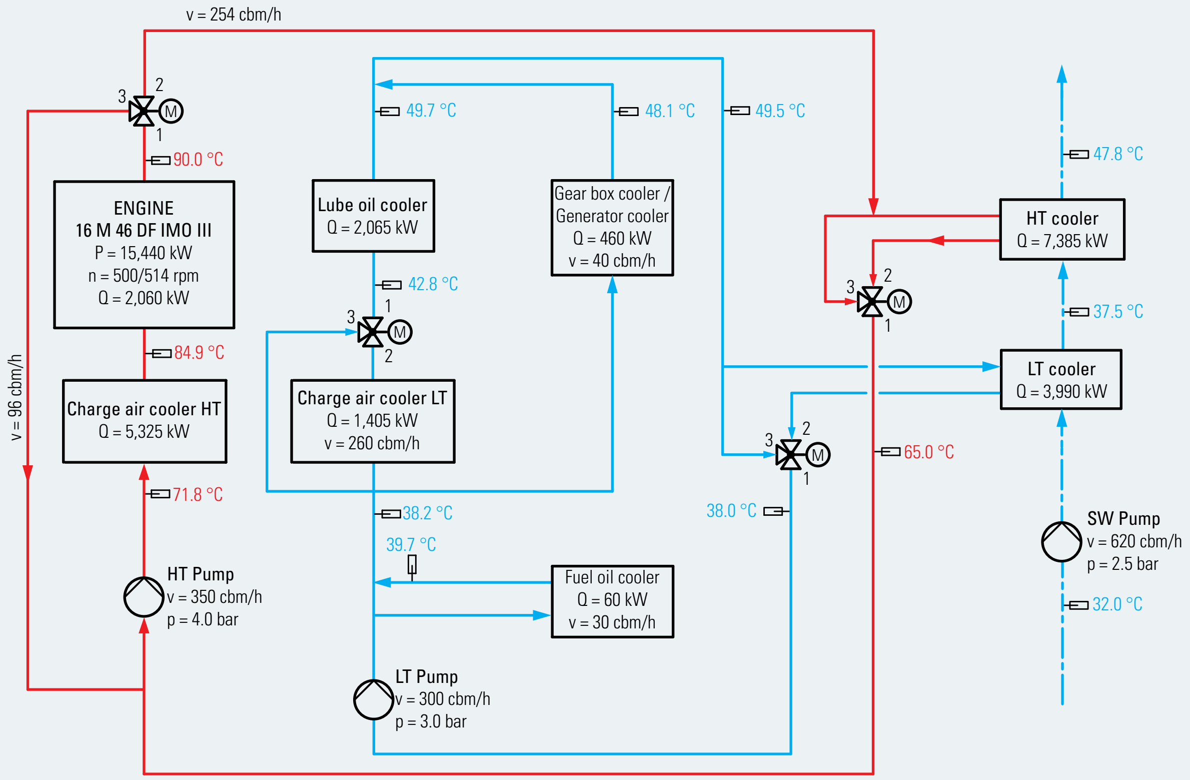


Fig. 8-10 Heat balance, system diagram 16 M 46 DF, 965 kW/Cyl.

8.6 Preheating (separate module)

8.6.1 Electrically heated

- The standard preheating system in plants delivered by Caterpillar Motoren is electrically heated.
- Consisting of baseframe mounted preheating pump FP7 (12 m³/h), electric heater FH5 (24 kW) and separate switch cabinet.
  Voltage 400 - 690, frequency 50/60 Hz.

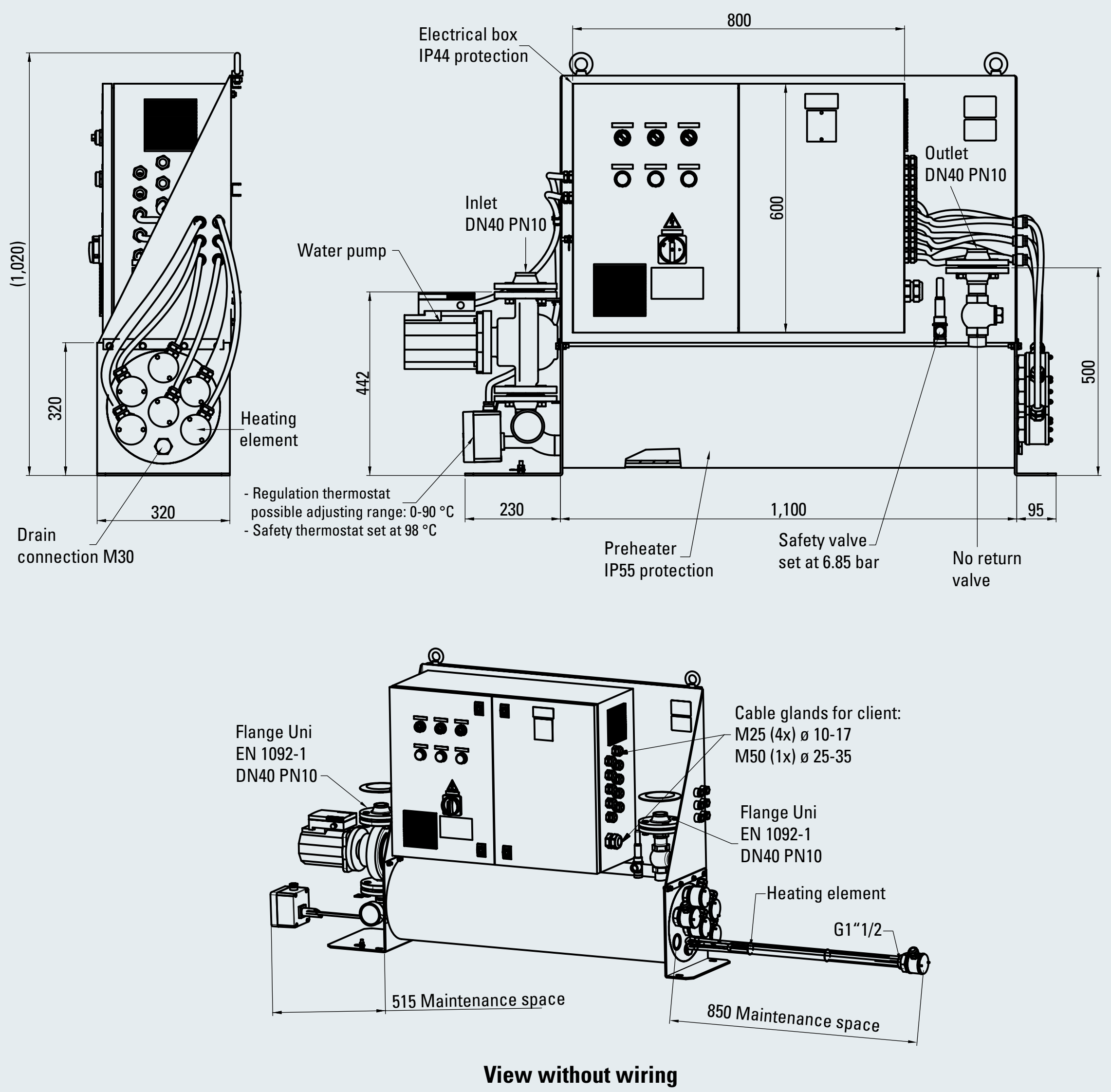


Fig. 8-11 Freshwater preheater FH5, preheating pump FP7

8.6.2 Other preheating systems

On request preheating systems heated by thermal oil or steam can be laid out and delivered by Caterpillar Motoren.

8.7 Box coolers system

On request box coolers can be laid out and delivered by Caterpillar Motoren.

8.8 Cooling circuit layout

The engine driven cooling water pumps are designed to provide the engine and its systems with cooling water.
For a rough layout of these circuits, a pressure drop of 0.5 bar per component can be calculated:
Taking the total estimated pressure loss of the whole circuit in account, the flow delivered by the pump can be read out from the pump performance curve.

8.9 Engine driven cooling water pumps

For VM 46 DF engines the HT cooling water pump is attached on and driven by the engine. Its performance is as shown in below curves.
For 16 M 46 DF an option is available, where through means of a small attached gearbox both the LT and the HT pump can be integrated on the engine. For this double pump arrangement please notice the red and blue curves in the according diagram, which are marked with the caption "double".

8.9.1 Engine driven cooling water pumps 12 M 46 DF

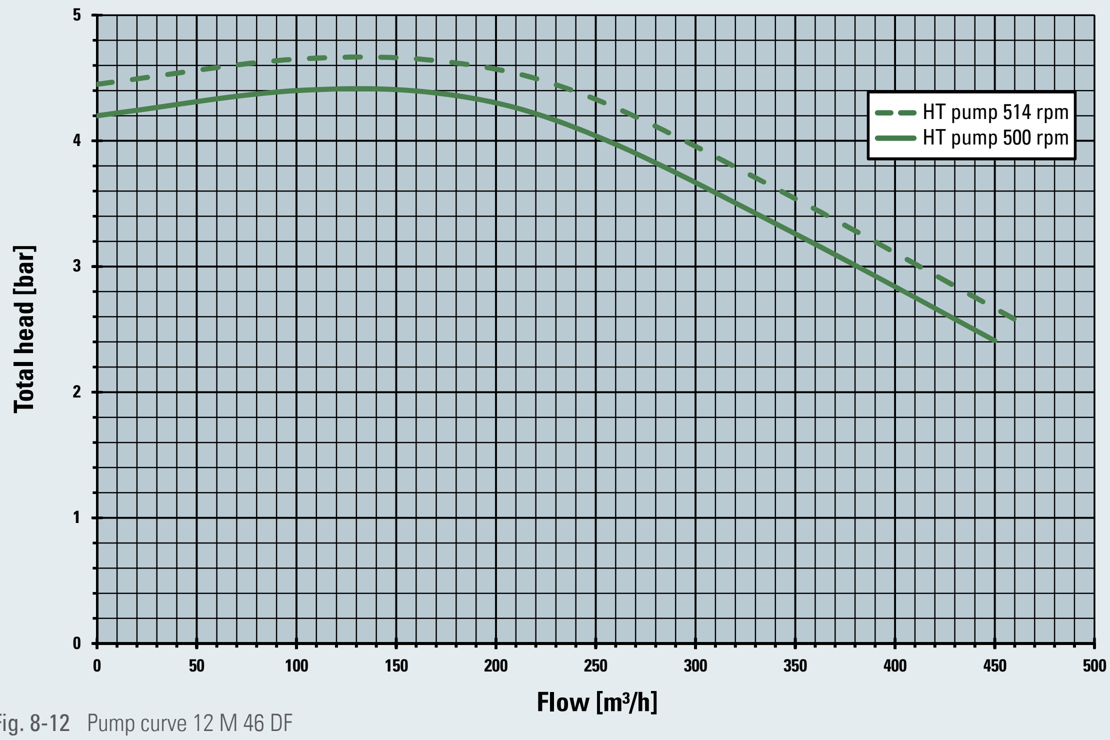


Fig. 8-12 Pump curve 12 M 46 DF

8.9.2 Engine driven cooling water pumps 16 M 46 DF

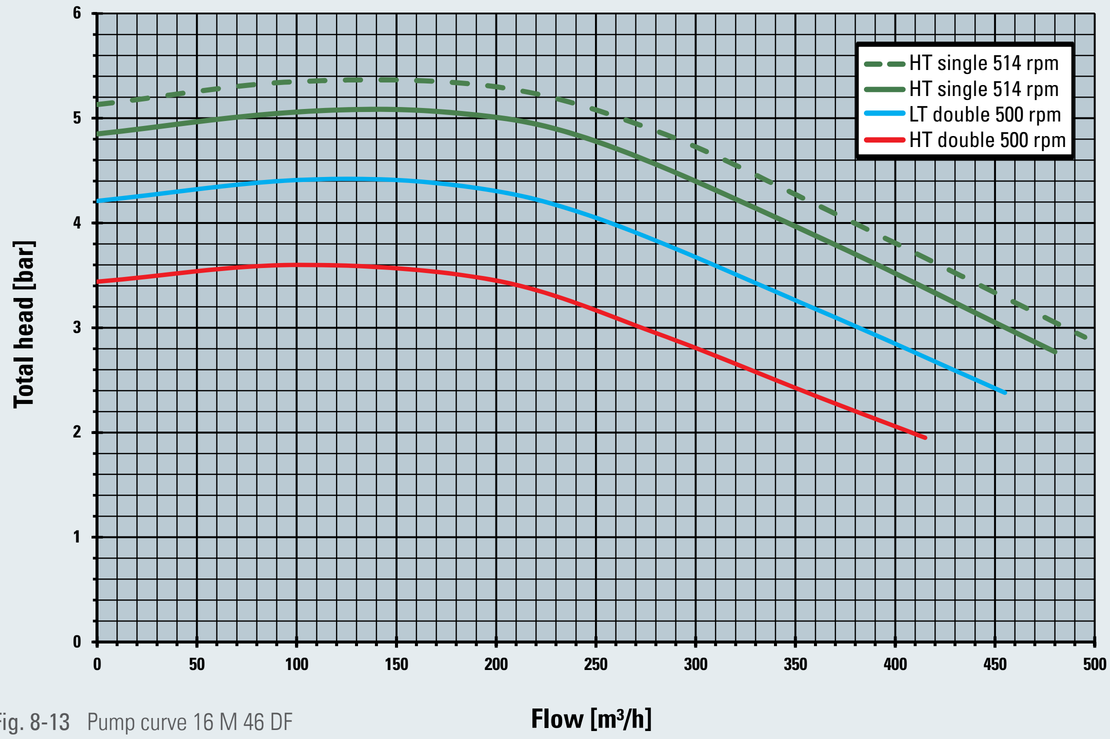


Fig. 8-13 Pump curve 16 M 46 DF

9.1 General

VM 46 DF engines require compressed air for starting the engine and providing actuating energy for safety and control devices as well as for Flexible Camshaft Technology (FCT).

The compressed air system consists at least of two compressors, two air receivers and its accessories such as filters, dryers, regulating and control valves and the piping system, of a capacity and air delivery rating dependent of the load profile of the ship and to meet the requirements of the respective classification society.

To ensure always the functionality of the compressed air system, it has to be free of solid particles and oil, see chapter 9.4 Compressed air quality.

9.2 Internal compressed air system

The VM 46 DF engine is started by means of compressed air with a nominal pressure of 30 bar.

The start is performed by direct injection of starting air into the cylinder through the starting air valves in the cylinder heads.

9.3 Compressed air system

Clean and dry starting air is required. A starting air filter has to be installed before engine, if required. Module P&ID's must be considered for detailed description.

Caterpillar Motoren recommends installing automatic drain valves.

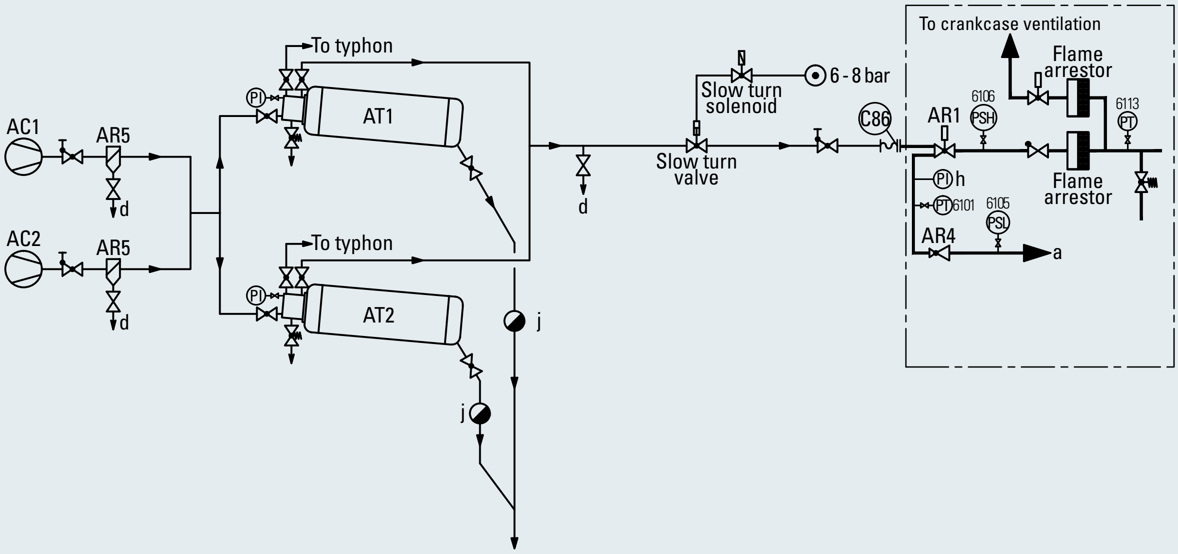


Fig. 9-1 External compressed air system, system diagram

AC1	Compressor	a	Control air
AC2	Stand-by compressor	d	Water drain (to be mounted at the lowest point)
AR1	Starting valve	h	Please refer to the measuring point list regarding design
AR4	Pressure reducing valve	j	Automatic drain required
AR5	Oil and water separator		
AT1	Starting air receiver (air bottle)		
AT2	Starting air receiver (air bottle)		

PI Pressure indicator

PT Pressure transmitter

C86 Connection / starting air

AT1/AT2 Option:

- Typhon valve
- Relief valve with pipe connection

9.3.1 Compressor AC1 / AC2

According to the requirements of the Marine Classification Society there should be minimum 2 starting air compressors with 50% total performance each.
The total performance has to be sufficient for refilling the starting air receivers to their normal pressure of 30 bar within one hour.

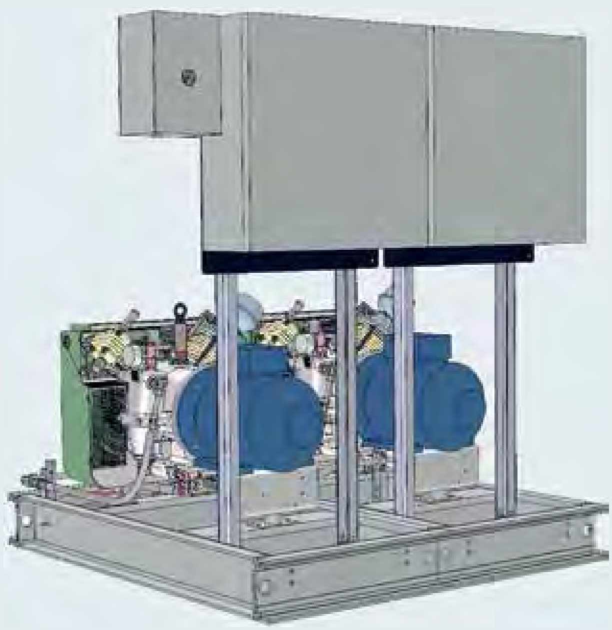


Fig. 9-2 Compressor AC1, AC2

Capacity:
$V\ [m^3/h] = \Sigma\ V_{Rec.} \cdot 30$

$V_{Rec.}$ Total receiver volume [m³]

9.3.2 Air receiver AT1, AT2

The starting air receivers are to be dimensioned for a nominal pressure of 30 bar.
M 46 DF engines require at least 14 bar as a minimum starting air pressure.
The total amount of air receivers and their capacity depend on the requirements of the classification societies and the type of installation.
It is required to install the receivers in a way, so that it can always sufficiently be drained manually or automatically at the deepest point of the receivers.

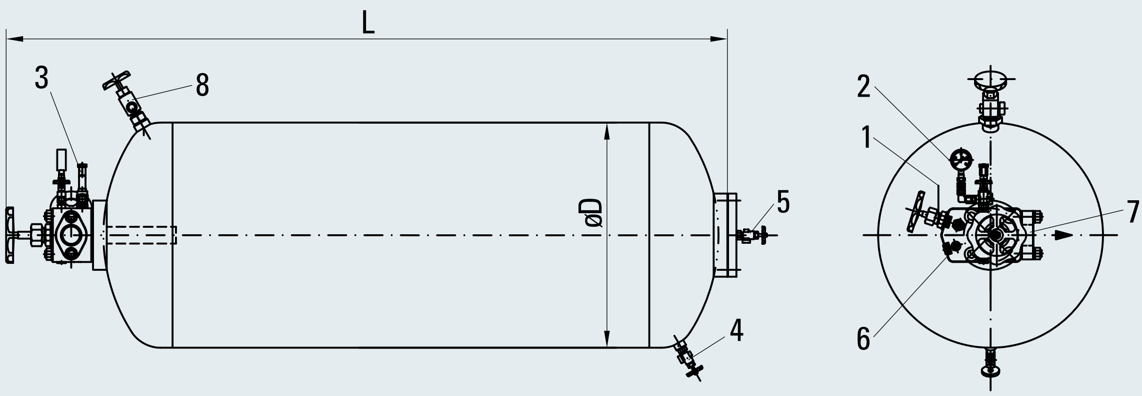


Fig. 9-3 Air receiver AT1, AT2

1	Filling valve
2	Pressure gauge G 1/4
3*	Relief valve DN 7
4	Drain valve DN 8
5	Drain position vertical
6	Connection G 1/2 with plug
7	Outlet of starting valve at engine
8	Typhon valve DN 16
Option:	* with pipe connection G 1/2

Normal requirements of classification societies:

No. of starts: 6 + 1 Slow turn
No. of receivers: min. 2

Calculation of air receiver volumes:

$$V = \frac{V_2 \cdot n \cdot P_{atm}}{P_{max} - P_{min}}$$

V = Air receiver volume
V_2 = Air consumption per start [Nm³]
n = Required number of starting procedures in sequence
P_{atm} = Ambient pressure [bar]
P_{max} = Maximum receiver pressure (30 bar)
P_{min} = Minimum receiver pressure (14 bar)

Receiver capacity acc. to GL recommendation AT1/AT2

	Single-engine plant	Twin-engine plant
12 M 46 DF	2 x 750 l	2 x 1,500 l
16 M 46 DF	2 x 1,000 l	2 x 2,000 l

Receiver capacity [l]	L [mm]	øD [mm]	Valve head	Weight approx. [kg]
250	2,037	480	DN 38	280
500	3,501	480	DN 50	460
750	3,033	650	DN 50	625
1,000	3,853	650	DN 50	810
1,500	3,753	800	DN 50	1,150
2,000	4,903	800	DN 50	1,490

When CO_2 fire extinguishing plants are arranged in the engine room, the blow-off connection of the safety valve is to be piped to the outside.

9.4 Compressed air quality

For a proper operation of the engine a compressed air quality of class 4 according ISO 8573-1 is required.

Instrument air specification:

Max. particle size:	15 µm
Max. particle density:	8 mg/m³
Water pressure dew point:	3 °C
Water:	6.000 mg/m³
Residual oil content:	5 mg/m³

- Oil content
  (Specification of aerosols and hydrocarbons which may be contained in the compressed air.)

- Particle size and density
  (Specification of size and concentration of particles which still may be contained in the compressed air.)

- Pressure dew point
  (Specification of the temperature on which the compressed air can cool down without the steam contained in it condensing. The pressure dew point changes with the air pressure.)

9.5 Slow turn

A slow turning device is mandatory and has to be installed, one per engine.

This is a precaution in case a cylinder has had oil or water leak into it, which would cause damage to the engine when starting.

If the engine completes two full revolutions on slow turn, the automatic main starting air will open for starting the engine.

	12 M 46 DF	16 M 46 DF
Air consumption per slow turn manoeuvre [Nm³]	6	7

9.6 Equipment

Compressor module

Caterpillar Motoren can design, offer and deliver integrated compressor modules:
Starting air receiver and compressors can be combined individually.
For further information please contact Caterpillar Motoren, technical department.

Fig. 9-4 Compressor module

10.1 Engine room ventilation

To obtain good working conditions in the engine room and to ensure a trouble free operation of all equipment a properly designed engine room ventilation system with cooling air and combustion air is required.

10.2 Combustion air system design

Combustion air describes the air the engine requires to burn fuel.
Combustion air demand see chapter 4, technical data.

10.2.1 Air intake from engine room (standard)

- Fans are to be designed for a slight overpressure in the engine room.
- On system side the penetration of water, sand, dust, and exhaust gas must be avoided.
- When operating under tropical conditions, the air flow must be conveyed directly to the turbocharger.
- The temperature at turbocharger filter should not fall below + 10 °C.
- In cold areas warming up of the air in the engine room must be ensured.

10.2.2 Air intake from outside

- The intake air duct is to be provided with a filter. Penetration of water, sand, dust and exhaust gas must be avoided.
- Connection to the turbocharger is to be established via an expansion joint.
  For this purpose the turbocharger will be equipped with a connection socket.
- At temperatures below + 10 °C Caterpillar Motoren / application engineering must be consulted.

10.3 Cooling air

Cooling air refers to the flow of air that removes radiant heat from the engine, generator, other driven equipment and other engine room components.
To dissipate the radiated heat a slight and evenly distributed air flow is to be led along the engine exhaust gas manifold starting from the turbocharger.

NOTE:
Radiated heat see technical data.

10.4 Condensed water from charge air duct

Operating the engine in tropical conditions, high ambient temperature and high humidity, may generate condensate (water) that needs to be drained.

The exhaust gas system discharges the exhaust gases, emitted from the engine, through a piping system to the atmosphere. To provide maximum efficiency of the engine, the resistance to the gas flow should be minimized. The back pressure directly after the turbocharger, influenced by the design of the exhaust gas piping and all installed components like exhaust gas boilers, catalysts and scrubbers is limited to 30 mbar. Higher values will increase the thermal load of the engine and may lead to higher fuel consumption.

11.1 Components

11.1.1 Exhaust gas nozzle

For an optimal integration of the engine in the engine room, regarding the discharge of the emitted exhaust gases different orientations of the exhaust gas nozzle are possible.
The orientation of the exhaust gas nozzle and transition piece for all VM 46 DF engines is 0 ° from the vertical line.

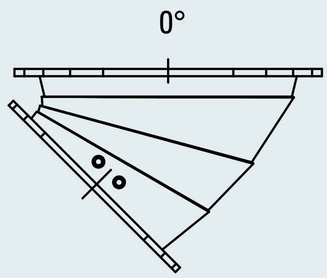


Fig. 11.1 Orientation of exhaust gas nozzle and transition piece

11.1.2 Exhaust gas compensator

The connection of the engine to the piping system of the ship has to be flexible to compensate possible engine vibrations, movements of resilient mounted engines and to reduce the forces generated by the thermal expansion of the exhaust gas piping acting to the turbocharger. For this connection a special type approved exhaust gas compensator which is flexible in all directions is available.
It is highly recommended to install the exhaust gas compensator directly after the above mentioned exhaust gas nozzle. If it is necessary to isolate the compensator area it must be possible that the compensator is able to expand and contract freely.

Basic design values of the standard exhaust gas compensators.

Type	Diameter [mm]	Length [mm]	Weight [kg]
12 M 46 DF	900	500	158
16 M 46 DF	1,000	620	209

11.1.3 Exhaust gas piping system

To minimize the forces acting through the compensator to the turbocharger and to guarantee a long lifetime of the compensator it is highly recommended to position a fixed point piping support directly after the compensator.

Each engine requires a separate exhaust gas pipe. The exhaust gas piping system of two or more engines is not allowed, otherwise exhaust gases from engines under operation be forced into cold engines not operating and causes engine damages as a result of condensed water from the exhaust gas.

Also the exhaust gas pipes and/or silencers should be equipped with water separating pockets and a drainage.

In order to minimize the pressure loss of the complete exhaust gas system it is recommended to use a suitable pipe diameter for the entire exhaust gas line.
According to the dimensions of the compensators (see table chapter 11.1.2) there are standard diameters proposed for the respective engine type in relation to the exhaust gas mass flow. In case of multiple of bends and other components integrated in the exhaust gas system it might be necessary to increase the pipe diameter.

For guidance the exhaust gas flow velocity should be less than 40 m/s.

For flushing the exhaust gas piping system after engine operation in gas mode an installation of a forced ventilation system is required.
According to class requirements explosion relief valves for single main engines and for multi-engine installations at least burst discs for explosion release device has to be installed in the exhaust gas system. For each individual installation the number and size of these devices will be determined by a simulation.

Resistance in exhaust gas piping

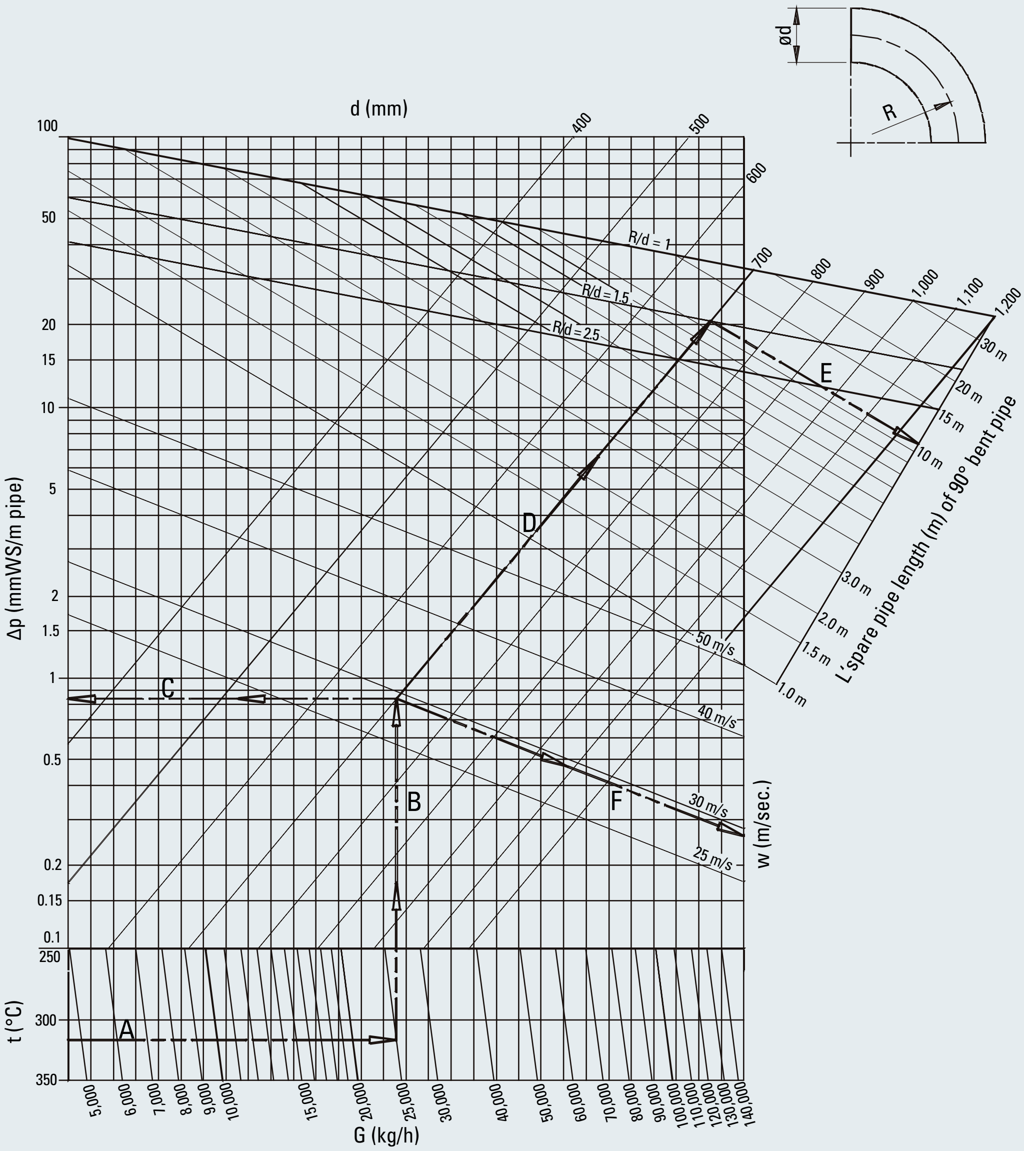


Fig. 11-2 Resistance in exhaust gas piping

Example (based on diagram data A to E):

T = 335 °C, G = 25,000 kg/h

L = 15 m straight pipe length, d = 700 mm

3 off 90 ° bend R/d = 1.5

1 off 45 ° bend R/d = 1.5

ΔPg = ?

Δp = 0.83 mm WC/m

L' = 3 · 11 m + 5.5 m

L = l + L' = 15 m + 38.5 m = 53.5 m

ΔPg = Δp · L = 0.83 mm WC/m - 53.5 m = 44.4 mm WC

t = Exhaust gas temperature [°C]

G = Exhaust gas massflow [kg/h]

Δp = Resistance/m pipe length [mm WC/m]

d = Inner pipe diameter [mm]

w = Gas velocity [m/s]

l = Straight pipe length [m]

L' = Spare pipe length of 90 ° bent pipe [m]

L = Effective substitute pipe length [m]

ΔPg = Total resistance [mmWC]

11.1.4 Silencer

The exhaust noise emission of the engine has to be reduced by an integration of at least one suitable silencer in the exhaust gas system to fulfil either the specifications of the relating classification company or legal regulations according to noise emissions or just to meet the clients comfort demand at open deck. Standard silencers which are especially designed for each engine type are available. As the silencers are of the absorptive type the flow resistance is low so just a back pressure of approximately 100 mmWC will arise. Long fibre absorbing heat resistant material is used for the noise absorption.
The noise attenuation of the standard silencers reaches at least 35 dB(A) and covers a wide frequency range. If necessary also silencers with a higher attenuation can be offered.
As standard the silencer can be provided either with or without a spark arrestor which will be provided with a soot collecting chamber. Each silencer is equipped with a water drain to draw out the condensed water. The silencer will be delivered with counter flanges, screws and gaskets. The mounting brackets for either horizontal or vertical installation as the insulation are not included. Optional the silencers can be delivered with loose or welded on mounting brackets accordng clients requirements.
Special attention has to be paid to the positioning of the silencer in the exhaust gas system to avoid resonance effects in the piping system. A wrong positioning of the silencer in the system can cause high noise levels before or after the silencer and can lead to extreme noise at the funnel end.

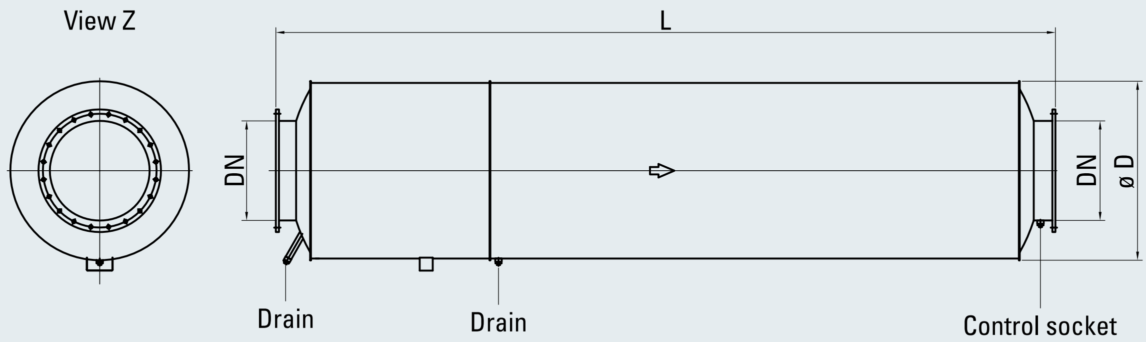


Fig. 11-3 Silencer

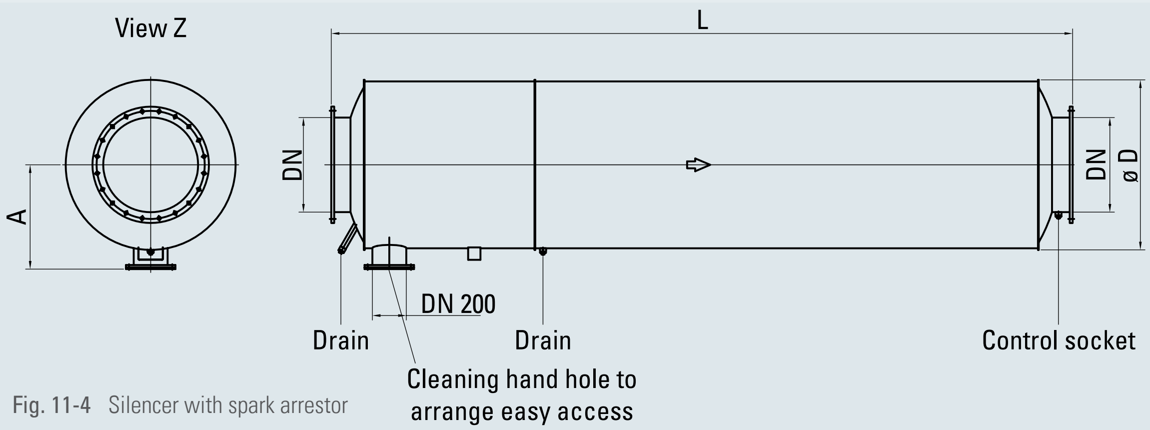


Fig. 11-4 Silencer with spark arrestor

Type	Dimensions [mm]				Weight	Weight with spark arrestor
	DN	A	D	L	[kg]	[kg]
12 M 46 DF	1,200	1,350	2,100	8,000	5,400	5,300
16 M 46 DF	1,500	1,480	2,400	9,500	8,600	8,600

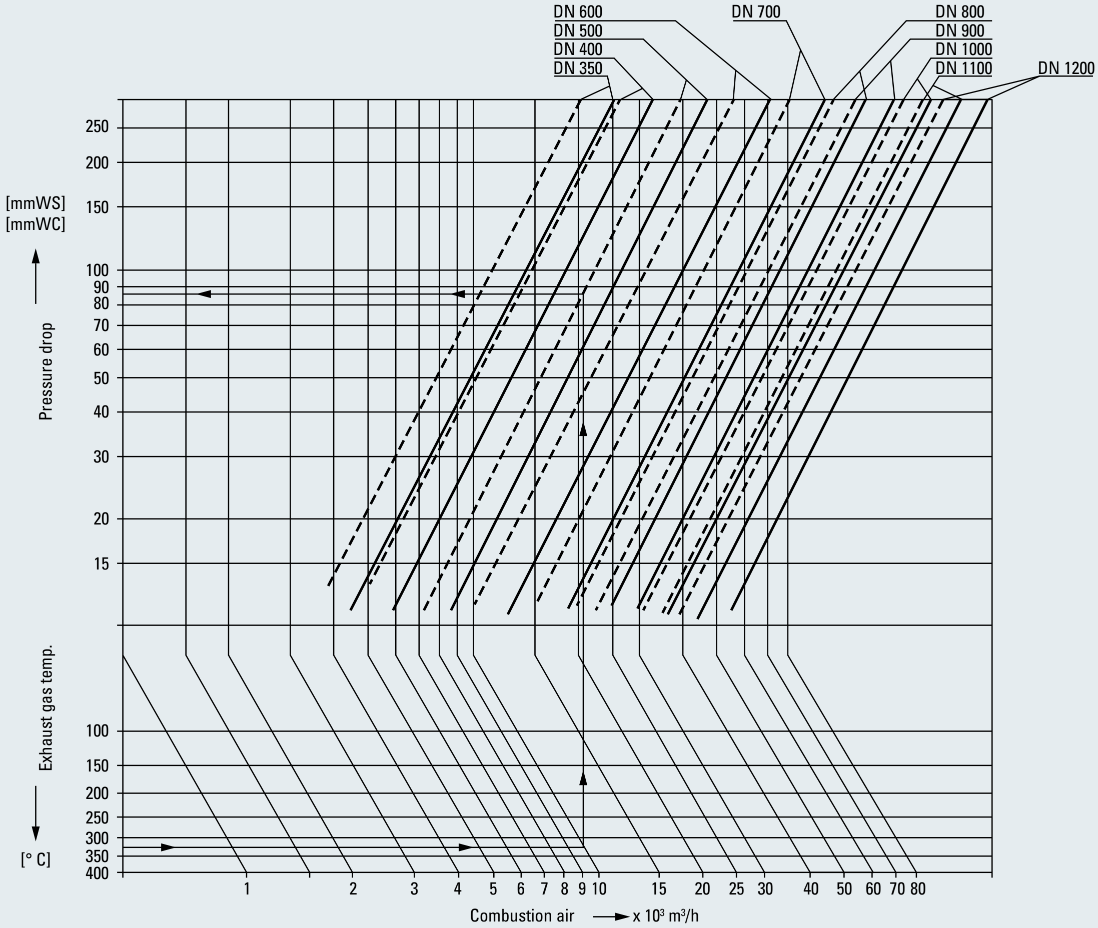


Fig. 11-5 Silencer diagram

11.1.5 Exhaust gas boiler

If exhaust gas boilers are used in the exhaust gas line each engine should have a separate boiler. If a common boiler is used for two or more engines the gas sections have to be separated.
Particularly when exhaust gas boilers are installed attention must be paid not to exceed the maximum recommended back pressure.

11.2 Turbocharger

11.2.1 Turbine cleaning system

Turbine cleaning is required for HFO operation. The cleaning is carried out with clean fresh water „wet cleaning“ during low load operation at regular intervals of 150 hours, depending on the fuel quality.

NOTE:
Duration of the cleaning period is approx. 20 minutes. Fresh water of 1.8 - 2.2 bar is required.

NOTE:
During cleaning the water drain should be checked. Therefore, the shipyard has to install a funnel after connection point C36.

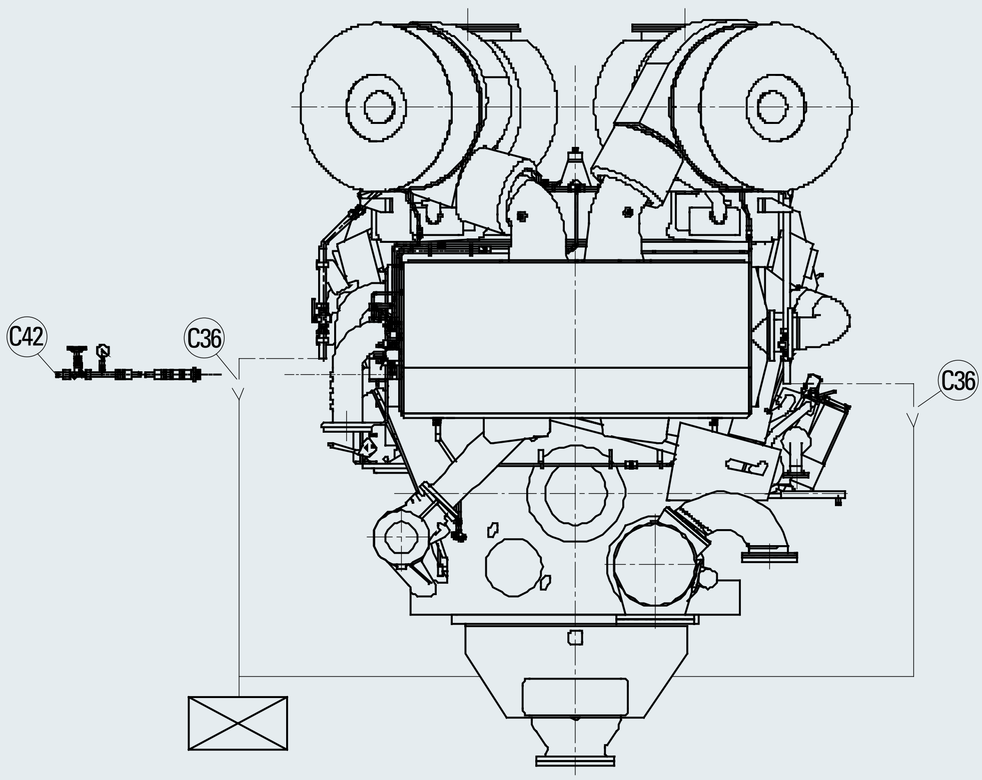


Fig. 11-6 Connection points fresh water and drain

C42 Fresh water supply, DN 12
C36 Drain, DN 30

Type	Water flow [l/min]	Injection time [min]
12 M 46 DF	22 - 28	10
16 M 46 DF	35 - 43	10

11.2.2 Compressor cleaning system

The components for cleaning (dosing vessel, pipes, shut-off valve) are engine mounted.

NOTE:
Water is fed every 24 hours before compressor wheel via injection pipes during full load operation.

12.1 Flexible Camshaft Technology (FCT)

The dual fuel engine has a modified FCT system, to ensure an optimal engine operation in all operating modes over the entire load range. The FCT system is basically known from the M 32 C diesel engine, where this technology is already validated.

Benefits:

- High potential for smoke reduction
- Low complexity
- Low technical risk-application of existing technology
- Increase knock margin at higher engine loads

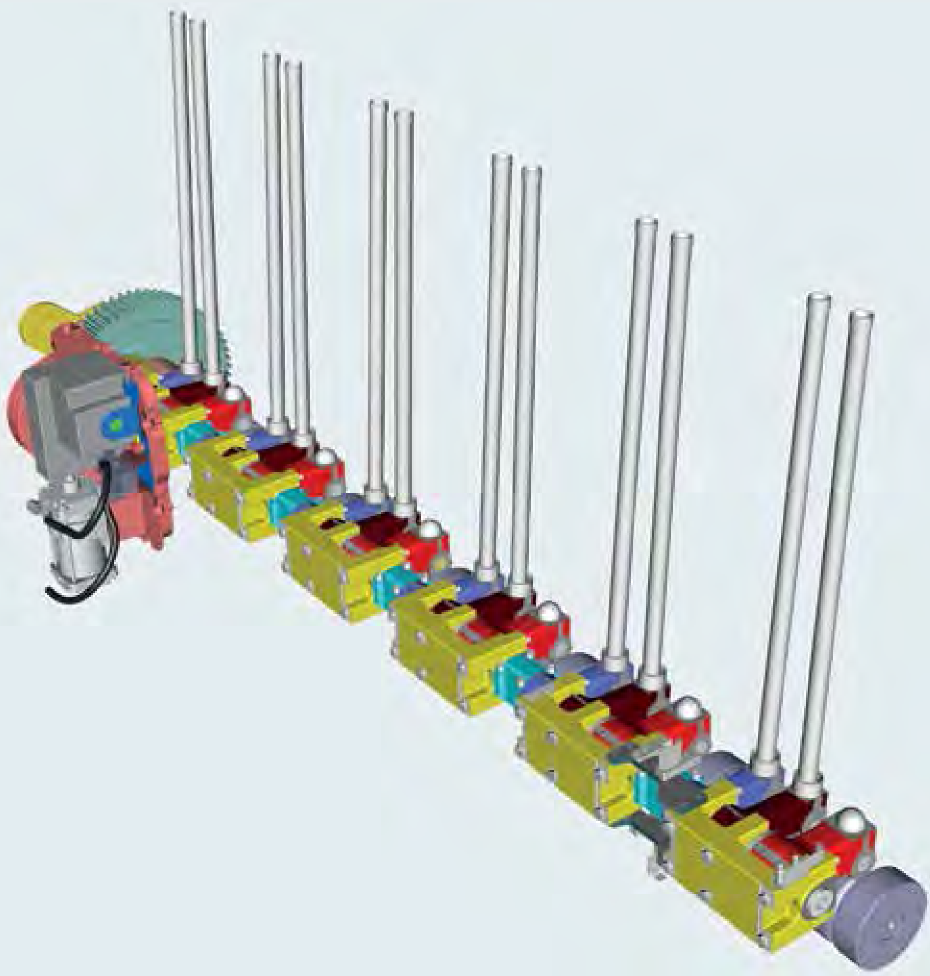


Fig. 12-1 Valve train with Flexible Camshaft Technology

13.1 Local control panel (LCP)

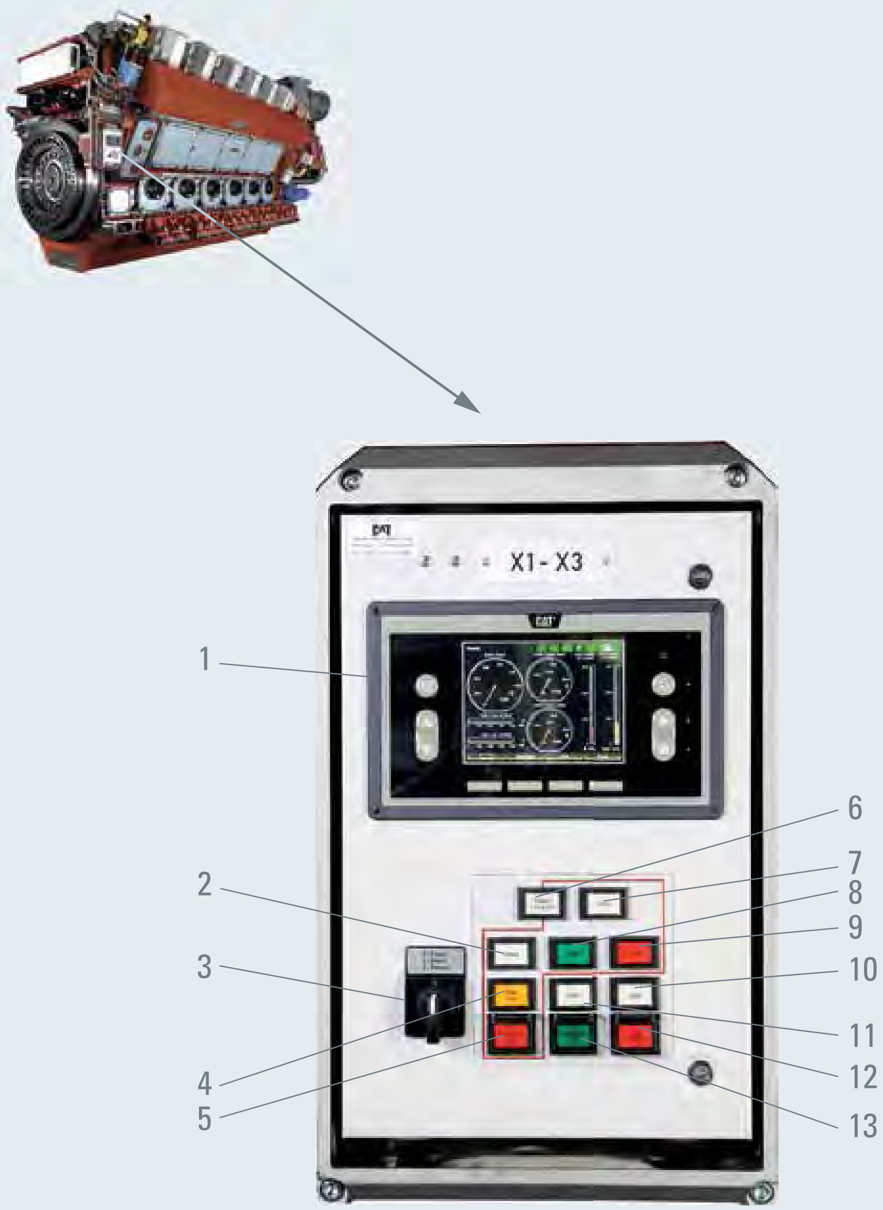
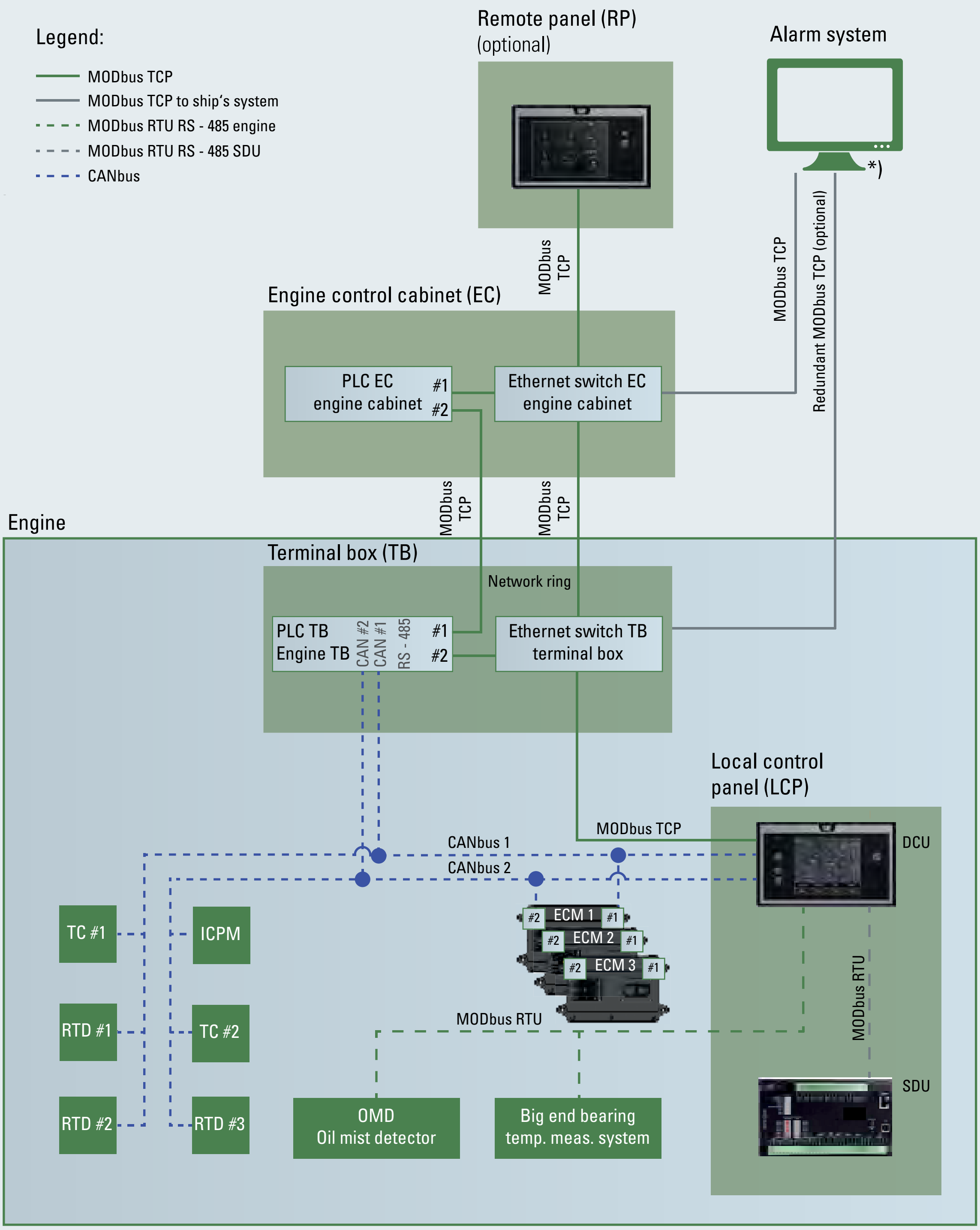


Fig. 13-1 Local control panel

1	DCU (Display and alarm system)	8	Start
2	Reset	9	Stop
3	0 = Repair, 1 = Engine, 2 = Remote	10	Lower
4	Slow turn	11	Raise
5	Emergency stop	12	Gas shut-off
6	Diesel mode indication, lamp test	13	Emergency start
7	Gas mode indication		

13.2 Data link overview



*) MODbus RTU for alarm system in optionally available

Fig. 13-2 Data link overview - VM 46 DF

MACS

Modular Alarm Control System

SDU
Protection system in local control panel
DCU
Display and alarm system in local control panel
PLC
PLC in engine cabinet (EC)
PLC in engine terminal box on engine (TB)
RTD
PT100 module for charge air temperature, lube oil temperature, cooling water HT/LT temperature and main bearing temperature
TC
Thermocouple modules for exhaust gas temperature
RP
Remote panel (optional)
External display for engine alarm and monitoring system
ECM
Engine control module
OMD
The oil mist detector measures each cylinder.
CTM
Big end bearing temperature monitoring
Each cylinder compartment of the cylinder crankcase is measured by the CTM.
ICPM
The “In-cylinder pressure monitoring“ computes combustion characteristics for each cylinder including knock intensity per cylinder

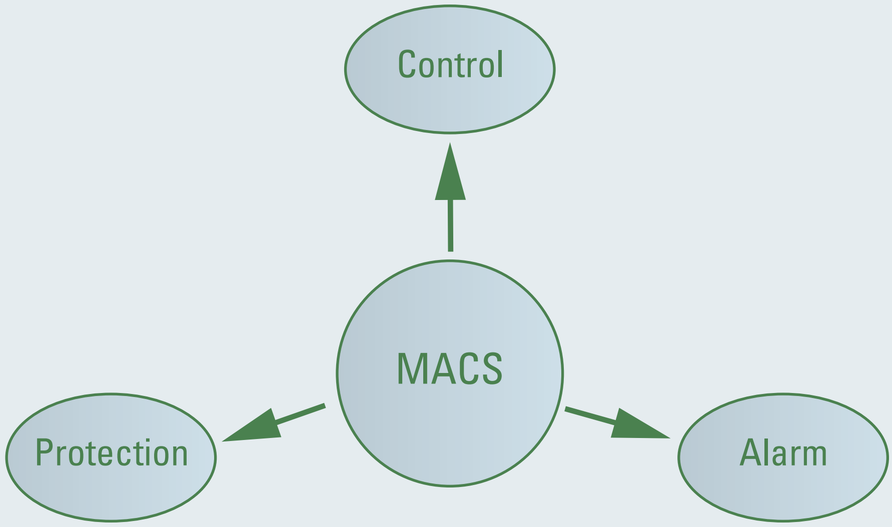
Regardless of RTU or TCP, the MODbus address registers are the same. Just the hardware protocol differs.

MODbus TCP
At MODbus TCP a connection between server and client will be established. Therefore an IP address will be assigned.

MODbus settings
Type: MODbus TCP
Interface: ethernet
IP: will be assigned
Baud rate: 10 mbit/s / 100 mbit/s
Connector: RJ45

13.3 Components

Modular Alarm and Control System (MACS)



The VM 46 DF engines will be provided with a new Modular Alarm and Control System, called MACS. The basic engine control and monitoring system will be installed in the local control panel. Where extension modules are necessary external plc based I/O extension modules will be installed.

The main functions of the control systems are:

- Alarm management
- Local start and stop, emergency start and stop from the engine control panel
- Remote start and stop from the power management system (PMS)
- Start and stop sequence control
- Critical parameter monitoring
- Slow turn control
- Flexible camshaft technology (FCT monitoring)
- Exhaust gas termperature monitoring
- Main and big end bearings temperature monitoring

For the following modules the control and monitoring is integrated in MACS:

- Ignition fuel module
- Ventilation module
- Crankcase gas detection

Engine control module (ECM)

The engine control module controls the fuel system, air fuel ratio, engine speed and Flexible Camshaft Technology (FCT). The module has its own set of sensors for all control relevant functions and can operate independently from start/stop system, alarm system (DCU) or protection system (SDU).
For multiple engine operation the ECM provides also load sharing functions. An isochronous load distribution by master/slave principle or droop operation is possible.

Oil mist detector (OMD)

The oil mist detector measures the oil mist concentration for each cylinder compartment and generate an alarm for high oil mist concentration. The data is available by MODbus RTU at the DCU. Hardwired outputs are also provided.

Big end bearing temperature measuring system (CTM)

The big end bearing temperature measuring system measures the temperature for each big end bearing and generates an alarm for high temperature. The data is available by MODbus RTU at the DCU. Hardwired outputs are also provided.

Gas valve unit (GVU)

The gas valve unit provides the engine with the desired gas fuel pressure and is controlled by the engine's control and monitoring system (MACS). It has several features (e.g. double block and bleed valve) to safety cut the engine from the gas train and to removce the gas fuel from the piping system (flushing).

Crankcase gas detection (CGD)

The crankcase gas detection system monitors the actual concentration of explosive atmosphere in the crankcase in means of methane concentration in lower explosion limit (LEL). If the concentration increases above a fixed value an alarm is triggered and in a second step the engine switches back to diesel mode.

Ventilation module (VM)

The aim of the ventilation module is to detect a leakage in the double walled gas pipes downstream the gas valve unit all the way over the engine. The air in the double walled gas pipe will be ventilated and the gas concentration will be measured.

Ignition fuel module (IFM)

The ignition fuel control system provides the required ignition fuel oil quality for the engine's ignition system.

Exhaust gas module (EGV)

The exhaust gas module is installed to ventilate the ship side exhaust gas system after an emergency stop of the engine in gas operation. The module consists of a ventilation fan, a separation butterfly valve and exhaust gas compensator for the conntection to the exhaust gas system.

Slow turn device (STD)

The slow turn function is used to detect water in the combustion chamber, e.g. after a long non-operation period.

13.4 Device overview

13.4.1 Remote engine control

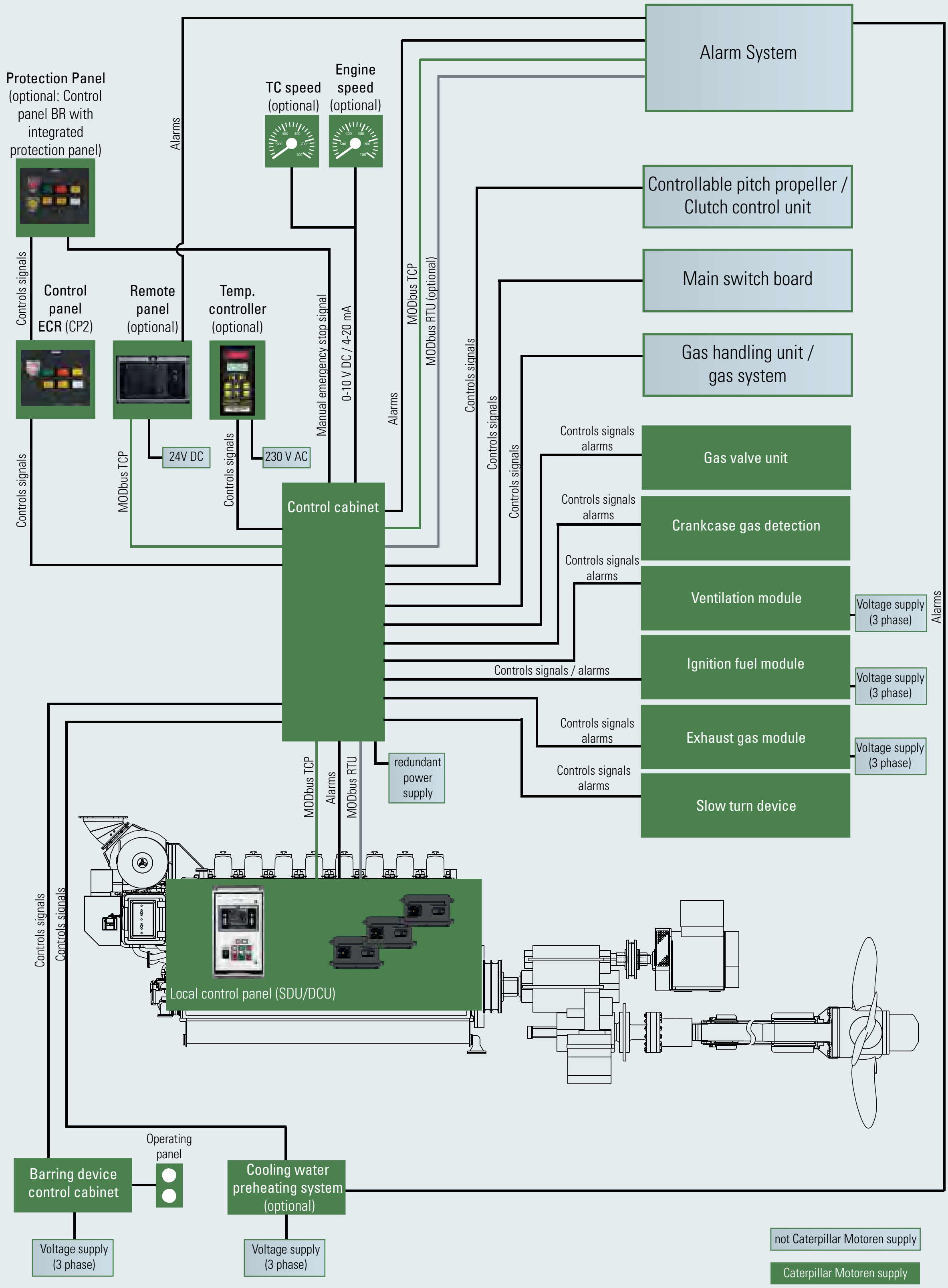


Fig. 13-3 Remote control for single-engine plant with one controllable pitch propeller

13.4.2 Genset control

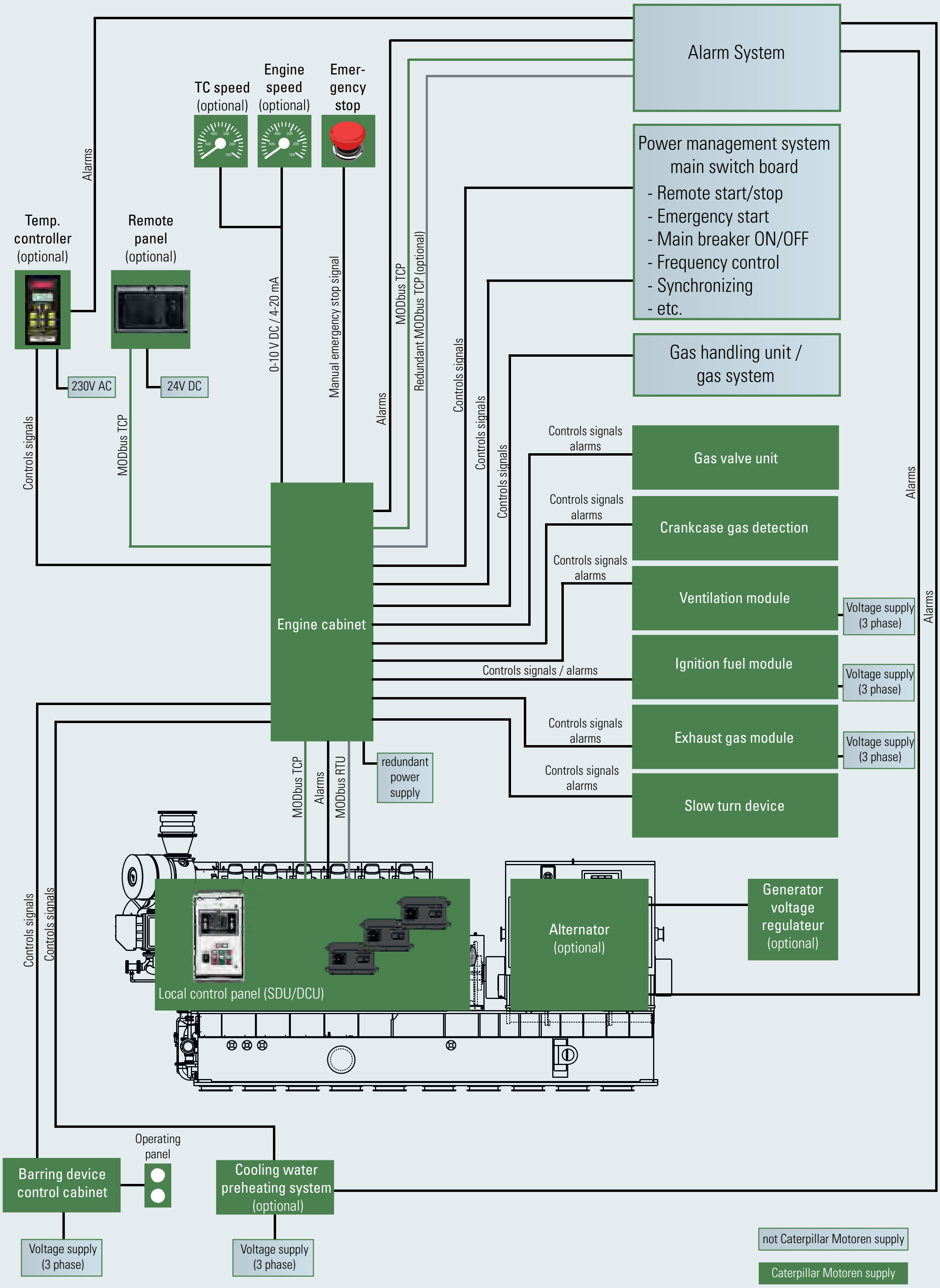
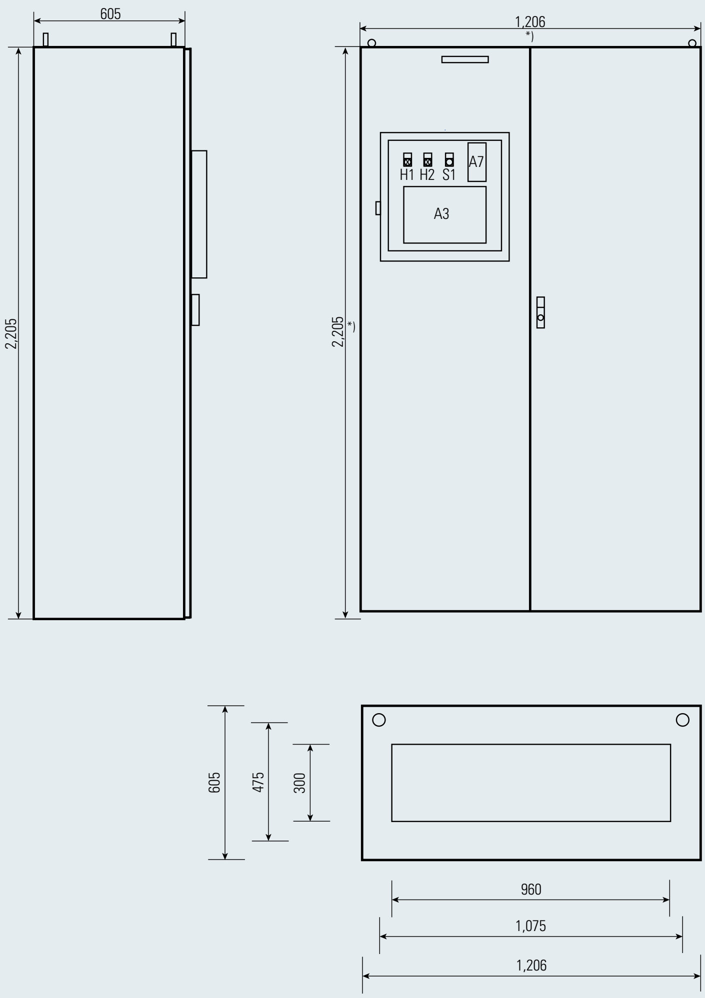


Fig. 13-4 Generator set control VM 46 DF

13.5 Control cabinet

Each engine is equipped with a separate control cabinet. The control cabinet acts as an interface between engine and external devices. Information about the engine status are available via MODbus TCP or MODbus RTU (optionally).
External signals for the engine control, monitoring and alarm system (for example gearbox, CPP control system, power management system, main switch board, gas system...) can be transferred as 4-20 mA, binary, or PT100 signals.
Safety relevant signals to the PLC are wire break and short circuit monitored.
The remote panel or the temperature controller can be optionally integrated in the control cabinet.



H1: Main supply without failure
H2: Back up supply without failure
S1: Lamp test

Optional in the control cabinet integrated

A3: Remote panel
A7: Charge air temperature controller

Degree of protection: IP54
Weight: Approx. 355 kg

*) **ATTENTION:** A distance of 300 mm on each side for air circulation is necessary.

NOTE: Dimesions are shown in mm

Fig. 13-5 Control panel

01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

13.5.1 Clutch control system

The diagram below shows an example of a typical soft-clutch engagenemt timeline, required by Caterpillar Motoren for marine main engines.
To avoid engine stalling in case of high speed drop, overload of the flexible couplings and visible smoke, the engaging operation has to be smooth and easily controllable.
Time T_2 is very important in this context: It indicates the real slipping time which has to be minimum 3 seconds.

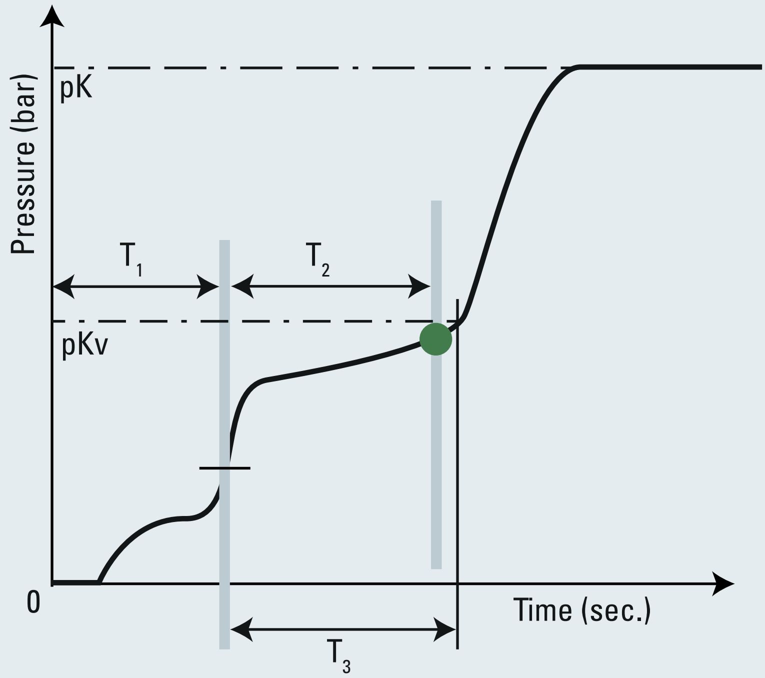


Fig. 13-6 Clutch in procedure for propulsion systems

pK = Lube oil switching pressure
pK_V = Control pre-pressure
T_y = Filling time
T_2 = Slipping time
T_3 = Pressure holding time
● = Point of synchronization

The clutch in speed of the engine should be min. 70 % of rated speed, but could be 60 % depending on TVC.

13.6 Requirements

13.6.1 Requirements on Control Pitch Propeller (CPP) System

Standard interface to gearbox and controllable pitch propeller for single-engine system

Gearbox	Lube oil pressure low (NO)	binary	→	24 V DC	Starting interlock for engine	Main engine
Gearbox	Common load reduction (NO)	binary	→	24 V DC	Slow down for engine	Main engine
Gearbox	Lube oil pressure low (NO)	binary	→	24 V DC	Shut down for engine	Main engine
Controllable pitch propeller	Actual engine speed		←	4-20 mA	Engine speed	Main engine
Controllable pitch propeller	Actual engine load		←	4-20 mA	Load signal 0-110%	Main engine
Controllable pitch propeller	Main engine in overload	24 V DC	←	binary	Overload indication at rated speed	Main engine
Controllable pitch propeller	Request remote control	24 V DC	←	binary	Local/remote switch contact at engine	Main engine
Controllable pitch propeller	Accept remote control	binary	→	24 V DC	Remote control accepted	Main engine
Controllable pitch propeller	Local/remote control	24 V DC	←	binary	Closed contact when main engine 1 is in remote control	Main engine
Controllable pitch propeller	Reduce to 40% load	24 V DC	←	binary	Slow down at engine	Main engine
Controllable pitch propeller	Pitch to zero / auto clutch out	24 V DC	←	binary	Shut down at engine	Main engine
Controllable pitch propeller	Speed setting signal	4-20 mA	→		Speed setting signal for load share unit (ECM)	Main engine
Controllable pitch propeller	Clutch engaged or pitch not zero	binary	→	24 V DC	Starting interlock	Main engine

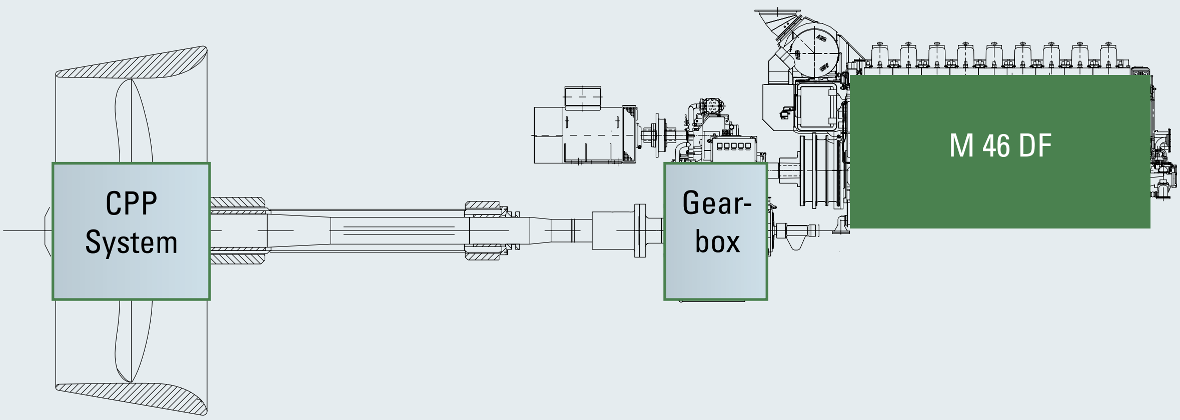


Fig. 13-7 Standard interface to gearbox and controllable pitch propeller for main engine system

01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

13.6.2 Requirements on power management system

Standard interface to power management system / main switch board

Power management system / main switch board				Main engine
External starting interlock	Binary contact	→	24 V DC	External starting interlock
External engine shutdown	Binary contact	→	24 V DC	External engine shutdown
Blackout	Binary contact	→	24 V DC	Blackout (start release of starting interlock prelubrication)
Indication shutdown undelayed/delayed	24 V DC	←	Binary contact	Shutdown undelayed/delayed
Load signal from kW transducer *)	4-20 mA	→	Max. load 250 Ω	Load signal from kW transducer
Raise / lower (remote)	Binary contact	→	24 V DC	Raise / lower (remote)
Isochronous / droop *)	Binary contact	→	24 V DC	Isochronous / droop
Status circuit breaker	Binary contact	→	24 V DC	Circuit breaker closed (on for closed)
Bus tie signal	Binary contact	→	24 V DC	Bus tie is closed
Manual activation slow turn	Binary contact	→	24 V DC	Slow turn mode change
Automatic slow turn	Binary contact	→	24 V DC	Slow turn selected for automatic
Start/stop remote	Binary contact	→	24 V DC	Start/stop in remote mode
Change genset	24 V DC	←	Binary contact	Engine fault - change genset
Normal stop indication	24 V DC	←	Binary contact	Normal stop indication
Start initiation indication	24 V DC	←	Binary contact	Start initiation indication
Starting interlock indication	24 V DC	←	Binary contact	Starting interlock indication
Remote control active	24 V DC	←	Binary contact	Remote control active
Ready to start, indication	24 V DC	←	Binary contact	Ready to start, indication
False start indication	24 V DC	←	Binary contact	False start indication
rpm contact	24 V DC	←	Binary contact	rpm contact
Offload *)	Binary contact	→	24 V DC	Offload
Isochronous selected *)	24 V DC	←	Binary contact	Isochronous selected
Emergency stop from PMS	Binary contact	→	24 V DC	External emergency stop (from PMS)

*) For optionally isochronous load sharing.

01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

13.6.3 Requirements on gas system

The table below shows the standard interface between the gas system and the dual fuel engine.

Standard interface to the gas system

Gas system	Indication diesel mode	24 V DC	←	binary	Engine cabinet
	Indication gas mode	24 V DC	←	binary	
	Activate gas supply to gas valve unit	24 V DC	←	binary	
	Switch over to gas operation failed	24 V DC	←	binary	
	Gas operation shut off machinery space	24 V DC	←	binary	
	Gas operation shut off engine	24 V DC	←	binary	
	Gas mode interlock	24 V DC	←	binary	
	Gas operation shut down	binary	→	24 V DC	
	Gas mode interlock	binary	→	24 V DC	
	Diesel mode select	binary	→	24 V DC	
	Gas mode select	binary	→	24 V DC	
	Inert gas supply pressure	4-20 mA	→	Analogue output	
	Pressure transmitter fuel gas supply to engine room	4-20 mA	→	Analogue output	

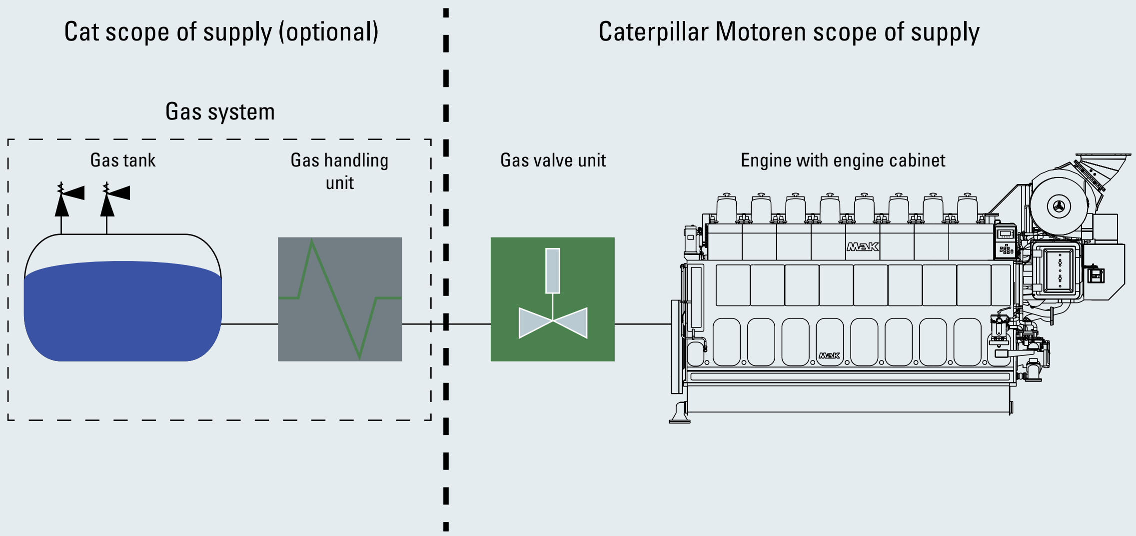


Fig. 13-8 Basic overview: dual fuel engine gas system

13.6.4 Uninterruptable power supply (UPS)

For the control and monitoring system an uninterruptable power supply (UPS) with a back-up power supply is needed (class requirement). The standard power supply is 24 V DC but on demand another power supply is possible (e.g. 230 V AC or 480 V AC three phase current).
The engine control cabinet has an integrated voltage distribution for the control and monitoring systems at the engine (see fig. 13-3). Each cabinet has its DC/DC converter and its insolation monitoring device.

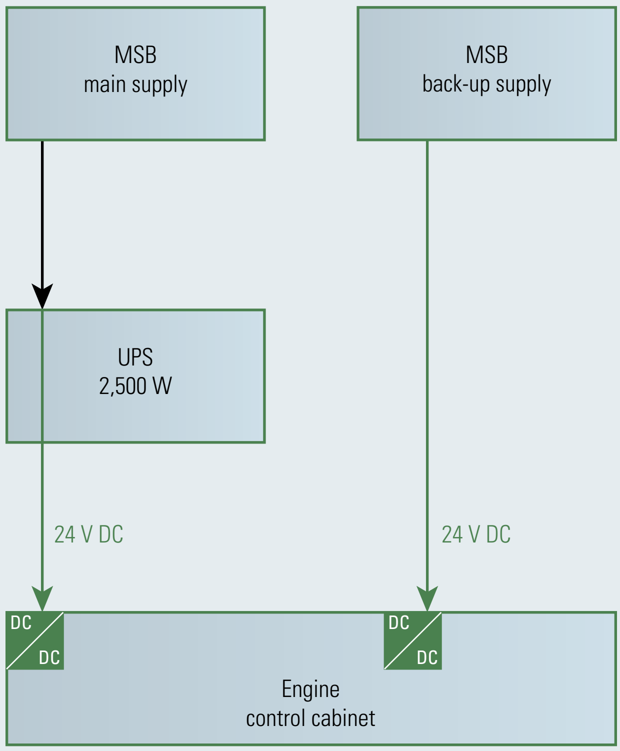


Fig. 13-9 Uninterruptable power supply - variants

13.7 Alarm indication

In general, the engine is equipped with the relevant alarm and safety sensorsaccording to classification society rules.
MACS provides an engine alarm system which is located in the local control panel. The engine alarm system and the local control display are consolidated in the DCU. The complete alarm management is handled by the DCU. All information is visualized via the screen in the LCP and additional several remote panels can be added.

The DCU receives measurement values and data from all I/O modules, PLCs and the engine control system (ECM). Furthermore it provides all measurement values, status values and alarms via MODbus TCP (MODbus RTU, optional) for the vessel's system and the remote monitoring system. The engine's alarm system determines critical engine conditions and activated alarms. The DCU has the ability of actuating the secondary safety stop valve. That means the DCU also works as well as a shut down unit and is able to stop the engine as reliable as the shut down unit (SDU). All alarms are stored in an alarm history and are shown in a manner requested by the MACS.

Fig. 13-10 Remote panel

Fig. 13-11 DCU (display and alarm system)

For the interface to ship's alarm system (IAMCS) the following functions are applicable:
- Transmitting measurement data to IAMCS
- Transmitting engine status to IAMCS
- Transmitting alarm to IAMCS
- Receiving ship's time stamp from IAMCS

All data is available via MODbus TCP. Upon request MODbus RTU is also possible. Device fault from the different MACS devices and some special alarms are provided as hardwired alarms.

The table below shows an example of an overview of the different engine systems/modules with their safety functions.

A project related list of measurting points with all necessary MODbus information will be created for each order.

	IND/ FUNC	STBL	Alarm	CHG	SHD	GMI	SHOGE	SHOGM
Lube oil	X	X	X	X	X			
Oil mist detector	X	X	X		X			
Fresh water HT	X		X		X			
Fresh water LT	X		X					
Air supply	X	X	X					
Charge air	X		X				X	
FCT	X		X		X		X	
Electrical status	X	X	X			X		
Engine status	X	X	X		X			
Combustion monitoring	X		X		X	X	X	
Exhaust gas	X		X	X			X	
Big end bearing	X		X		X			
Main bearing	X		X		X			
Load share unit (optional)			X		X			
ECM	X		X				X	
Inert gas flushing	X					X	X	X
Ignition fuel system engine	X	X	X		X	X	X	
Fuel gas system engine	X						X	
Fuel gas leakage monitoring	X		X			X	X	
Diesel gas mode control signals	X		X			X	X	X
Gas valve unit	X		X			X	X	X
Ignition fuel module	X	X	X				X	
Crankcase gas detection	X		X				X	
Exhaust gas module	X	X			X	X	X	
Slow turn	X	X						
Ventilation modules	X							

Furthermore an evaluation of sensor faults is integrated. Depending on the importance of the failure it causes a STBL, E-STBL, CHG, GMI and SHOGE.

NOTE:
An active gas operation shut off (SHOGE/SHOGM) will activate gas mode interlock (GMI) and an engine shutdown will adtivate a starting interlock (STBL) as well as a gas shut off for the engine (SHOGE).

FUNC	Used in software function
IND	Only for indication
A	Alarm
STBL	Starting interlock (overrideable by E-start of blackout start)
E-STBL	Emergency starting interlock (not overrideable by E-start or blackout start)
CHG	Change generator set
SHD	Shutdown
GMI	Gas mode interlock
SHOGE	Gas shut off for engine / Shut off gas supply to engine. The double block and bleed group in the gas valve unit (GVU) is closed.
SHOGM	Gas shut off for engine and machinery space. The master gas valve has to be closed.

13.8 Local and remote indicators

Local indication	Remote indicators
Installed at the engine	96 x 96 mm (optional)
Fuel oil temperature at engine inlet	X 2)
Fuel oil differential pressure at filter	
Lube oil temperature at engine inlet	X 2)
Lube oil differential pressure at filter	
Fresh water temp. at engine inlet (HT circuit)	
Fresh water temp. at engine outlet (HT circuit)	X 2)
Fresh water temperature (LT circuit)	X 2)
Fresh water temperature cooler inlet	
Fresh water temperature cooler outlet	
Charge air temperature cooler inlet	
Charge air temperature engine inlet	X 2)
Fuel oil pressure	X 2)
Lube oil pressure	X 2)
Fresh water pressure (HT circuit)	X 2)
Fresh water pressure (LT circuit)	X 2)
Start air pressure	X 2)
Charge air pressure cooler outlet	X 2)
Stop air pressure	
Engine speed	X 1)
Turbocharger speed	X 1)
Charge air temp. cooler inlet (digital value)	
Exhaust gas temp. after cylinder (digital value)	
Exhaust gas temp. before / after turbocharger (digital value)	

1) 144 x 144 mm possible / **2)** Signal is supplied by the alarm system

13.9 Cat Connect for Marine provided by Caterpillar Marine Asset Intelligence (MAI)

MAI provides technology enabled solutions and services, that

- Provide remote monitoring and automated analytics via the internet
- Combines equipment and application information
- Applies predictive analytics
- Utilizes interpretive expertise

13.9.1 MAI - MaK engine solution only

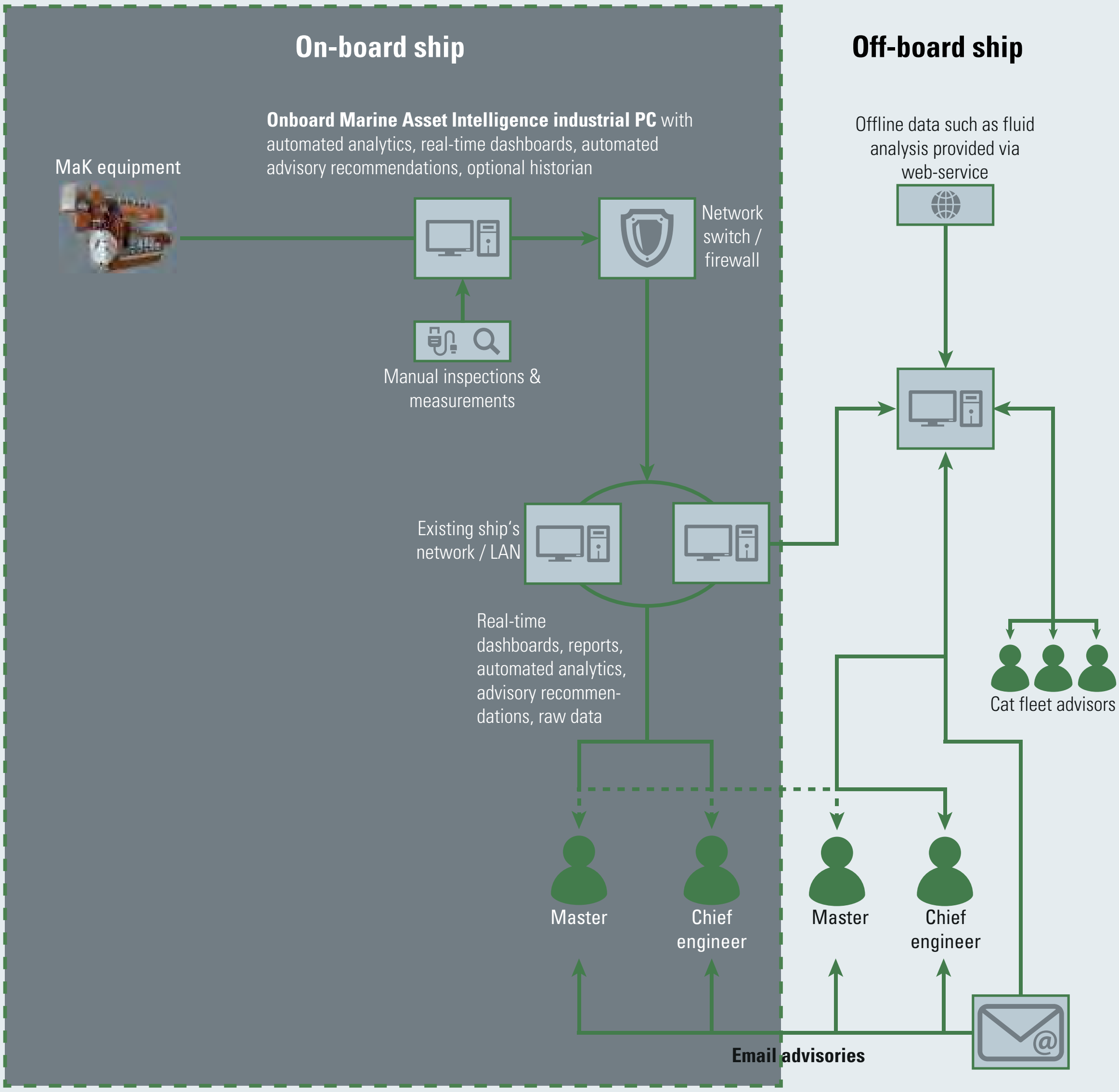


Fig. 13-12 MAI – MaK engine solution only

13.9.2 MAI - Extended solution

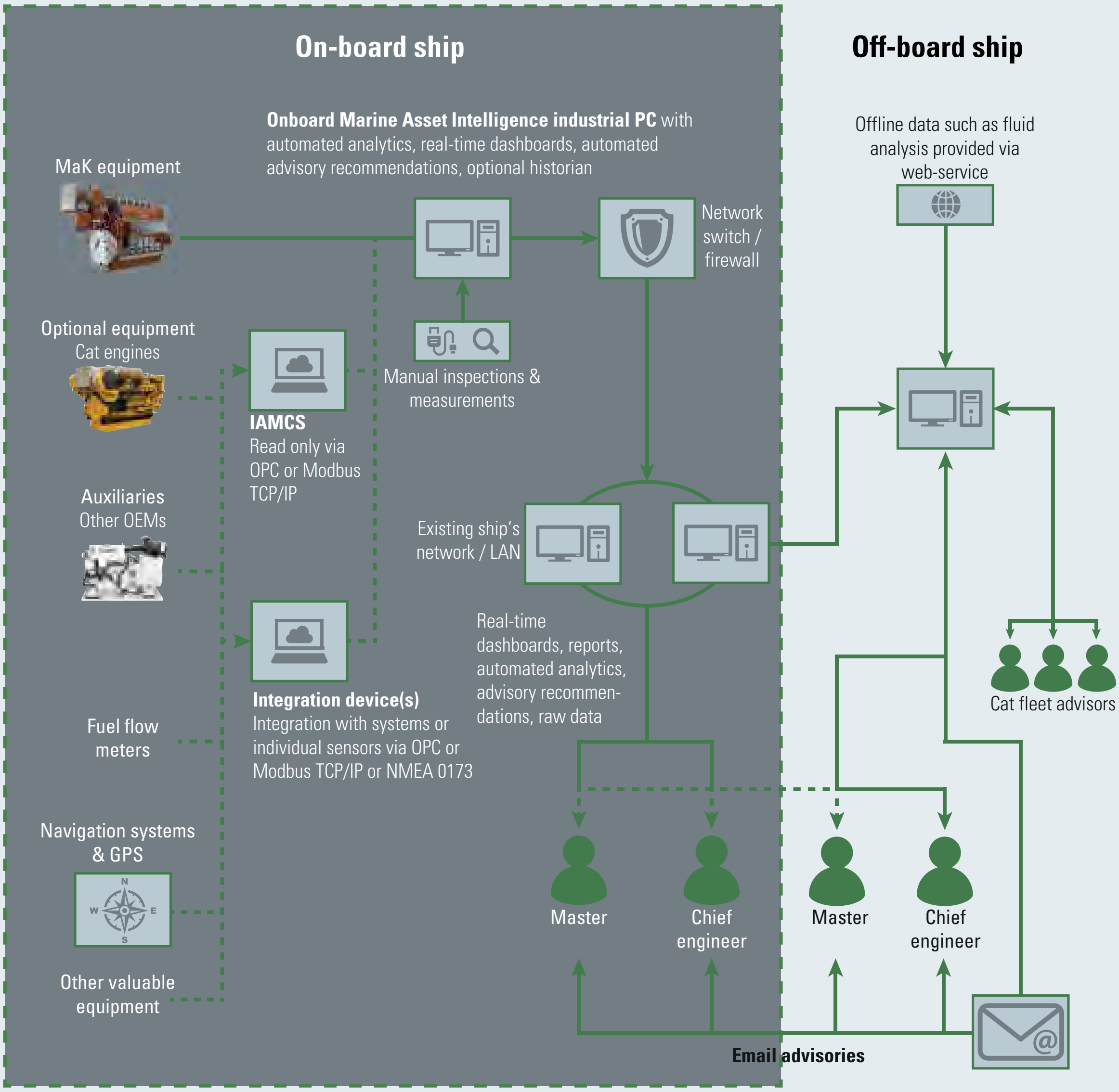


Fig. 13-13 MAI – Extended solution

13.9.3 General information

Capabilities

- Consolidates data and analyzes across all five condition monitoring elements.
- Analyzes data using multiple engines to identify and highlight exceptions.
- Creates a complete view of the equipment and performance.
- Allows more knowledgeable planned maintenance and scheduled repairs.
- Enables optimized tuning of equipment to maximize fuel efficiency.

Comprehensive scope possible

- Monitors and analyzes variety of systems across the total vessel, based on what is important for each vessel.
- Can monitor Caterpillar/MaK equipment as well as non-Caterpillar/MaK equipment.
- Can monitor diesel engines and non-diesel engines.
- Primary services available:
  - Protect: Identify potential problems with equipment before there is a failure, assist onboard crew with remote expert troubleshooting.
  - Improve: Optimize fuel consumption for individual equipment through better maintenance and for entire vessel through operations and maintenance optimization.
  - Optimize: Move to condition based maintenance.
- Supporting services available:
  - Account: Ensure fuel accountability, measure and track fuel bunkering and consumption.
  - Save: Create visibility for unsafe operations or equipment condition.
  - Comply: Ensure equipment is operated and performs in compliance with regulations.
  - Manage: Customized dash-boards for different levels of management without custom software development.
  - Integrate: Integrate with other enterprise systems, such as Computerized Maintenance Management System (CMMS).

System Benefits

- Support most cost efficient operation.
- Provides optimized planning of service activities.
- Helps to avoid unexpected downtime.
- Helps reduce fuel cost for both the individual equipment and the entire vessel (depending on scope included).

Scope of delivery

- Electrical engine equipment MACS and Modbus interface for data streaming.
- Industrial PC with interfaces for connection to ship's network, automation system and other onboard systems.
- Software for real-time dashboard with online data view via ship's network (from any computer connected to ship's network).
- Network router with firewall for data replication via internet.
- Configuration of shore interface for shore customer users.
- Analytics with flexible reports and dashboards that can be configured and modified by the customer.
- Option: connection with additional systems beyond MaK/Caterpillar engines, to include other engines/generators, auxiliary systems, other systems, individual sensors such as fuel flow sensors, torque meters, anemometers, GPS/ECDIS, etc via OPC, Modbus or NMEA data protocols.

Customer assumption

- Network infrastructure and data transfer via satellite communication to be provided by customer.

14.1 Safety

Selected mode \ Potential operation	Diesel operation	Gas operation
Diesel mode	Yes	No
Gas mode	Possible	Yes

"Mode" specifies the desired engine operation.

"Operation" specifies the actually burned fuel.

Fig. 14-1 Definition: "Mode" vs. "Operation"

Additional safety requirements need to be fulfilled to operate a dual fuel engine in a marine application. The safety concept for the MaK dual fuel engine is designed according the upcoming IGF code (draft international code of safety for ships using gases or other low-flashpoint fuels) to provide a gas safe machinery space.

14.1.1 Safety concept

The main intention of the safety concept is to avoid any hazardous situation. To this aim the safety concept for the dual fuel engine has to prevent the formation of any harzardous explosive atmosphere.
Therefore a detection system is used in combination with automatic safety actions that will finally result in a changeover to diesel mode and flushing the fuel gas supply line with inert gas to avoid any endangering.
Additionally a ventilation system for the exhaust pipe will inhibit an accumulation of fuel gas.
Already during the design phase ignition sources have been considered and were excluded where possible.
To ensure highest level of safety CFD (Computational Fluid Dynamics) simulations were used and based on those data safety valves with sufficient relief areas were applied is necessary.

14.1.2 Gas safe machinery space

The safety concept for the dual fuel engine is based on a gas safe machinery space. The aim of this concept is that no hazardous atmosphere can occur in the machinery space. In case of any malfunction, the dual fuel engine will not shut down, instead the fuel supply will switch over to fuel oil as there are MDO and MGO. After reaching the diesel mode the engine can be switched over to HFO.
The switch over from fuel oil to fuel gas or vice versa will be bumpless and without any losses in power performance of the engine.
To avoid any hazardous area in the machinery space the fuel gas pipes in the machinery space are of double walled design from entering the engine room, via the gas valve unit throughout the cylinders.
For detection of any leakage a suitable monitoring system is installed.

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To fulfill the requirements of a gas safe machinery space according to IMO resolution MSC.285(86) the following measures are taken:

- Fuel gas piping inside the machinery space must be of double walled design.
- All parts of the engine's fuel gas supply system inside the machinery space are double walled.
- The double wall is permanently monitored for leakage while the inner pipes are containing fuel gas.
- Flushing the fuel gas line with inert gas must be possible.
- Gas concentration must be monitored in the crankcase ventilation pipe.
- The lube oil system must be suitable for gas, class requirements have to be observed.
- The cooling water system must be suitable for gas, class requirements have to be observed.
- Means must be provided to inert and vent the crankcase for maintenance reasons.
- No direct access to gas hazardous areas must be possible.
- In case of a starting failure or an emergency shutdown of the engine while running on fuel gas the exhaust system will be ventilated automatically after emergency stop.
- In case of an emergency shutdown of the fuel gas supply or the engine, while the engine is running on fuel gas, the fuel gas supply lines will be flushed automatically with inert gas.
- Furthermore the system integrator needs to pay special attention to
  - The machinery space.
  - The gas handling room.
  - All rooms adjacent to possibly hazardous areas.

The engine control, monitoring and protection system, called MACS (Modular Alarm Control System), consists of different functional components. It includes the start-stop system, the gas management, the monitoring system and the engine protection system. A screen is fitted in the local control panel and shows measurement data as well as diagnostics and engine status.

14.1.3 Gas related safety equipment

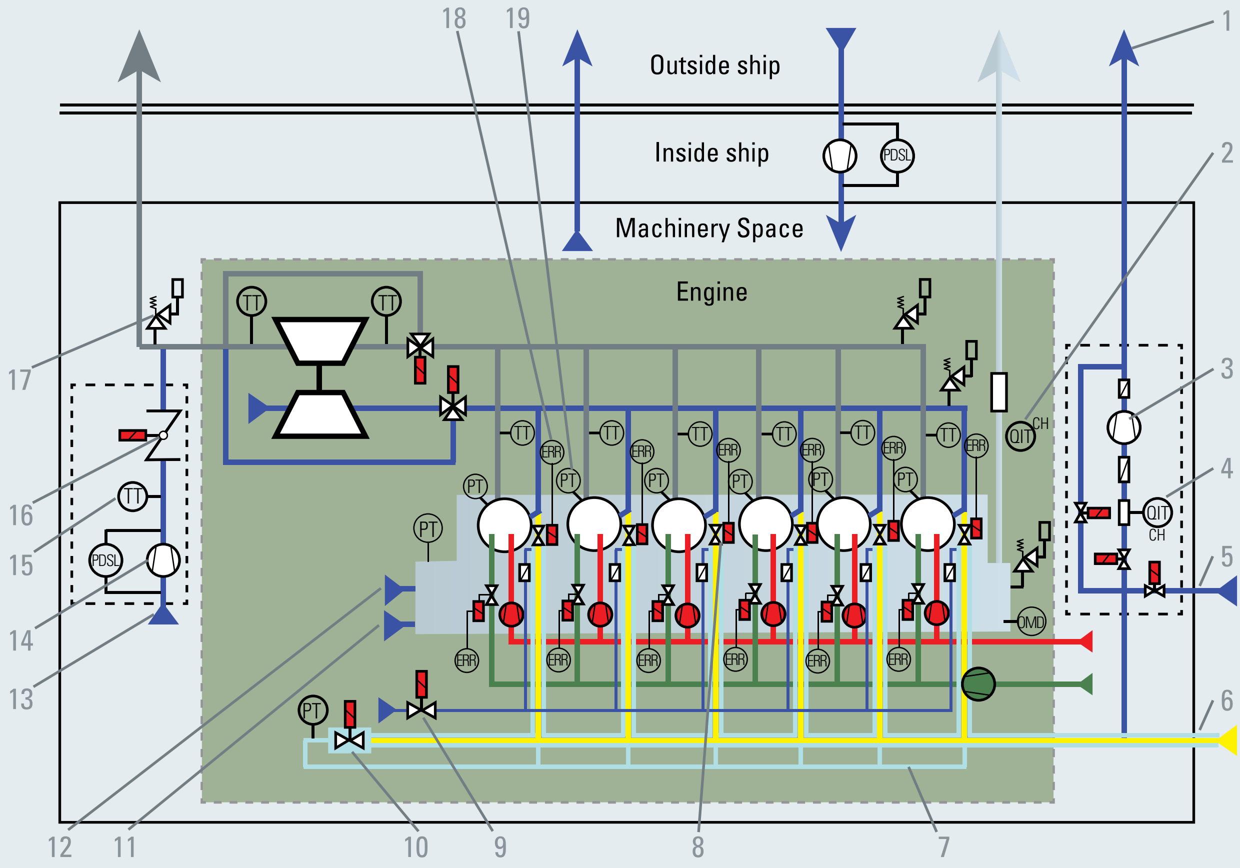

Fig. 14-2 Gas related safety equipment

1	Inertgas ventilation outlet	11	Crankcase flushing valve for inertgas
2	Gas sensor in crankcase ventilation line	12	Crankcase purging valve for compressed air
3	Vacuum pump in ventilation module	13	Air inlet for exhaust gas duct purging
4	Gas sensor in ventilation module	14	Fan for exhaust gas duct purging
5	Inertgas supply inlet	15	Temperature transmitter
6	Fuel gas supply	16	Butterfly isolation valve
7	Inertgas compartment	17	Explosion relief valve
8	GAV (Gas Admission Valve)	18	In cylinder pressure sensor
9	Fresh air flushing valve	19	In cylinder pressure transmitter
10	Inertgas flushing valve		

15.1 Rigid mounting of main engines and alignment

The vertical reaction forces resulting from the torque variation are the most important disturbances to which the engine foundation is subjected. With regards to dynamic load, the indicated moments only represent the exciting values and can only be compared among each other. The effective forces to which the foundation is subjected depend on the mounting arrangement and the rigidity of the foundation itself. In order to make sure that there are no local resonant vibrations in the ship`s structure, the natural frequencies of important components and partial structures should differ sufficiently from the indicated main exciting frequencies.
The dynamic foundation forces can be considerably reduced by means of resilient engine mounting.

15.1.1 General information

- The shipyard is solely responsible for the adequate design and quality of the foundation.
- Information on foundation bolts (required retightening torques, elongation, yield point), steel chocks, side stoppers and alignment bolts is to be gathered from the foundation plans.
- Examples "for information only" for the design of the screw connections will be made available as required.
- If cast resin is used it is recommendable to employ authorized workshops of resin manufacturers approved by the classification societies for design and execution.
- It has to be taken into account that the permissible surface pressure for resin is lower than for steel chocks and therefore the tightening torques for the bolts are reduced correspondingly.
- When installing the engine on steel chocks the top plate should be build with an inclination outwards from engine centerline. Wedge type chocks with the corresponding inclination only be use. The material can be cast iron or steel.

Surface treatment:

- The supporting surface of the top plate has to be milled. When fitting the chocks, a bearing contact of min. 80 % is to be obtained.
- Outwards inclination of the top plate are needed in case of using steel chocks. Without this it is not permissible to install steel chocks.

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15.1.2 Engine with dry sump

Dimension of foundation dry sump pan

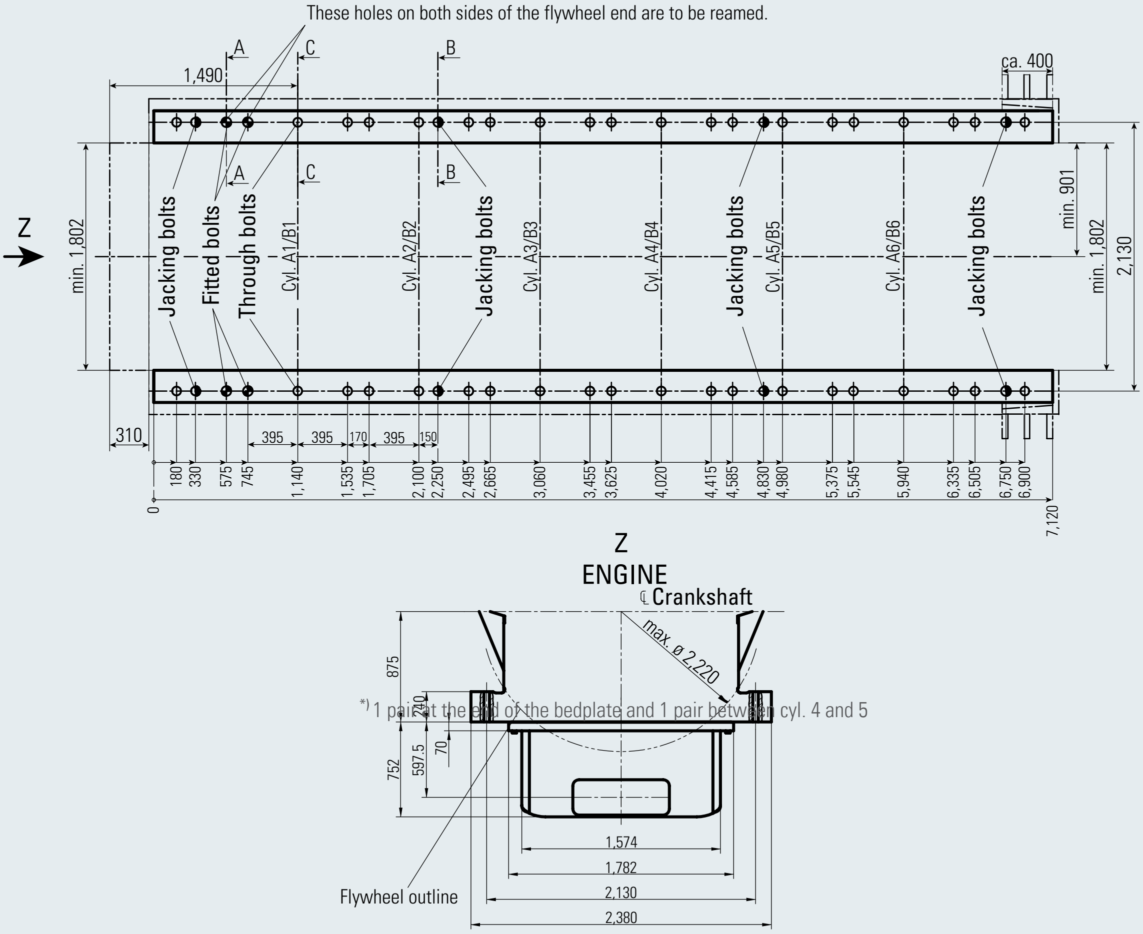


Fig. 15-1 Dimension of foundation dry sump pan

Jacking bolts

- To be protected against contact / bond with resin
- After setting of resin dismantle the jacking screws completely

To be supplied by yard:
Foundation bolts, fitted bolts, nuts and tension sleeves, side stoppers, steel chocks, cast resin.

The shipyard is solely responsible for adequate design and quality of the foundation.

Proposal for rigid mounting

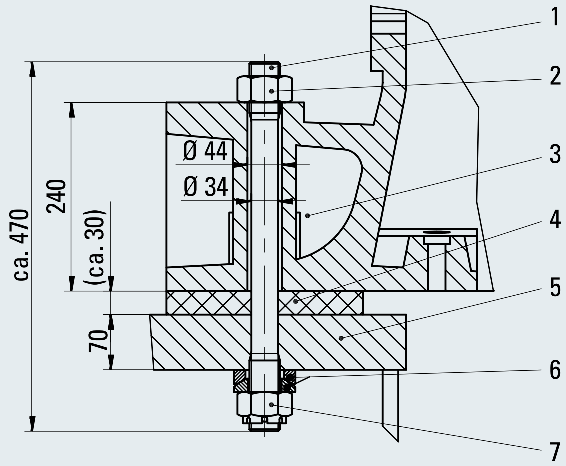


Fig. 15-2 Through bolt

1	Material 8.8	5	Top plate
2	EN 28673 M39 x 3-8, ISO 8673	6	Spheric washers, DIN 6319 C 43/D 43
3	Engine foot	7	Nut, DIN 935 M39 x 3-8
4	Steel chock / cast resin chock		

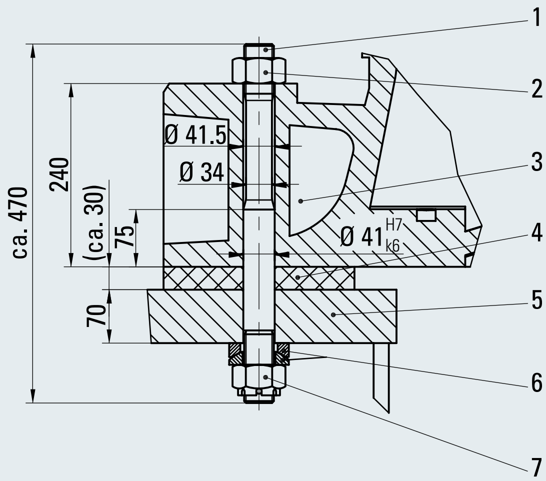


Fig. 15-3 Fitted bolt

1	Material 8.8	5	Top plate
2	EN 28673 M39 x 3-8, ISO 8673	6	Spheric washers, DIN 6319 C 43/D 43
3	Engine foot	7	Nut, DIN 935 M39 x 3-8
4	Cast resin chock		

Tightening force M 39		Tightening force (oil) M 39	
Cast resin / steel		Cast resin / steel	
Through bolts [N]	Fitted bolts [N]	Through bolts M [N_m]	Fitted bolts M [N_m]
Max. 340,000	Max. 340,000	Max. 2,050	Max. 2,050

15.2 Resilient mounting

15.2.1 Basic design and arrangement

The resilient mounting consists of conical rubber elements to achieve a passive isolation of the free moments and forces and emitted structure borne noise of the engine. The resilient mounting arrangement is designed to assure the best possible load distribution of the engine weight in respect of the maximal permissible deflection of the conical rubber element. For each engine configuration (different speed, different side of turbocharging mounted unit, different couplings, with or without PTO, with installation angle) the natural frequencies and the behavior of the engine during ship movements will be individually calculated and submitted to the respective classification society for approval and to check the design of the resilient installation under different arrangement situations.

15.2.2 Conical mountings

General

The used conical design provides high deflection and load capacity combined with long service life. The life expectancy of the rubber elements will be approx. 20 years in ideal circumstances. In fact of bad influences out of environmental circumstances the (working) life expectancy will be approx. 10 years.

Specifications

The used conical mountings have been approved by all relevant classification societies. All mounting rubber inserts are individually tested and selected on stiffness by our supplier. An adjustable central buffer controls the mounted equipment displacements due to ship movements vertically and horizontally within defined limits, so there is no need for separate buffers.

After 48 hours the conical elements are loaded with the complete engine weight during installation more than half of the total creeping figure is achieved. Therefore the engine will be lowered because of the creeping effect, but just approximately one additional mm within the following 20 years.

15.2.3 Conical resilient element

Major components

- Conical rubber elements for active insulation of dynamic engine forces and structure-borne noise are combined with horizontal, lateral and vertical stoppers to limit the engine movements.
- Dynamical balanced highly flexible coupling.
- Flexible pipe connections for all media.
- Specially designed exhaust gas below.

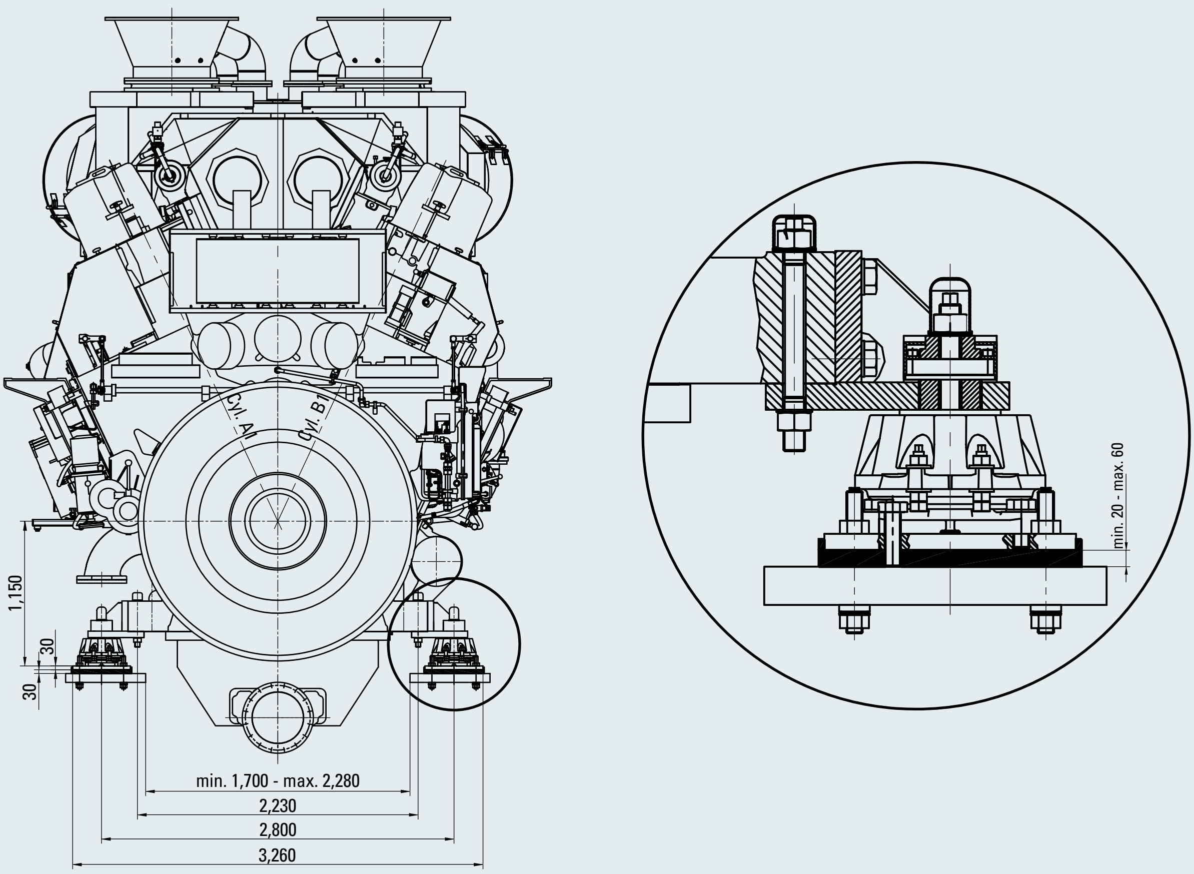


Fig. 15-4 Conical resilient standard element

Number of rubber elements

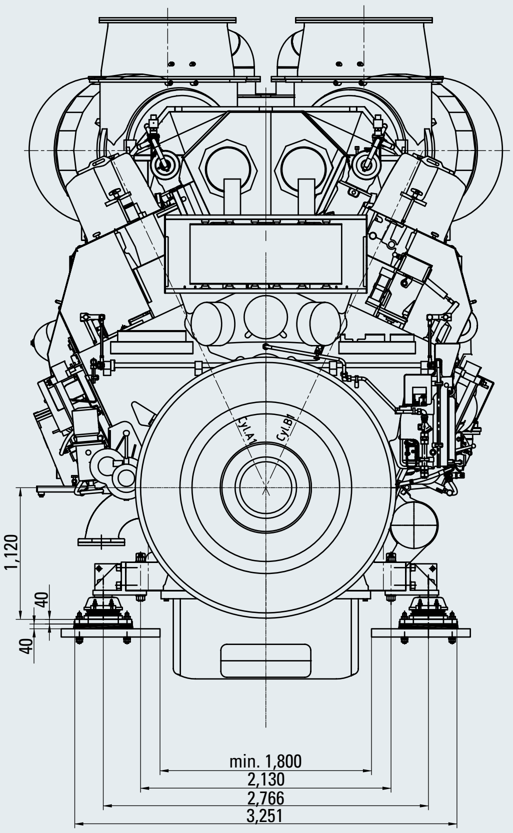
	Combined elements
12 M 46 DF	10
16 M 46 DF	14

NOTE:
The resilient mounting alone does not provide any guarantee for a silent ship operation. Other sources of noise like propeller, gearbox ans aux. engines have to be considered as well.
Radial restoring forced of the flexible coupling (due to seaway) may be of importance for the layout of the reduction gear.

15.3 Resilient cruise line mounting

15.3.1 Basic design and arrangement

To achieve a higher reduction of the structure borne noise emissions caused by engine vibrations a special cruise mounting has been developed. With the introduction of high quality mountings with even better attenuation properties the highest comfort requirements as demanded especially at cruise vessels were able to fulfill. All mounting rubber inserts are individual tested and selected on stiffness with reduced tolerance by our supplier.
Besides the great structure borne noise reduction properties the used connical mountings provides high deflection and load capacity combined with a long service life. The life expectancy of the rubber elements will be approx. 20 years in ideal circumstances.
In fact of the small creeping effect of the conical elements over this long period of time, a realignment of the engine will not be necessary if the installation has been carried out correctly according to the provided detailed installation instructions.



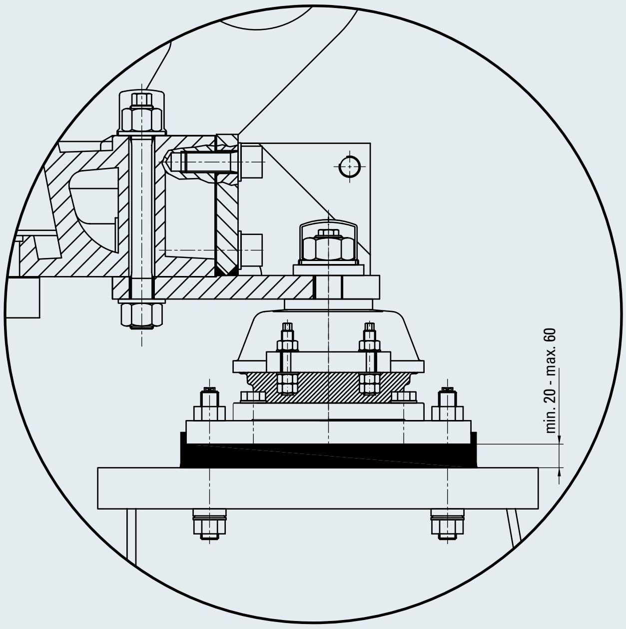


Fig. 15-5 Conical resilient cruise line element

Number of rubber elements

	Combined elements
12 M 46 DF	28
16 M 46 DF	36

15.4 Earthing of engine

Information about the execution of the earthing

The earthing has to be carried out by the shipyard during the assembly on board.
The engine is already equipped with M 16, 25 mm deep threaded holes with the earthing symbol in the engine foot.
If the engine is resiliently mounted it is important to use flexible conductors.

In case of using welding equipment it is important to earth the welding equipment close to the welding area (the distance should not exceed 10 m).

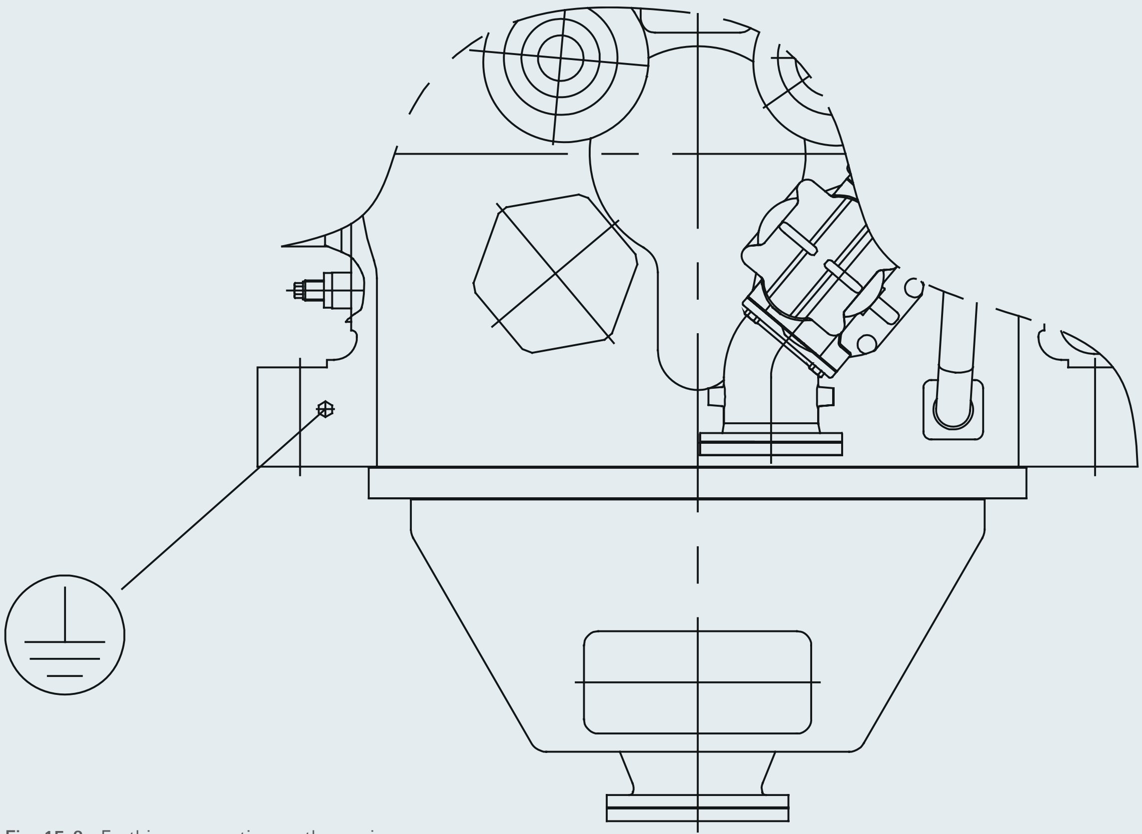


Fig. 15-6 Earthing connection on the engine

01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

16.1 General requirements

The following information is relevant to the foundation design and the aftship structure.
The engine foundation is subjected to both static and dynamic loads.

16.2 Static load

The static load from the engine weight which is distributed approximately evenly over the engine´s foundation supports and the mean working torque T_N resting on the foundation via the vertical reaction forces. T_N increases the weight on one side and reduces it on the other side by same amount.

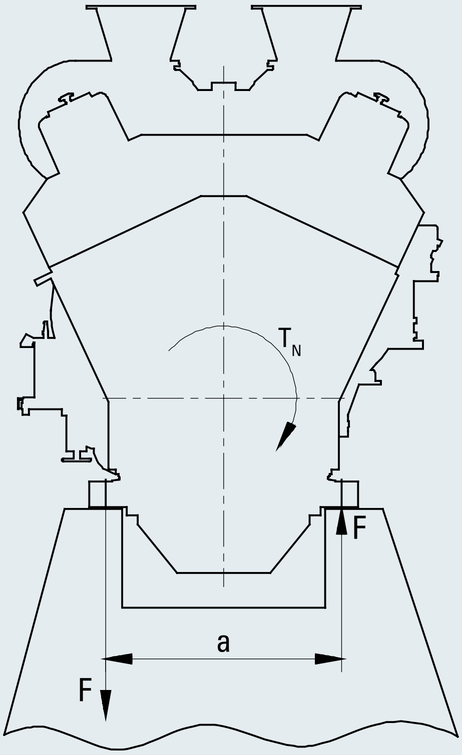


Fig. 16-1 Static load

	Output	Speed	T_N
	[kW]	[rpm]	[kNm]
12 M 46 DF	10,800	500/514	206.3/200.7
12 M 46 DF	11,580	500/514	221.2/215.2
16 M 46 DF	14,400	500/514	275.0/267.5
16 M 46 DF	15,440	500/514	294.9/286.9

Support distance a = 2,130 mm

F = T_N/a
T_N = Nominal torque
F = Force
a = Support distance

01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

16.3 Dynamic load

The dynamic forces and moments are superimposed on the static forces. They result on the one hand from the firing forces causing a pulsating torque and on the other hand from the external mass forces and mass moments.
The table indicates the dynamic forces and moments as well as the related frequencies.

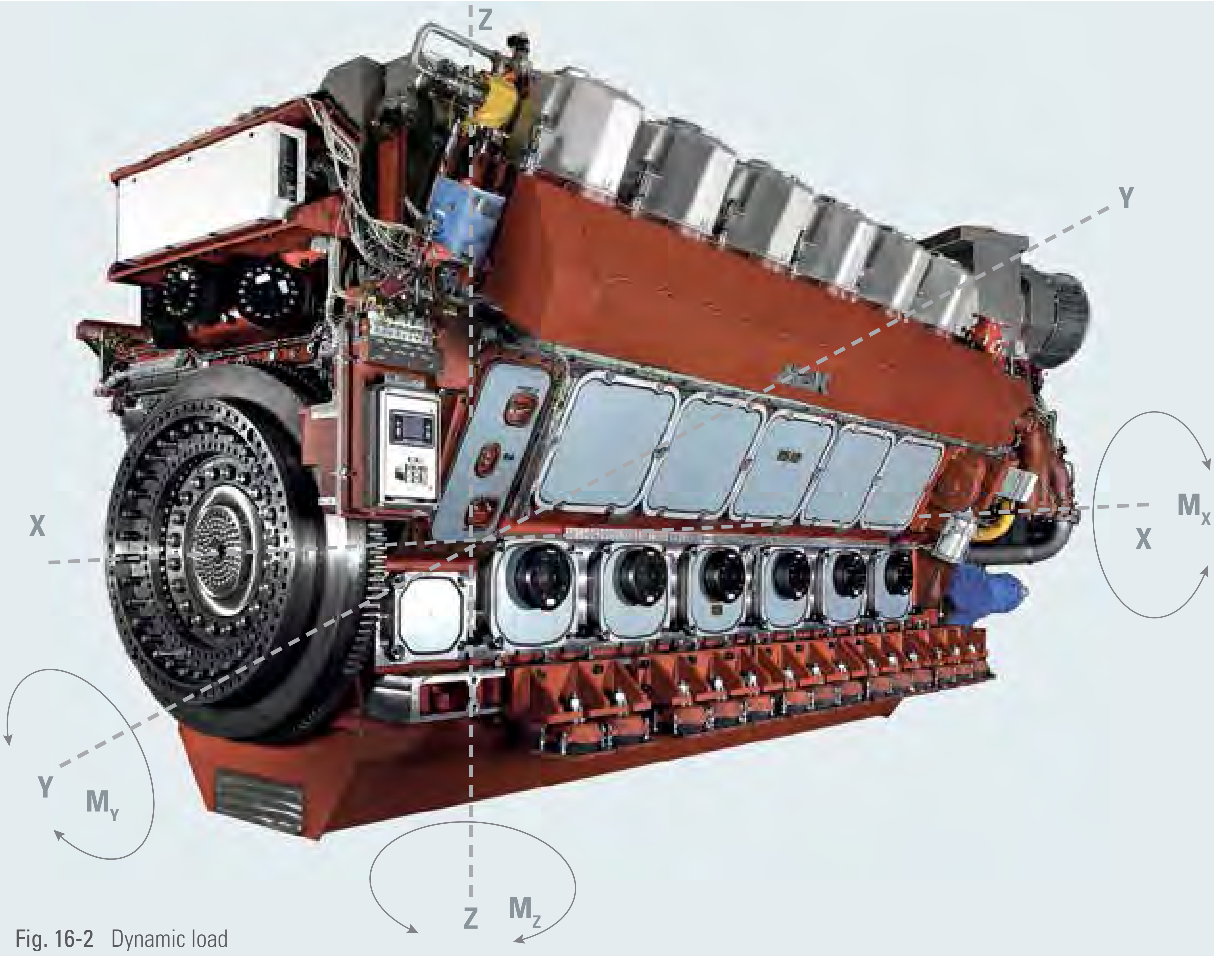


Fig. 16-2 Dynamic load

	Output	Speed	Order-no.	Frequency	M_X
	[kW]	[rpm]		[Hz]	[kNm]
12 M 46 DF	10,800	500/514	3.0 6.0	25.0/25.7 50.0/51.4	19.1/15.9 72.4/70.4
12 M 46 DF	11,580	500/514	3.0 6.0	25.0/25.7 50.0/51.4	28.1/24.4 84.7/82.4
16 M 46 DF	14,400	500/514	4.0 8.0	33.3/34.3 66.6/68.6	41.7/40.4 50.3/49.0
16 M 46 DF	15,440	500/514	4.0 8.0	33.3/34.3 66.6/68.6	46.2/44.7 66.1/64.3

All forces and moments not indicated are irrelevant or do not occur. The effect of these forces and moments on the ship's foundations depends on the type of engine mounting.

01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

17.1 Data for torsional vibration calculation

To determine the location and resonance points of each engine and equipment Caterpillar Motoren calculates the torsional vibration behaviour of the engine, including all components, such as coupling, gearboxes, shaft lines and propellers, pumps, and generators.
The normal as well as the emergency operating mode is covered.
The classification societies require a complete torsional vibration calculation.

To be able to provide a correct torsional vibration calculation, we would like to ask you to fill in the documents in the appendix, according to your scope of supply.

Please send the completed data to your local dealer 6 month prior to the engine delivery at the latest.
For further information please compare the data sheet for torsional vibration calculation.
(following 3 pages).

CAT

Additional engine plant data part "B"

☐ Main drive
☐ Aux. Engine
☐ DE drive
Ktr.-No.: _____

Shipyard: _____
Shipowner: _____
Type of vessel: _____
Newbuilding No.: _____

Remark:

Please note that the application and installation drawings will be delivered not later than 6 weeks after receiving the completed "Additional engine plant data sheet" part "B". The "Additional engine plant data sheet" part "A" to be delivered together with the order.

General information, required for all applications:

Flag state (needed for EIAPP cert): ____________________

Please note that Caterpillar Motoren will issue an "EAPP Document of Compliance" or an "EIAPP Certificate" as per flag state authorization only in case the flag state information is provided at least eight (8) weeks prior to the engine delivery date as per the Sales Contract (Appendix 1). In case such information has not been provided to Caterpillar Motoren until such date, Caterpillar Motoren will provide an "EAPP Statement of Compliance" which has to be converted into "EAPP Documents of Compliance" or an "EIAPP Certificate" as per flag state authorization. In this case the application and costs for the before mentioned conversion has to be borne by the Buyer.

Alarm system

☐ yard   maker: _____   type: _____   yard contact manager: _____

Make of automation/bus system

☐ yard   maker: _____   type: _____   yard contact manager: _____

Additional information for cooling water system:

Add. heat exchanger integrated in LT system, ☐ Yes ☐ No, if "**Yes**" please provide the following data:

☐ number of aux. engine _____
  ☐ heat dissipation _____ kW   ☐ required water flow _____ m³/h   ☐ pressure drop _____ bar
☐ oil cooler gear box   ☐ number of cooler _____
  ☐ heat dissipation _____ kW   ☐ required water flow _____ m³/h   ☐ pressure drop _____ bar
☐ air cond. unit   ☐ number of air cond. unit _____
  ☐ heat dissipation _____ kW   ☐ required water flow _____ m³/h   ☐ pressure drop _____ bar
☐ others   Please specify: _____
  ☐ heat dissipation _____ kW   ☐ required water flow _____ m³/h   ☐ pressure drop _____ bar

Comments/Remarks:

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Fig. 17-1 Additional engine plant data, part "B" (1/3)

CAT®

Additional engine plant data, part "B"

TVC data - Information for main engine(s) only:

Flex. coupling main engine:

Supplied by Caterpillar ☐ Yes ☐ No, if "**No**" please provide the following data:

☐ Vulkan	☐ Stromag	☐ Centa
Type: _____	Size: _____	☐ TVC scheme attached
	☐ Drawing attached	☐ Drawing attached
☐ Other maker _____		
Type: _____	Size: _____	☐ TVC scheme attached
		☐ Drawing attached

Norminal torque [kNm]:	_____	Perm. vibratory torque [kNm]:	_____
Perm. power loss [kW]:	_____	Perm. rotational speed [1/min]:	_____
Dyn. torsinal stiffness[kNm/rad]:	_____	Relative damping:	_____

Flex. coupling engine PTO shaft (on engine free-end)

Supplied by Caterpillar ☐ Yes ☐ Not applicable ☐ No, if "**No**" please provide the following data:

☐ Vulkan	☐ Stromag	☐ Centa
Type: _____	Size: _____	☐ TVC scheme attached
	☐ Drawing attached	☐ Drawing attached
☐ Other maker _____		
Type: _____	Size: _____	☐ TVC scheme attached
		☐ Drawing attached

Norminal torque [kNm]:	_____	Perm. vibratory torque [kNm]:	_____
Perm. power loss [kW]:	_____	Perm. rotational speed [1/min]:	_____
Dyn. torsinal stiffness[kNm/rad]:	_____	Relative damping:	_____

Flex. coupling gearbox PTO

Supplied by Caterpillar ☐ Yes ☐ Not applicable ☐ No, if "**No**" please provide the following data:

☐ Vulkan	☐ Stromag	☐ Centa
Type: _____	Size: _____	☐ TVC scheme attached
	☐ Drawing attached	☐ Drawing attached
☐ Other maker _____		
Type: _____	Size: _____	☐ TVC scheme attached
		☐ Drawing attached

Norminal torque [kNm]:	_____	Perm. vibratory torque [kNm]:	_____
Perm. power loss [kW]:	_____	Perm. rotational speed [1/min]:	_____
Dyn. torsinal stiffness[kNm/rad]:	_____	Relative damping:	_____

Gearbox

Supplied by Caterpillar ☐ Yes ☐ No, if "**No**" please provide the following data:

Maker: _____	Type: _____	☐ TVC scheme attached
Max. permissible PTO output [kW]:	_____	☐ Drawing attached

Front gearbox for engine PTO

Supplied by Caterpillar ☐ Yes ☐ Not applicable ☐ No, if "**No**" please provide the following data:

Maker: _____	Type: _____	☐ TVC scheme attached
Max. permissible PTO output [kW]:	_____	☐ Drawing attached

PTO shaft generator/fire fighting pump or similar consumer, driven by engine PTO shaft/front step up gear

Supplied by Caterpillar ☐ Yes ☐ Not applicable ☐ No, if "**No**" please provide the following data:

Maker: _____	Type: _____	
Output [kW]: _____	rpm [1/min]: _____	☐ TVC scheme attached
☐ Plain bearing, external lubrication		☐ Drawing attached

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Fig. 17-2 Additional engine plant data, part "B" (2/3)

CAT®

Additional engine plant data, part "B"

TVC data - Information for main engine(s) only:

PTO shaft generator, driven via gearbox

Supplied by Caterpillar ☐ Yes ☐ Not applicable ☐ No, if " **No**" please provide the following data:

Maker: _____ Type: _____

Output [kVA]: _____ rpm [1/min]: _____ ☐ TVC scheme attached

☐ PTI operation PTI output [kW]: _____

Shaft arrangement between engine - gearbox

Supplied by Caterpillar ☐ Yes ☐ No, if " **No**" please provide the following data:

Maker: _____ ☐ TVC scheme attached detail drawing: _____

Propeller and propeller shafting data:

Supplied by Caterpillar ☐ Yes ☐ No, if " **No**" please provide the following data:

☐ CPP ☐ FPP ☐ Voith ☐Rudder FPP/CPP ☐ Others _____

numbers of blades: _____ Ø propeller [mm]: _____

Moments of inertia in water [kgm²]: _____ Moments of inertia in air [kgm²]: _____

Maker: _____ ☐ TVC scheme attached or detail drawing: _____

Propeller and propeller shafting information:

Supplied by Caterpillar ☐ No ☐ Yes, in case of "Yes" please provide the following data:

☐ Wake field attached ☐ Propulsion test attached (tank test) ☐ Length of shafting incl. drawing attached

Comments/Remarks:

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Confirmed by buyer: ______________________________

Date: ______________________________

Stamp and signature: ______________________________

Caterpillar cannot be held liable for any mistakes made by the buyer.

Components not mentioned in Cat's technical specification/No. ______, dd. _____ and essential for installation/operation of the equipment will be buyer's scope of supply.

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Fig. 17-3 Additional engine plant data, part "B" (3/3)

17.2 Sound levels

17.2.1 Airborne noise

The airborne noise level requirement in the engine room specified by IMO Resolution A.468 will be satisfied by M 46 DF (even for multiple installations).

The airborne noise level is measured in a test cell according to EN ISO 9614-2.

17.3 Vibration

The vibration level of M 46 DF engines complies with ISO 20283-4 and ISO 10816-6.
From these ISO standards, the following values are an applicable guideline:

Displacement	S_{eff}	< 0.448 mm	f> 2 Hz < 10 Hz
Vibration velocity	V_{eff}	< 28.2 mm/s	f> 10 Hz < 250 Hz
Vibration acceleration	a_{eff}	< 44.2 m/s^2	f> 250 Hz < 1,000 Hz

01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

18.1 Flexible coupling

General

For all types of plants the engines will be equipped with flexible flange couplings.
The guards for the flexible couplings should be made of perforated plate or gratings to ensure optimum heat dissipation (yard supply).

18.1.1 Mass moments of inertia

	Speed	Engine *	Flywheel	Total
	[rpm]	[kgm²]	[kgm²]	[kgm²]
12 M 46 DF	500/514	3,720	1,844	5,564
16 M 46 DF	500/514	3,420	1,844	5,264

* Running gear with balance weights and vibration damper

18.1.2 Selection of flexible couplings

The calculation of the coupling torque for main couplings is carried out according to the following formula.

$$T_{KN} \geq \cdot \frac{P_0}{\omega} = \frac{P_0 \cdot 60}{2 \cdot \pi \cdot n_0}$$

P_0 = Engine output
n_0 = Engine speed
T_{KN} = Nominal torque of the coupling in the catalogue

ATTENTION:
For installations with a gearbox PTO it is recommended to oversize the PTO coupling by the factor 1.5 in order to have sufficient safety in the event of misfiring.

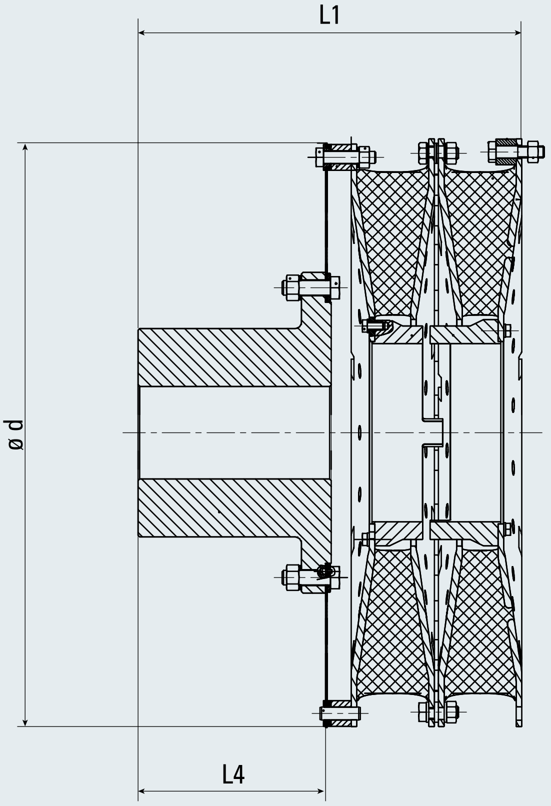

Fig. 18-1 Flywheel and flexible coupling

	Power	Speed	Nominal torque of coupling	Dimensions				Weight	
				d	L1 1)	L1 2)	L4 3)	1)	2)
	[kW]	[rpm]	[kNm]	[mm]	[mm]	[mm]	[mm]	[kg]	[kg]
12 M 46 DF	10,800/11,580	500/514	250	1,710	988.6	1,087	520	3,397	4,120
16 M 46 DF	14,400/15,440	500/514	380	1,815	1,197	1,189	570	4,603	5,124

1) Without torsional limit device / **2)** With torsional limit device / **3)** Length of hub

Space requirements for OD-Box (oil distribution box) are to be considered!
Couplings for twin rudder propeller have to be designed with a supplementary torque of 50 %.

18.2 Power take-off from the free end (for CPP only)

The PTO output is limited to:

- 12 M 46 DF 8,400 kW
- 16 M 46 DF 7,800 kW

The connection requires a highly flexible coupling.

A combination (highly flexible coupling / clutch) will not be supplied by Caterpillar Motoren. The weight force of the clutch cannot be absorbed by the engine and must be borne by the succeeding machine.

The coupling hub is to be adapted to suit the PTO shaft journal.

The (definite) final coupling type is subject to confirmation by the torsional vibration calculation.

19.1 Pipe dimensions

The external piping systems are to be installed and connected to the engine by the shipyard.
Piping systems are to be designed so as to keep the pressure losses at a reasonable level. To achieve this at justifiable costs, it is recommended to keep flow rates as indicated below (see chapter 19.2).
Nevertheless, depending on specific conditions of piping systems, it may be necessary to adopt even lower flow rates.

ATTENTION:
Generally it is not recommended to adopt higher flow rates.

19.2 Flow velocities in pipes

	Recommended flow rates [m/s]		
	Suction side	Delivery side	Kind of system
Fresh water (cooling water)	1.5 - 3.0	1.5 - 3.0	Closed
Lube oil	0.5 - 1.0	1.5 - 2.5	Open
Sea water	1.0 - 1.5	1.5 - 2.5	Open
Diesel fuel oil	0.5 - 1.0	1.5 - 2.5	Open
Heavy fuel oil	0.3 - 0.8	1.0 - 1.5	Open / closed pressurized system
Exhaust gas	20 - 40		Open

19.3 Trace heating

Trace heating is highly recommended for all pipes carrying HFO or leak oil. For detailed explanation see fuel oil diagrams, showing the trace heated pipes marked as ------------ .

19.4 Insulation

All pipes with a surface temperature > 60 °C should be insulated to avoid risk of physical injury. This applies especially to exhaust gas piping.
To avoid thermal loss, all trace heated pipes should be insulated.
Additionally, lube oil circulating pipes, the piping between engine and lube oil separator as well as the cooling water pipes between engine and preheater set should be insulated.

19.5 Flexible pipe connections

Flexible pipe connections become necessary to connect resilient mounted engines with external piping systems. these components have to compensate the dynamic movements of the engine in relation to the external piping system.

The shipyard's pipe system must be exactly arranged so that the flanges or screw connections fit without lateral or angular offset. It is recommended to adjust the final position of the pipe connections after engine alignment is completed.

It is important to support as close as possible to the flex connection and stronger than normal. The pipes outside the flexible connection must be well fixed and clamped to prevent from vibrations, which could damage the flexible connections.

Installation of steel compensators

Steel compensators can compensate movements in line and transversal to their center line. They are not suitable for compensating twisting movements. Compensators are very stiff against torsion.

It is very important that all steel compensators are not allowed to be installed on resilient mounted engines in vertical direction.

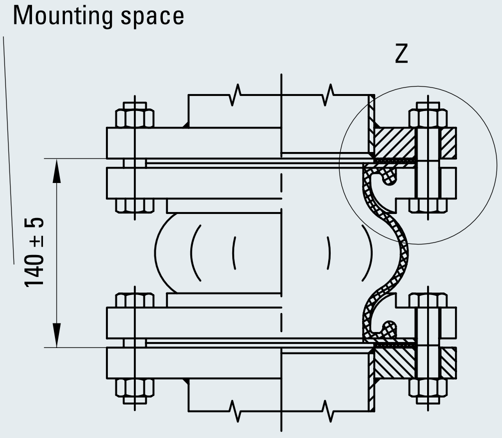

Fig. 19-1 Rubber expansion joint

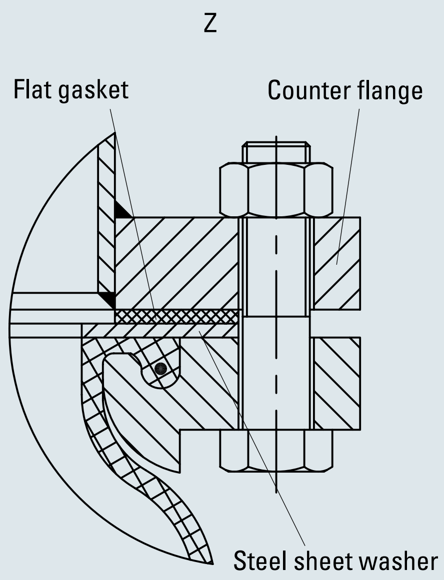

Fig. 19-2 Rubber expansion joint, detail Z

20.1 Engine center distances

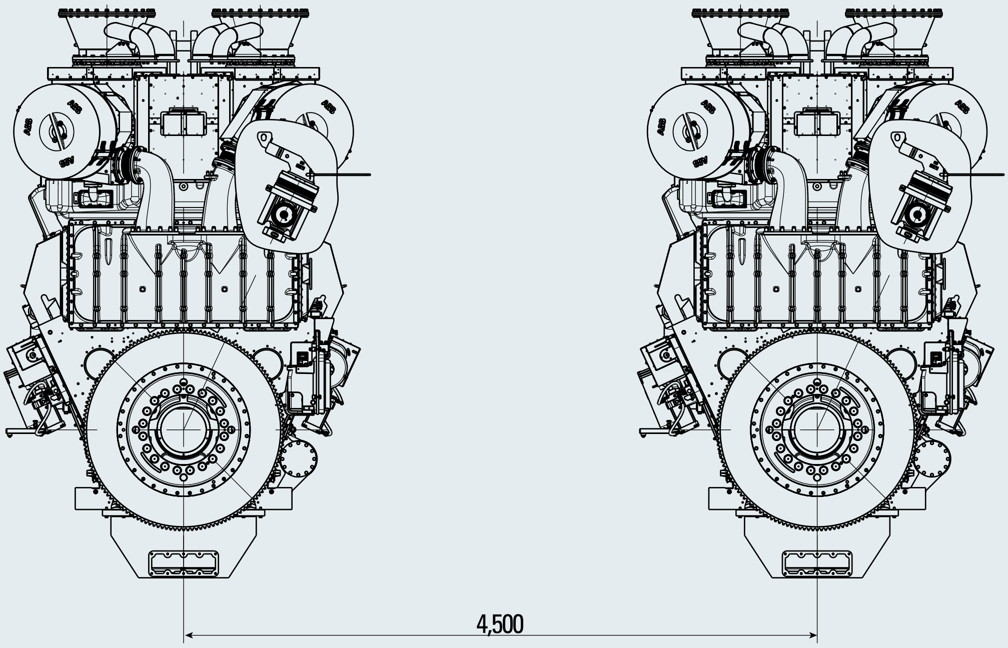

Fig. 20-1 Center distance of twin-engine plants

Type	Dimensions [mm]
	A
12/16 M 46 DF	4,500

Engine center distance
(2 engines side by side)
Minimum distance 4,500 mm

20.2 Space requirement for maintenance

20.2.1 Removal of charge air cooler and turbocharger cartridge

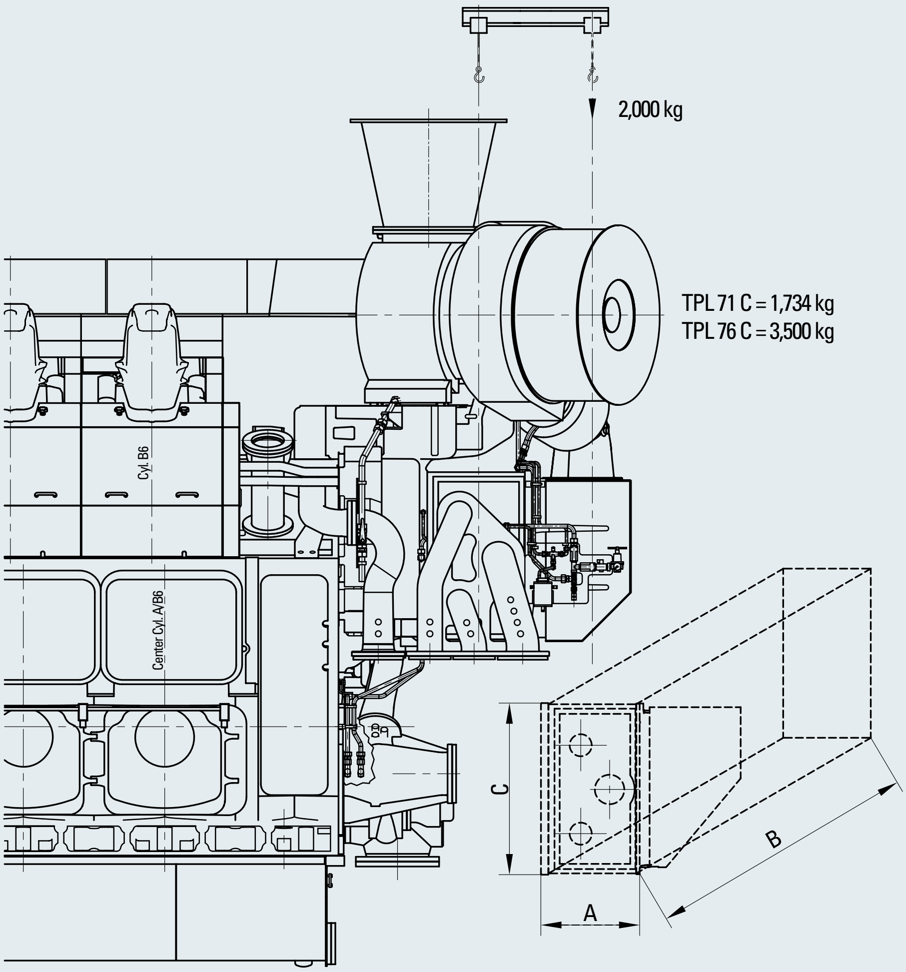

Fig. 20-2 Space requirement for dismantling of charge air cooler and turbocharger cartridge

Charge air cooler cleaning

Cleaning is carried out with charge air cooler dismantled. A container to receive the cooler and cleaning liquid is to be supplied by the yard. Intensive cleaning is achieved by using ultra sonic vibrators.

Turbocharger dismantling

To provide a lifting rail with a travelling trolley right above the center of the turbocharger in order to carry out scheduled maintenance work is recommended.

Engine type	Charge air cooler dimensions [mm]			Weight	Vibration damper dimensions [mm]		
	A	B	C	[kg]	Diam.	Width	Weight [kg]
12 M 46 DF	670	2,760	1,164	2,493	1,340	170	1,530
16 M 46 DF	670	2,760	1,164	2,493	1,200	170	1,180

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20.2.2 Removal of piston and cylinder liner

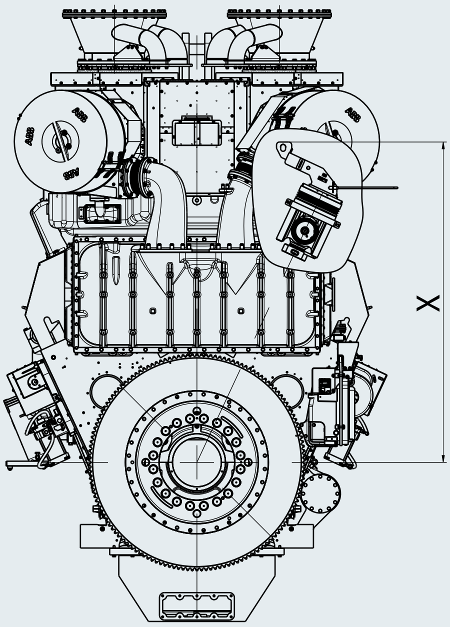

Fig. 20-3 Removal of piston and cylinder liner

Removal of		
Piston:	in transverse direction	X = 3,200 mm
Cylinder liner:	in transverse direction	Y = 3,700 mm

21.1 Inside preservation

21.1.1 Factory standard N 576-3.3 – Inside preservation

Components
- Main running gear and internal mechanics

Application
- Max. 2 years

NOTE:
Inside preservation does not have to be removed when the engine is commissioned.

21.2 Outside preservation

21.2.1 Factory standard N 576-3.2 – Outside preservation VCI 368

Conditions
- Europe and overseas
- Sea and land transportation
- Storage in the open, protected from moisture max. 2 years with additional VCI packaging

Appearance of the engine
- Castings with red oxide antirust paint
- Pipes and machined surfaces left as bare metal
- Attached components with colours of the manufacturers

NOTE:
Outside preservation must be removed before commissioning of the engines.
Environmentally compatible disposal is to be ensured.
Durability and effect depend on proper packaging, transportation, and storage (i.e. protected from moisture, stored at a dry place and sufficiently ventilated). Inspections are to be carried out at regular intervals.

21.2.2 Factory standard N 576-4.1 – Clear varnish

Conditions

- Europe
- Roofed land transportation
- Storage in a dry and tempered atmosphere, protected from moisture max. 1 year with additional VCI packaging

NOTE:
Clear varnish is not permissible for sea transportation of engine and storage of engines in the open, even if they are covered with tarpaulin.

Appearance of the engine

- Castings with red oxide antirust paint
- Pipes and machined surfaces left as bare metal
- Attached components with colours of the manufacturers
- Surfaces sealed with clear varnish
- Bare metal surfaces provided with VCI 368 preservation

NOTE:
VCI packaging as per factory standard N 576-5.2 is generally required!
Durability and effect depend on proper packaging, transportation, and storage (i.e. the engine is to be protected from moisture, VCI film not ripped or destroyed).
Inspections are to be carried out at regular intervals.
If the above requirements are not met, all warranty claims in connection with corrosion damage shall be excluded.

21.2.3 Factory standard N 576-4.3 – Painting

Conditions
- Europe and overseas
- Sea and land transportation
- Short-term storage in the open, protected from moisture up to max. 4 weeks
- Longer than 4 weeks VCI packaging as per factory standard N 576-5.2 is required
- Max. 2 years with additional VCI packaging

Appearance of the engine
- Surfaces mostly painted with varnish
- Bare metal surfaces provided with VCI 368 preservation

NOTE:
Durability and effect depend on proper packaging, transportation, and storage (i.e. the engine is to be protected from moisture, VCI film not ripped or destroyed).
Inspections are to be carried out at regular intervals.

21.2.4 Factory standard N 576-5.2 – VCI packaging

Conditions
- Engines with outside preservation VCI 368 as per factory standard N 576-3.2
- Engines with clear varnish as per factory standard N 576-4.1

  NOTE:
  These engines are always to be delivered with VCI packaging!
  Nevertheless, they are not suitable for storage in the open!
- Engine or engine generator sets with painting as per factory standard N 576-4.3
- Europe and overseas
- Storage in the open, protected from moisture

NOTE:
Durability and effect depend on proper packaging, transportation, and storage (i.e. the engine is to be protected from moisture, VCI film not ripped or destroyed).
Inspections are to be carried out at regular intervals.

Apperance of the engine

- Bare metal surfaces provided with VCI 368 or VCI oil
- VCI impregnated flexible PU foam mats attached to the engine using tie wraps.
  Kind and scope depending on engine type.
  The attached mats should not come into contact with the painted surface.
- Cover the engine completely with air cushion film VCI 126 LP. Air cushions are to face inwards!
  The air cushion film is fastened to the transportation skid (wooden frame) by means of wooden laths. Overlaps at the face ends and openings for the lifting gear are to be closed by means of PVC scotch tape. In case of engines delivered without oil pan, the overhanging VCI film between engine and transport frame is to be folded back upwards before fastening the air cushion film.

ATTENTION:
The corrosion protection is only effective if the engine is completely wrapped in VCI film. The protective space thus formed around the component can be openend for a short time by slitting the film, but afterwards it must be closed again with adhesive tape.

21.2.5 Factory standard N 576-5.2 Suppl. 1 – Information panel for VCI preservation and inspection

An information panel for VCI preservation and inspection will be supplied.

Application

- Engines with VCI packaging as per factory standard N 576-5.2

Description

- This panel provides information on initial preservation and instructions for inspection.
- Arranged on the transport frame on each side so as to be easily visible.

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21.3 Factory standard N 576-6-1 – Protection period, check, and representation

21.3.1 Protection period

There will only be an effective corrosion protection of the engine if the definitions and required work according to factory standard N 576-6.1 are duly complied with.
Normally, the applied corrosion protection is effective for a period of max. 2 years, if the engine or engine generator set is protected from moisture.
After two years representation must be carried out.
However, depending on the execution of the preservation or local conditions shorter periods may be recommended.

21.3.2 Protection check

Every 3 months specific inspections of the engine or engine generator set are to be carried out at defined inspection points.
Any corrosion and existing condensation water are to be removed immediately.

21.3.3 Representation as per factory standard N 576-6.1

After 2 years representation must be carried out.

22.1 Lifting of engines

For the purpose of transport the engine is equipped with a lifting device, which shall remain the property of Caterpillar Motoren. The lifting device has to be returned to Caterpillar Motoren.
Device to be used for transport of engine types 12/16 M 46 DF only.

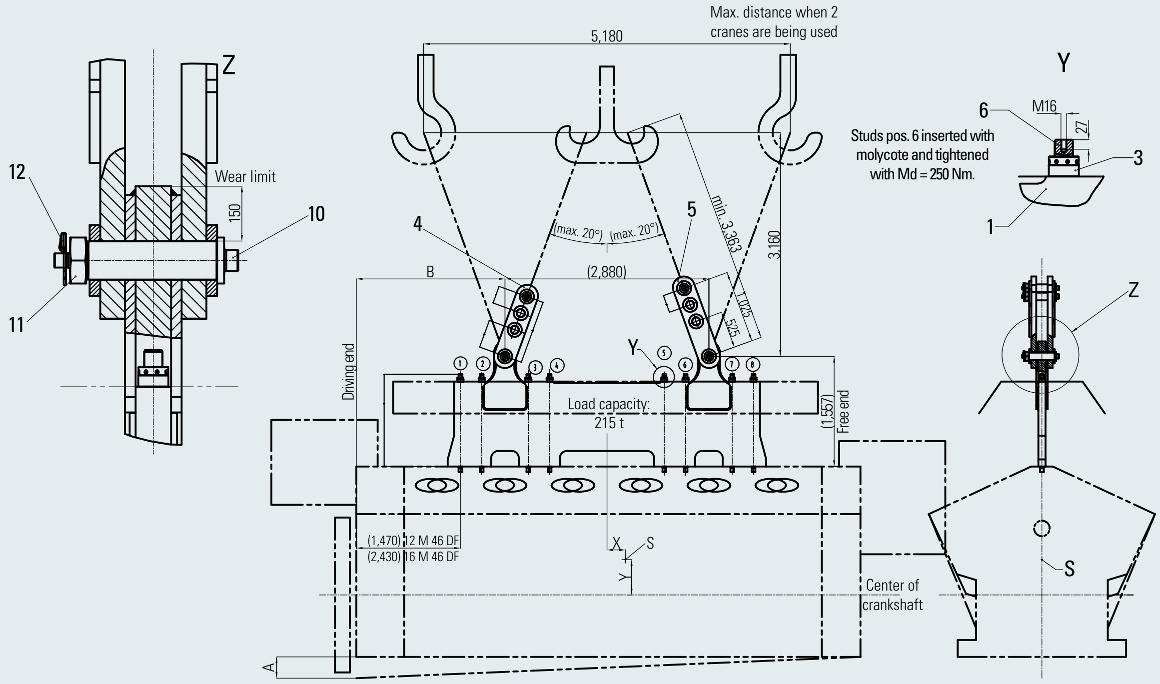

Fig. 22-1 Spreader bar

	Turbocharger at driving end	Turbocharger at free end	Weight	Center of gravity S		Mass dimension	
			[t]	[mm]		[mm]	
				X	Y	A	B
12 M 46 DF	X		170.0	1,787	1,090	100	2,100
		X	170.0	2,775	1,020	100	2,100
16 M 46 DF	X		208.0	1,103	2,704	100	3,060
		X	208.0	1,026	3,817	100	3,060

ATTENTION:
Do not push parts of the engine like cylinder head cover!
If the engine is lifted in an oblique position,
the dimension “A“ must not be exceeded.

Transport of engine with turbocharger at driving end

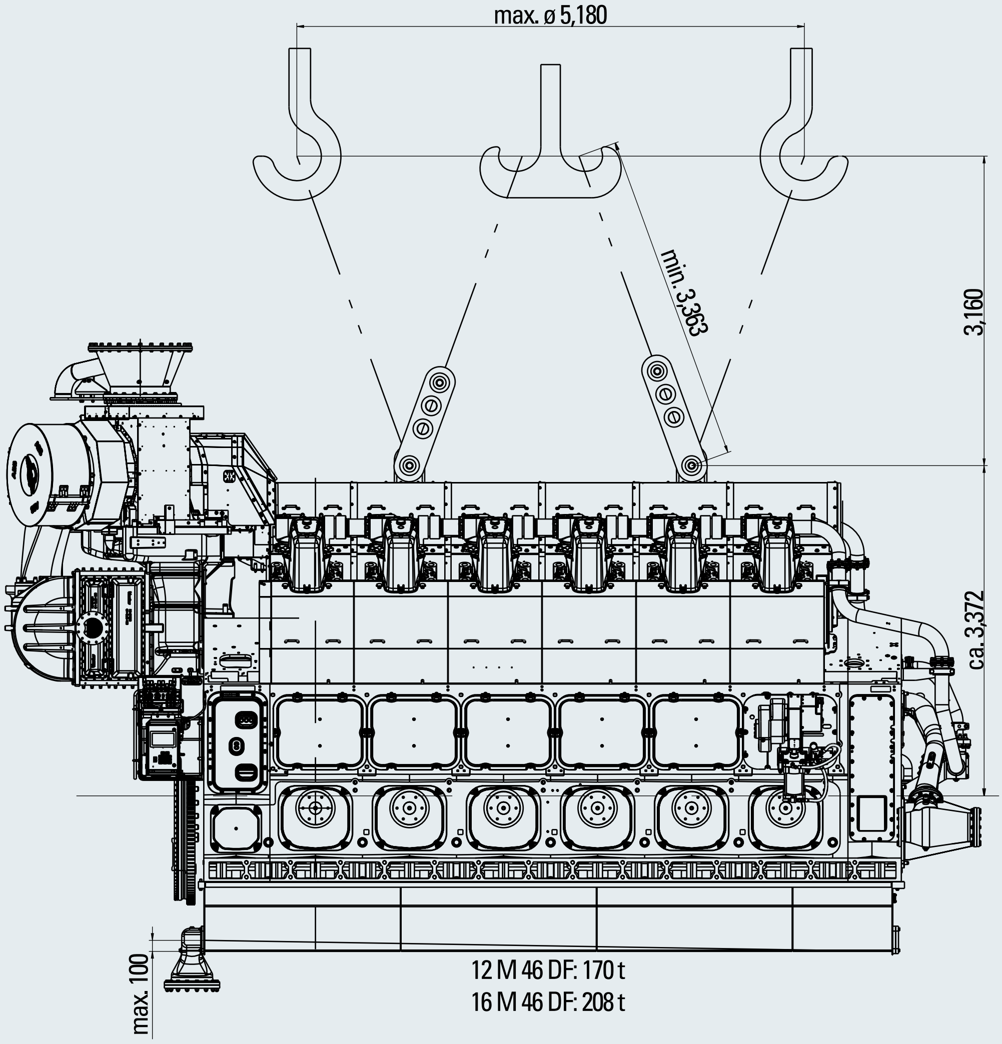

Fig. 22-2 Transport of 12/16 M 46 DF with turbocharger at driving end

Transport of engine with turbocharger at free end

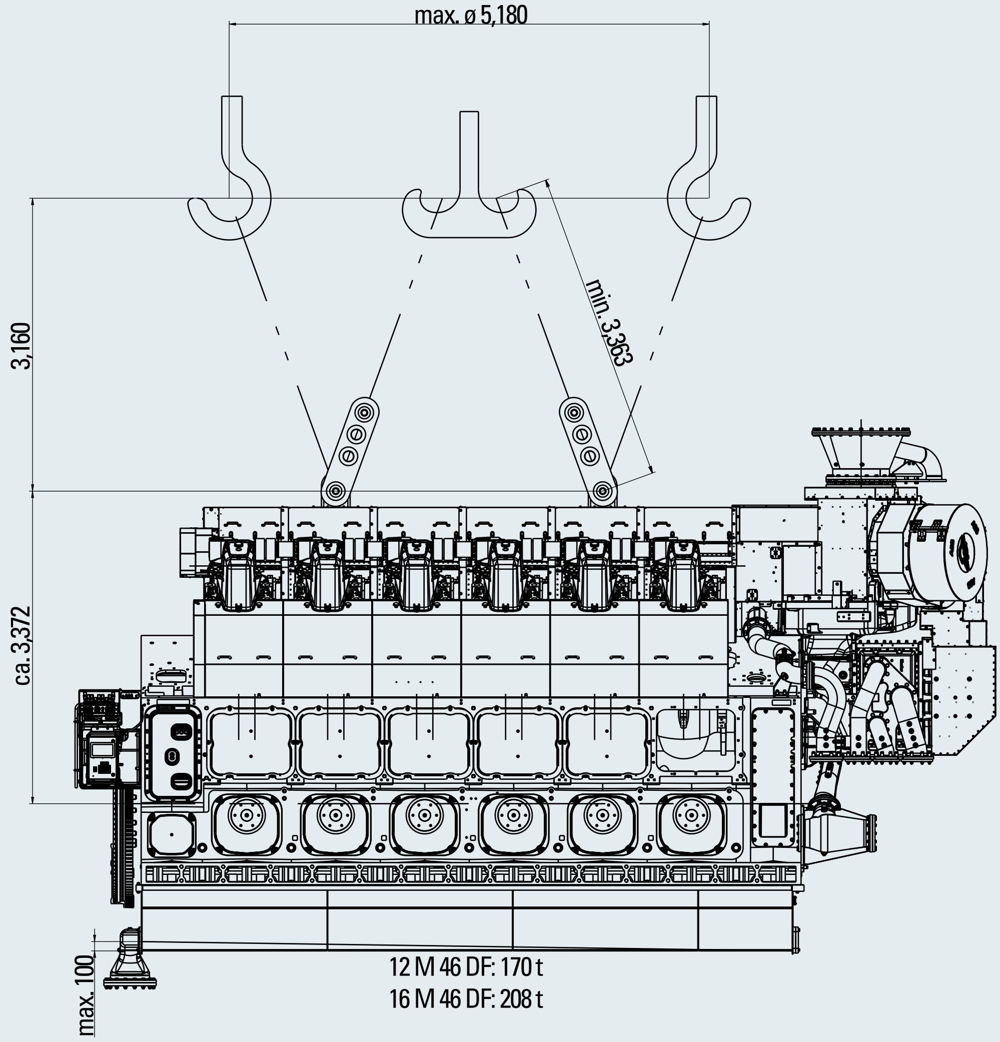

Fig. 22-3 Transport of 12/16 M 46 DF with turbocharger at free end

22.2 Dimensions of main components

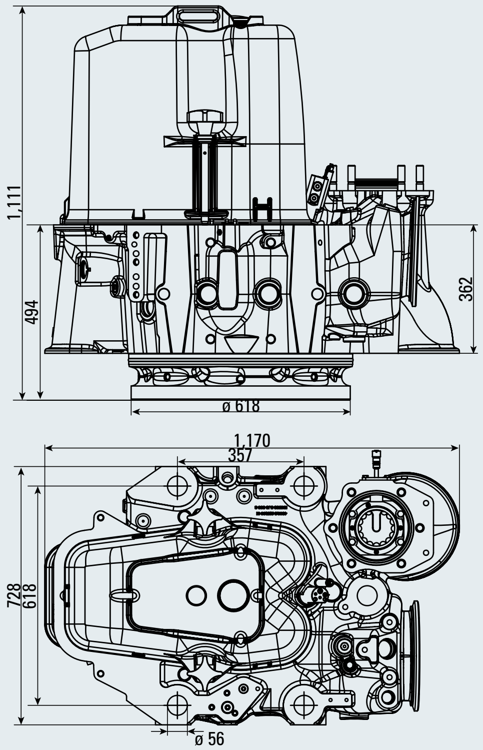

Fig. 22-4 Cylinder head (2D), weight 1,147 kg

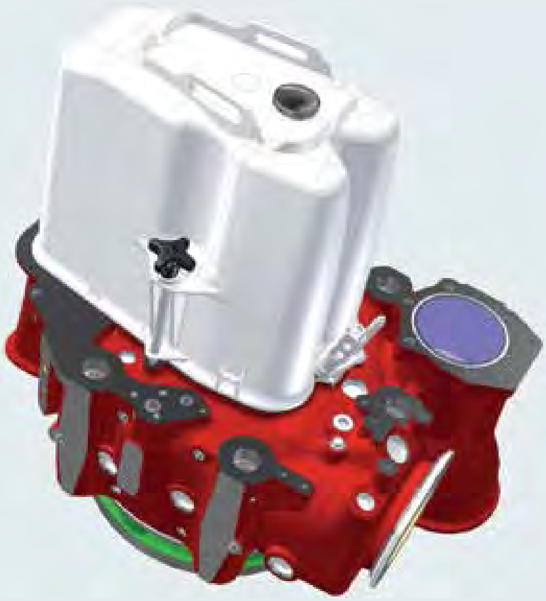

Fig. 22-5 Cylinder head (3D)

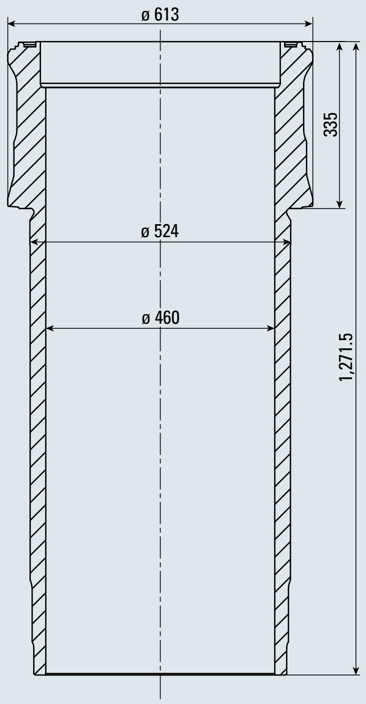

Fig. 22-6 Cylinder liner (2D), weight 560 kg

Fig. 22-7 Cylinder liner (3D)

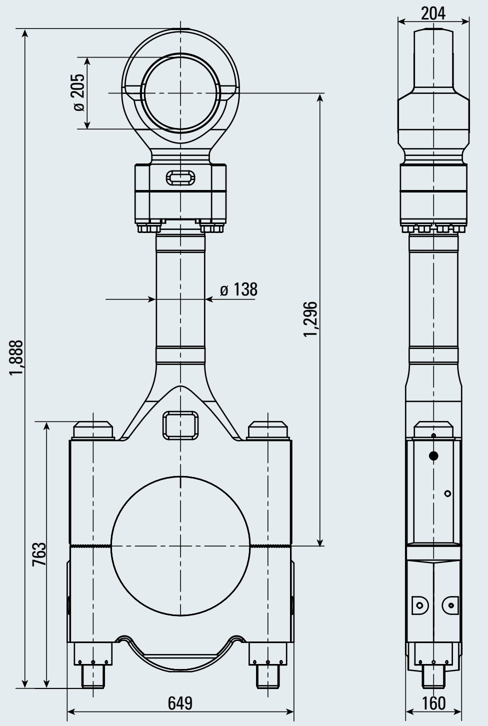

Fig. 22-8 Connecting rod (2D), weight 560 kg

Fig. 22-9 Connecting rod (3D)

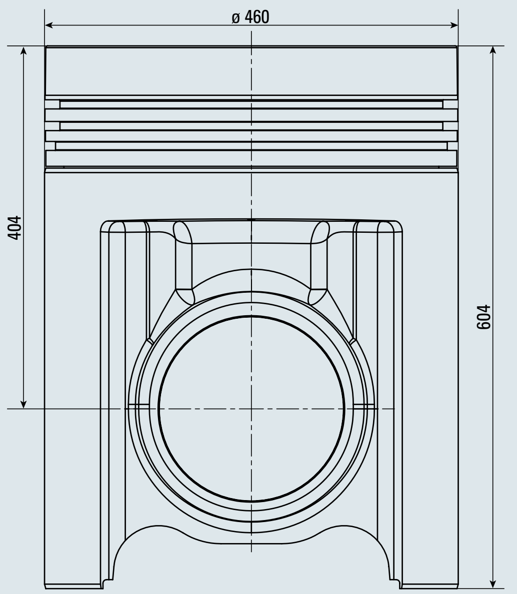

Fig. 22-10 Piston (2D), weight 230 kg

Fig. 22-11 Piston (3D)

23.1 Standard acceptance test run

The acceptance test run is carried out on the testing bed with customary equipment and auxiliaries using exclusively MDO and under the respective ambient conditions of the testing bed. During this test run the fuel rack will be blocked at the contractual output value. In case of deviations from the contractual ambient conditions the fuel consumption will be converted to standard reference conditions.
The engine will be run at the following load stages according to the rules of the classification societies.

Diesel mode

Load [%]	Duration [min]
Diesel mode	
25	20
50	20
75	20
85	20
100	60
110	30
Gas mode	
25	20
50	20
75	20
85	20
100	60

The load stages above can vary according to the requirements of the classification societies.

After reaching steady state conditions of pressures and temperatures these will be recorded and registered according to the form sheet of the acceptance test certificate.

Additional functional tests

In addition to the acceptance test run the following functional tests will be carried out:

- Governor test
- Overspeed test
- Emergency shut-down via minimum oil pressure
- Start/stop via central engine control
- Starting trials up to a minimum air pressure of 10 bar
- Measurement of crank web deflection (cold/warm condition)

After the acceptance, main running gear, camshaft drive and timing gear train will be inspected through the opened covers. Individual inspection of special engine components such as piston or bearings is not intended, because such inspections are carried out by the classification societies at intervals on series engines.

01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

24.1 Required spare parts (Marine Classification Society MCS)

Classification societies	GL	RS	KR	CCS
Rules references	Pt. 1, Ch. 17	Pt. 7, Ch. 10	Pt. 5, Ch. 1	Ch. 15, Sec. 1&2
Parts				
Main bearing	1	1	1	1
Thrust washer	1	1	1	1
Cylinder liner, complete	1	1	1	1
Cylinder head, complete	1	1	1	1
Cylinder head, only with valves (w/o injection valve)	–	–	–	–
Set of gaskets for one cylinder head	–	–	–	–
Set bolts and nuts for cylinder head	1/2	1/2	1/2	1/2
Set of exhaust valves for one cylinder head	1	(2)*	2	2
Set of intake valves for one cylinder head	1	(1)*	1	1
Starting air valve, complete	1	1	1	1
Relief valve, complete	1	1	1	1
Injection valve, complete	–	–	–	–
Set of injection valves, complete, for one engine	1	1	1	1
Set of conrod top & bottom bearing for one cylinder	1	1	1	1
Piston, complete	1	1	1	1
Piston, without piston pin + piston rings	–	–	–	–
Connecting rod	1	1	1	1
Big end bearing	–	–	–	–
Gudgeon pin with bushing for one cylinder	1	1	1	1
Set of piston rings	1	1	1	1
Fuel injection pump	1	1	1	1
Fuel injection piping	1	1	1	1
Set of gaskets and packing for one cylinder	1	1	1	1
Exhaust compensators between cylinders	1	–	1	1
Turbocharger rotor, complete	–	(1)*	–	–
Set of gear wheels	–	–	–	–
ECU	1	1	1	1
Speed pick up camshaft	1	1	1	1
Speed pick up crankshaft	1	1	1	1
DCU	1	–	–	–
Only for electronic speed setting Pick up for electronic speed setting	–	–	–	–
Only if oil mist detector is provided Sintered bronze filter (for crankcase monitor)	–	–	–	–

* Recommendation only

24.2 Recommended spare parts

Classification societies	ABS	DNV	LR	BV **	RINA **
Rules references	Pt. 4, Ch. 2 Sec. 1	Pt. 4, Ch. 1, Sec. 5	Pt. 5, Ch. 16, Sec. 1	Pt. A, Ch. 1, Sec. 1	Pt. A, Ch. 1, Sec. 1
Parts					
Main bearing	1	1	1	–	–
Thrust washer	1	1	1	–	–
Cylinder liner, complete	1	1	1	–	–
Cylinder head, complete	1	1	1	–	–
Cylinder head, only with valves (w/o injection valve)	–	–	–	–	–
Set of gaskets for one cylinder head	–	–	–	–	–
Set bolts and nuts for cylinder head	1/2	1/2	1/2	–	–
Set of exhaust valves for one cylinder head	2	2	2	–	–
Set of intake valves for one cylinder head	1	1	1	–	–
Starting air valve, complete	1	1	1	–	–
Relief valve, complete	1	1	1	–	–
Injection valve, complete	–	–	–	–	–
Set of injection valves, complete, for one engine	1	1	1	–	–
Set of conrod top & bottom bearing for one cylinder	1	1	1	–	–
Piston, complete	1	1	1	–	–
Piston, without piston pin + piston rings	–	–	–	–	–
Connecting rod	1	1	1	–	–
Big end bearing	–	–	–	–	–
Gudgeon pin with bushing for one cylinder	1	1	1	–	–
Set of piston rings	1	1	1	–	–
Fuel injection pump	1	1	1	–	–
Fuel injection piping	1	1	1	–	–
Set of gaskets and packing for one cylinder	1	1	1	–	–
Exhaust compensators between cylinders	1	1	1	–	–
Turbocharger rotor, complete	–	–	–	–	–
Set of gear wheels	1	–	–	–	–
ECU	1	1	1	1	1
Speed pick up camshaft	1	1	1	1	1
Speed pick up crankshaft	1	1	1	1	1
Only for electronic speed setting Pick up for electronic speed setting	–	–	–	–	–
Only if oil mist detector is provided Sintered bronze filter (for crankcase monitor)	–	–	–	–	–

* Recommendation only / ** Owner's responsibility

Caterpillar recommendation	Caterpillar
Rules references	
Parts	
Main bearing	1
Thrust washer	–
Cylinder liner, complete	1
Cylinder head, complete	–
Cylinder head, only with valves (w/o injection valve)	1
Set of gaskets for one cylinder head	1
Set bolts and nuts for cylinder head	1/2
Set of exhaust valves for one cylinder head	–
Set of intake valves for one cylinder head	–
Starting air valve, complete	–
Relief valve, complete	–
Injection valve, complete	1
Set of injection valves, complete, for one engine	–
Set of conrod top & bottom bearing for one cylinder	–
Piston, complete	–
Piston, without piston pin + piston rings	1
Connecting rod	–
Big end bearing	1
Gudgeon pin with bushing for one cylinder	–
Set of piston rings	1
Fuel injection pump	1
Fuel injection piping	1
Set of gaskets and packing for one cylinder	–
Exhaust compensators between cylinders	1
Turbocharger rotor, complete	–
Set of gear wheels	–
ECU	1
Speed pick up camshaft	1
Speed pick up crankshaft	1
DCU	1
Gas admission valve	2
Ignition injector	2
Cylinder pressure sensor	1
Set of dual fuel gaskets	1
Rail pressure sensor	1
Gas compensator	1
Ignition fuel high pressure pump	1

25.1 Gas systems technology – Scope of supply

Beside the gas / dual fuel engines itself Caterpillar offers also the whole gas system which is needed to operate the engine onboard the vessel.
Whether on a new building or for a retrofit project, the service can include:

- Gas / dual fuel engines
- FEED study (Front End Engineering and Design study)
- A&I engineering
- Bunker station
- LNG storage tank
- Gas handling system
- Gas and LNG piping
- Gas valve unit
- Control & monitoring
- Safety systems

The customer can benefit from getting a whole solution from one hand. Supported by our strong dealer and customer support organizations.

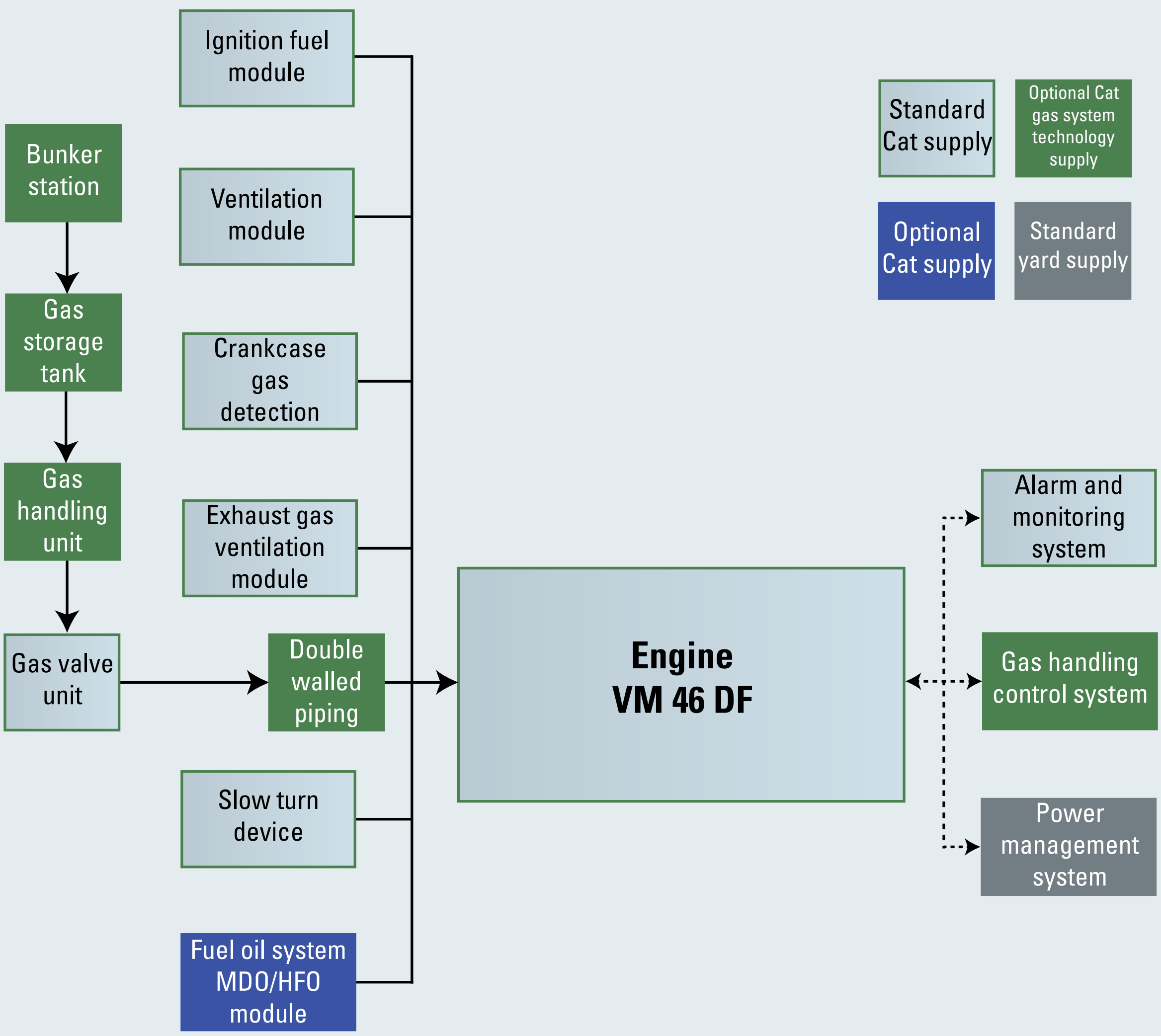

Fig. 25-1 Scope of supply VM 46 DF Gas systems technology – block diagram

25.2 Caterpillar Propulsion

Performance You Can Rely On

Caterpillar Propulsion supplies complete, world-leading propulsion systems.

Custom-designed and optimized for uptime and cost-effective operations, our top-of-the-line controllable pitch propellers, thrusters, control systems, and hubs are all manufactured at our state-of-the-art production facilities in Sweden and Singapore.


Fig. 25-2 Main propeller

We are experts in innovative hydrodynamics to ensure heavy-duty, reliable performance for our customers.

How we deliver uptime

Our guiding principle is to deliver maximum uptime for our customers' peace-of-mind and profitability.

For us, this means using more material to ensure our propulsion systems are built to last even in the most extreme conditions. And with extreme attention to detail, we study your vessel's design, the job at hand – anything and everything that affects the hydrodynamics.

Using all our expertise, we're not finished until the system is as optimized and reliable as possible. Please visit us at catpropulsion.com.


Fig. 25-3 Azimuth thrusters


Fig. 25-4 Tunnel thrusters


Fig. 25-5 Remote control system

The Power You Need.

The Cat® and MaK™ brands of Caterpillar Marine offer premier high- and medium-speed propulsion, auxiliary, and generator set solutions, as well as optional dual fuel, diesel-electric, and hybrid system configurations. With the launch of Caterpillar Propulsion our comprehensive and evolving product line gives customers one source for the most extensive engine power range available, complete propulsion systems, controllable pitch propellers, transverse and azimuth thrusters, and controls. Cat and MaK products and technologies are proven reliable and are built to last in all marine applications, demonstrating superior productivity and the lowest lifecycle cost.

The Cat Global Dealer Network, more than 2,200 global service locations strong, ensures that you'll have local expertise, highly-trained technicians, rapid parts delivery, and the proper equipment and services to keep you working – anytime, anywhere.

Construction, term, or repower financing through Cat Financial helps you make Cat and MaK power a reality. With our knowledge of customer needs, local markets, and legal and regulatory requirements, we've been providing tailored financing solutions and exceeding expectations since our start in 1986.

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