WÄRTSILÄ Engines

WÄRTSILÄ 46F
PROJECT GUIDE

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Introduction

This Project Guide provides data and system proposals for the early design phase of marine engine installations. For contracted projects specific instructions for planning the installation are always delivered. Any data and information herein is subject to revision without notice. This 1/2008 issue replaces all previous issues of the Wärtsilä 46F Project Guides.

Issue	Published	Updates
1/2008	29.05.2008	Starting air consumption increased, turbocharger cleaning chapter updated and several other minor updates.
1/2007	29.11.2007	First issue of Wärtsilä 46F Project Guide.

Wärtsilä Ship Power

Technology, Product Support

Vaasa, May 2008

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1. General data and outputs

The Wärtsilä 46F is a 4-stroke, non-reversible, turbocharged and intercooled diesel engine with direct fuel injection.

Cylinder bore	460 mm
Stroke	580 mm
Piston displacement	96.4 l/cyl
Number of valves	2 inlet valves and 2 exhaust valves
Cylinder configuration	6, 7, 8 and 9 in-line
Direction of rotation	clockwise, counter-clockwise on request
Speed	600 rpm
Mean piston speed	11.6 m/s

1.1 Maximum continuous output

Table 1.1 Maximum continuos output

Engine	kW	bhp
6L46F	7500	10200
7L46F	8750	11900
8L46F	10000	13600
9L46F	11250	15300

The mean effective pressure P_e can be calculated using the following formula:

$$P_e = \frac{P \times c \times 1.2 \times 10^9}{D^2 \times L \times n \times \pi}$$

where:

P_e = mean effective pressure [bar]

P = output per cylinder [kW]

n = engine speed [r/min]

D = cylinder diameter [mm]

L = length of piston stroke [mm]

c = operating cycle (4)

1.2 Reference conditions

The output is available up to a charge air coolant temperature of max. 38°C and an air temperature of max. 45°C. For higher temperatures, the output has to be reduced according to the formula stated in ISO 3046-1:2002 (E).

The specific fuel oil consumption is stated in the chapter *Technical data*. The stated specific fuel oil consumption applies to engines without engine driven pumps, operating in ambient conditions according to ISO 15550:2002 (E). The ISO standard reference conditions are:

total barometric pressure	100 kPa
air temperature	25°C
relative humidity	30%
charge air coolant temperature	25°C

Correction factors for the fuel oil consumption in other ambient conditions are given in standard ISO 3046-1:2002.

1.3 Dimensions and weights

Figure 1.1 In-line engines (DAAE012051a)

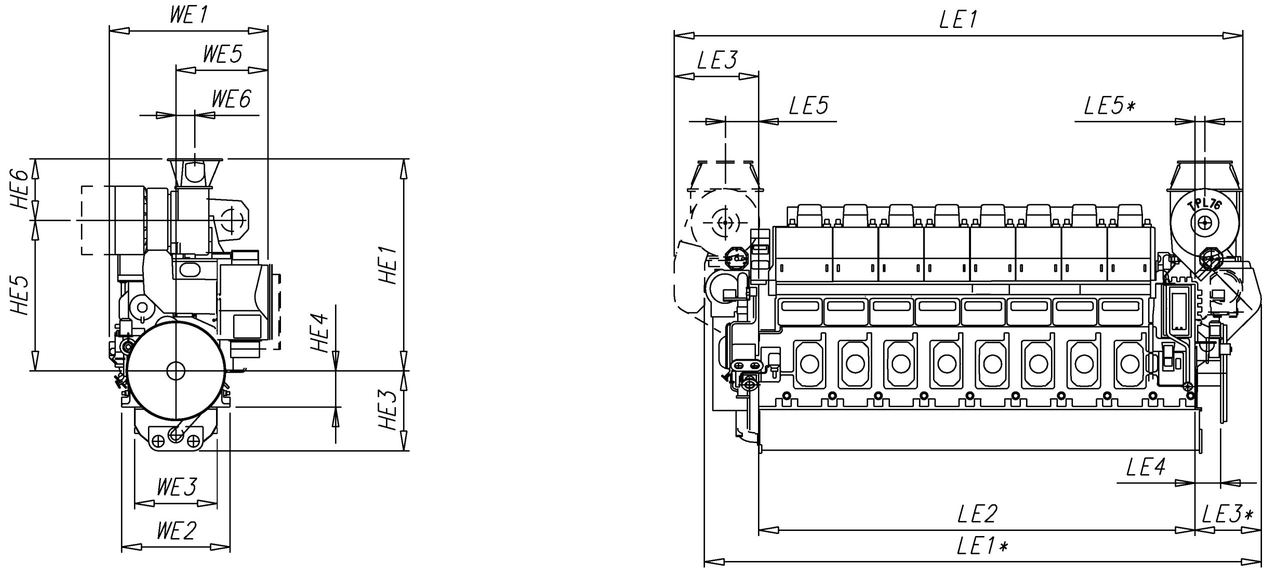


Table 1.2 Main dimensions [mm]

Engine	LE1*	LE1	LE2	LE3*	LE3	LE4	LE5*	LE5	HE1	HE3	HE4	HE5	WE1	WE2	WE3	WE5	WE6	Dry Weight (ton)
6L46F	8430	8620	6170	1290	1550	460	120	690	3500	1430	650	2710	2930	1940	1480	1530	390	97
7L46F	9260	9440	6990	1290	1550	460	180	800	3800	1430	650	2700	2950	1940	1480	1720	340	113
8L46F	10080	10260	7810	1290	1550	460	180	800	3800	1430	650	2700	2950	1940	1480	1720	340	124
8L46F	10900	11080	8630	1290	1550	460	180	800	3800	1430	650	2700	2950	1940	1480	1720	340	140

* Turbocharger at flywheel end

The weights are dry weights of rigidly mounted engines without flywheel.

Table 1.3 Additional weights [ton]:

Item	6L46F	7L46F	8L46F	9L46F
Flywheel	1...2	1...2	1...2	1...2
Flexible mounting (without limiters)	3	3	3	3

2. Operating ranges

2.1 Engine operating range

Below nominal speed the load must be limited according to the diagrams in this chapter in order to maintain engine operating parameters within acceptable limits. Operation in the shaded area is permitted only temporarily during transients. Minimum speed and speed range for clutch engagement are indicated in the diagrams, but project specific limitations may apply.

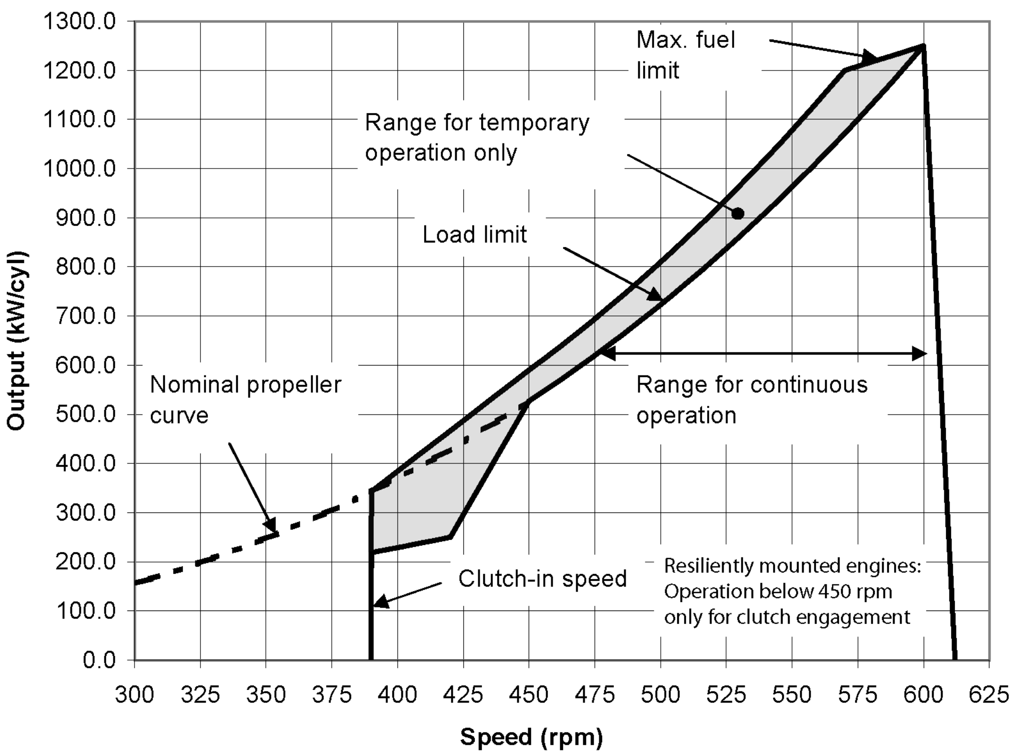
2.1.1 Controllable pitch propellers

An automatic load control system is required to protect the engine from overload. The load control reduces the propeller pitch automatically, when a pre-programmed load versus speed curve ("engine limit curve") is exceeded, overriding the combinator curve if necessary. The engine load is derived from fuel rack position and actual engine speed (not speed demand).

The propulsion control should also include automatic limitation of the load increase rate. Maximum loading rates can be found later in this chapter.

The propeller efficiency is highest at design pitch. It is common practice to dimension the propeller so that the specified ship speed is attained with design pitch, nominal engine speed and 85% output in the specified loading condition. The power demand from a possible shaft generator or PTO must be taken into account. The 15% margin is a provision for weather conditions and fouling of hull and propeller. An additional engine margin can be applied for most economical operation of the engine, or to have reserve power.

Figure 2.1 Operating field for CP Propeller, 1250 kW/cyl, 600 rpm



2.2 Loading capacity

Controlled load increase is essential for highly supercharged diesel engines, because the turbocharger needs time to accelerate before it can deliver the required amount of air. Sufficient time to achieve even temperature distribution in engine components must also be ensured. This is especially important for larger engines.

If the control system has only one load increase ramp, then the ramp for a preheated engine should be used. The HT-water temperature in a preheated engine must be at least 60 °C, preferably 70 °C, and the lubricating oil temperature must be at least 40 °C.

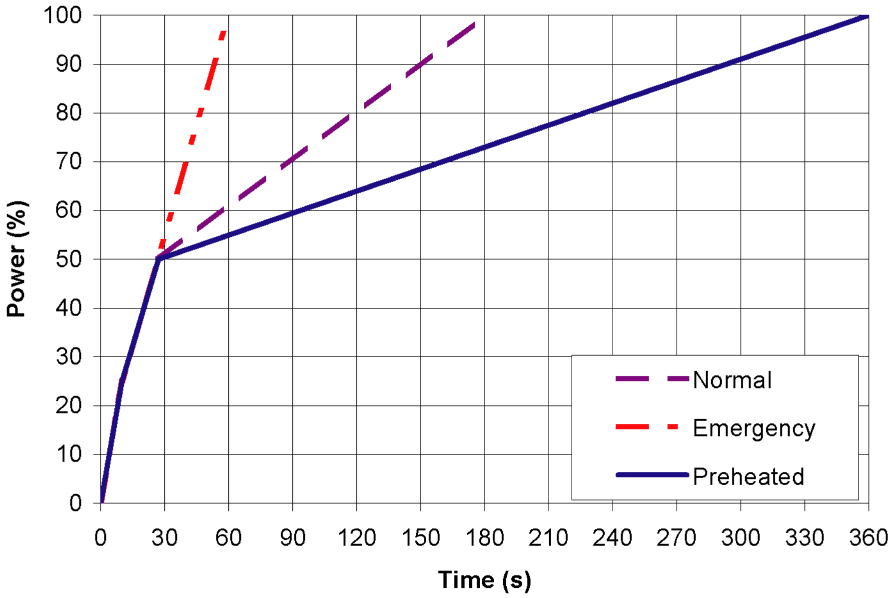
The ramp for normal loading applies to engines that have reached normal operating temperature.

Emergency loading may only be possible by activating an emergency function, which generates visual and audible alarms in the control room and on the bridge.

The load should always be applied gradually in normal operation. Class rules regarding load acceptance capability of diesel generators should not be interpreted as guidelines on how to apply load in normal operation. The class rules define what the engine must be capable of, if an unexpected event causes a sudden load step.

2.2.1 Mechanical propulsion, controllable pitch propeller (CPP)

Figure 2.2 Maximum load increase rates for variable speed engines

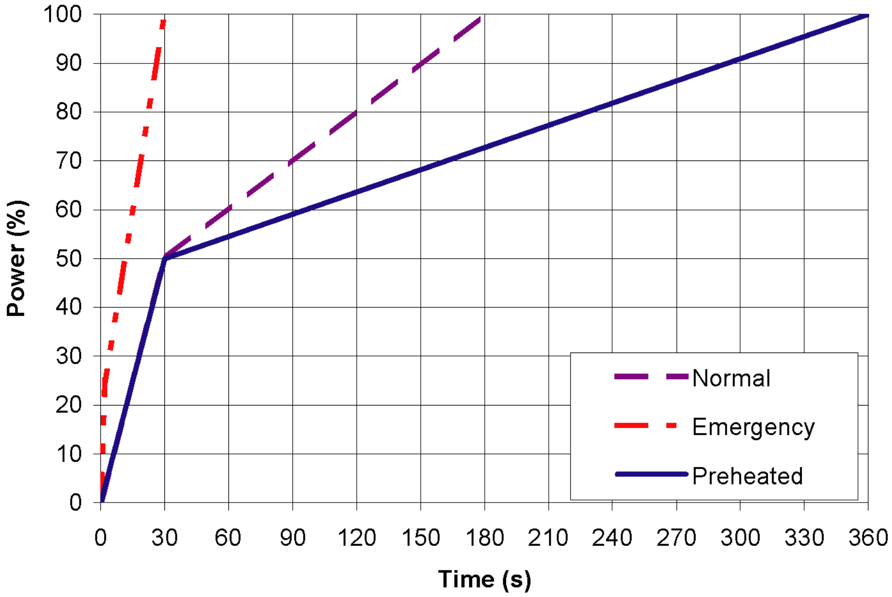


If minimum smoke during load increase is a major priority, slower loading rate than in the diagram can be necessary below 50% load.

In normal operation the load should not be reduced from 100% to 0% in less than 15 seconds. When absolutely necessary, the load can be reduced as fast as the pitch setting system can react (overspeed due to windmilling must be considered for high speed ships).

2.2.2 Diesel electric propulsion

Figure 2.3 Maximum load increase rates for engines operating at nominal speed



In normal operation the load should not be reduced from 100% to 0% in less than 15 seconds. In an emergency situation the full load can be thrown off instantly.

The maximum deviation from steady state speed is less than 10%, when applying load according to the emergency loading ramp. Load increase according to the normal ramp correspondingly results in less than 3% speed deviation.

Maximum instant load steps

The electrical system must be designed so that tripping of breakers can be safely handled. This requires that the engines are protected from load steps exceeding their maximum load acceptance capability. The maximum permissible load step for an engine that has attained normal operating temperature is 33% MCR. The resulting speed drop is less than 10% and the recovery time to within 1% of the steady state speed at the new load level is max. 5 seconds.

When electrical power is restored after a black-out, consumers are reconnected in groups, which may cause significant load steps. The engine must be allowed to recover for at least 10 seconds before applying the following load step, if the load is applied in maximum steps.

Start-up time

A diesel generator typically reaches nominal speed in about 25 seconds after the start signal. The acceleration is limited by the speed control to minimise smoke during start-up.

2.3 Low air temperature

In cold conditions the following minimum inlet air temperatures apply:

- Starting + 5°C
- Idling - 5°C
- High load - 10°C

The two-stage charge air cooler is useful for heating of the charge air during prolonged low load operation in cold conditions. Sustained operation between 0 and 40% load can however require special provisions in cold conditions to prevent too low HT-water temperature. If necessary, the preheating arrangement can be designed to heat the running engine (capacity to be checked).

For further guidelines, see chapter *Combustion air system design*.

2.4 Operation at low load and idling

The engine can be started, stopped and operated on heavy fuel under all operating conditions. Continuous operation on heavy fuel is preferred rather than changing over to diesel fuel at low load operation and manoeuvring. The following recommendations apply:

Absolute idling (declutched main engine, disconnected generator)

- Maximum 10 minutes if the engine is to be stopped after the idling. 3-5 minutes idling before stop is recommended.
- Maximum 6 hours if the engine is to be loaded after the idling.

Operation below 20 % load

- Maximum 100 hours continuous operation. At intervals of 100 operating hours the engine must be loaded to minimum 70 % of the rated output.

Operation above 20 % load

- No restrictions.

3. Technical data

3.1 Introduction

This chapter contains technical data of the engine (heat balance, flows, pressures etc.) for design of ancillary systems. Further design criteria for external equipment and system layouts are presented in the respective chapter.

Separate data is given for engines driving propellers “ME” and engines driving generators “DE”.

3.1.1 Ambient conditions

The heat balance is given for ISO standard reference conditions (25°C suction air and 25°C LT-water temperature). The heat rates are however affected by ambient conditions, especially the intake air (suction air) temperature has a significant influence. Corrections for higher intake air temperature are given in the table below. The heat rates and the exhaust gas flow are multiplied with a factor, while a temperature increase is added to the exhaust gas temperature. At higher loads than approx. 85% the charge air pressure is controlled by the exhaust wastegate. The influence of the intake air temperature is therefore significantly different above 85% load.

The cooling water system is designed to maintain a constant charge air temperature. Variations in cooling water temperature will therefore not affect the heat balance as long as the cooling water temperature is below the maximum value.

Table 3.1 Correction of heat balance per 10 C higher intake air temperature compared to ISO conditions (25 C)

	Below approx. 85% load	Above approx. 85% load
HT total (charge air + cylinder jackets)	1.052	1.080
LT total (charge air + lubricating oil)	1.003	1.018
HT + LT total	1.032	1.054
Exhaust gas flow	0.972	0.997
Exhaust gas temperature	+12 °C	+17 °C

Coolers in the external systems are usually dimensioned for tropical conditions; engine intake air temperature 45 °C and seawater temperature 32 °C. The central cooler should be able to maintain an LT-water temperature of max. 38 °C before the engine at full engine load under these conditions.

3.1.2 Engine driven pumps

The fuel consumption stated in the technical data tables is without engine driven pumps. The increase in fuel consumption with engine driven pumps is given in the table below; correction in g/kWh.

Table 3.2 Fuel consumption increase with engine driven pumps [g/kWh]

		Engine load [%]			
		100	85	75	50
Constant speed	Lubricating oil pump	2.0	2.5	3.0	4.0
	HT- & LT-pump total	1.0	1.3	1.6	2.0
Propeller law	Lubricating oil pump	2.0	2.0	2.0	2.0
	HT- & LT-pump total	1.0	1.0	1.0	1.0

3.2 Technical data tables

3.2.1 Wärtsilä 6L46F

Wärtsilä 6L46F		**ME**	**DE**	**ME-CR**	**DE-CR**
Cylinder output	**kW**	**1250**	**1250**	**1250**	**1250**
Engine speed	**rpm**	**600**	**600**	**600**	**600**
Engine output	kW	7500	7500	7500	7500
Mean effective pressure	MPa	2.59	2.59	2.59	2.59
Combustion air system (Note 1)					
Flow at 100% load	kg/s	13.1	13.1	13.1	13.1
Temperature at turbocharger intake, max. (TE 600)	°C	45	45	45	45
Temperature after air cooler, nom. (TE 601)	°C	50	50	50	50
Exhaust gas system (Note 2)					
Flow at 100% load	kg/s	13.5	13.5	13.5	13.5
Flow at 85% load	kg/s	12.1	12.3	12.1	12.3
Flow at 75% load	kg/s	11.0	11.4	11.0	11.4
Flow at 50% load	kg/s	9.2	9.8	9.2	9.8
Temp. after turbo, 100% load (TE 517)	°C	373	373	373	373
Temp. after turbo, 85% load (TE 517)	°C	322	319	322	319
Temp. after turbo, 75% load (TE 517)	°C	327	317	327	317
Temp. after turbo, 50% load (TE 517)	°C	299	291	299	291
Backpressure, max.	kPa	3.0	3.0	3.0	3.0
Calculated pipe diameter for 35 m/s	mm	945	945	945	945
Heat balance at 100% load (Note 3)					
Jacket water, HT-circuit	kW	725	725	725	725
Charge air, HT-circuit	kW	1740	1745	1740	1745
Charge air, LT-circuit	kW	750	750	750	750
Lubricating oil, LT-circuit	kW	940	940	940	940
Radiation	kW	275	280	275	280
Fuel system (Note 4)					
Pressure before injection pumps (PT 101)	kPa	800...1000	800...1000	800...1000	800...1000
Flow to engine, approx.	m^3/h	6.0	6.0	4.5	4.5
HFO viscosity before engine	cSt	16...24	16...24	16...24	16...24
MDF viscosity, min.	cSt	2.0	2.0	2.0	2.0
Max. HFO temperature before engine (TE 101)	°C	135	135	135	135
Clean leak fuel quantity, HFO at 100% load	kg/h	4.5	4.5	2.3	2.3
Clean leak fuel quantity, MDF at 100% load	kg/h	22.5	22.5	11.3	11.3
Clean leak fuel quantity at stop, max.	l	-	-	11	11
Fuel consumption at 100% load	g/kWh	180	180	180	180
Fuel consumption at 85% load	g/kWh	175	176	175	176
Fuel consumption at 75% load	g/kWh	177	178	177	178
Fuel consumption at 50% load	g/kWh	181	185	181	185
Lubricating oil system					
Pressure before bearings, nom. (PT 201)	kPa	450	450	450	450
Pressure after pump, max.	kPa	800	800	800	800
Suction ability of built-on pump, including losses, max.	kPa	400	400	400	400
Priming pressure, nom. (PT 201)	kPa	80	80	80	80
Temperature before bearings, nom. (TE 201)	°C	56	56	56	56
Temperature after engine, approx.	°C	75	75	75	75
Pump capacity (main), engine driven	m^3/h	175	155	175	155
Pump capacity (main), electrically driven	m^3/h	150	150	150	150
Oil flow through engine	m^3/h	130	130	130	130
Priming pump capacity	m^3/h	35	35	35	35
Control oil flow, steady	l/min	-	-	3.2	3.2
Control oil flow, max. momentary	l/min	-	-	110	110
Absolute mesh size of built-on automatic filter	µm	30.0	30.0	30.0	30.0
Absolute mesh size of built-on safety filter	µm	100.0	100.0	100.0	100.0
Oil volume in separate system oil tank	m^3	9.0	9.0	9.0	9.0
Oil consumption at 100% load, approx.	g/kWh	0.7	0.7	0.7	0.7
Crankcase ventilation flow rate at full load	l/min	1350	1350	1350	1350
Crankcase ventilation backpressure, max.	Pa	200	200	200	200
Oil volume in turning device	l	9.5	9.5	9.5	9.5
Oil volume in speed governor	l	1.7	1.7	-	-

Wärtsilä 6L46F		ME	DE	ME-CR	DE-CR
Cylinder output	**kW**	**1250**	**1250**	**1250**	**1250**
Engine speed	**rpm**	**600**	**600**	**600**	**600**
High temperature cooling water system					
Pressure at engine, after pump, nom. (PT 401)	kPa	250 + static	250 + static	250 + static	250 + static
Pressure at engine, after pump, max. (PT 401)	kPa	530	530	530	530
Temperature before cylinders, approx. (TE 401)	°C	74	74	74	74
Temperature after cylinders, nom. (TE 402)	°C	82	82	82	82
Temperature after charge air cooler at 100% load, approx.	°C	91	91	91	91
Capacity of engine driven pump, nom.	m^3/h	115	115	115	115
Pressure drop over engine (including temp. control valve)	kPa	150	150	150	150
Pressure drop in external system, max.	kPa	100	100	100	100
Pressure from expansion tank	kPa	70...150	70...150	70...150	70...150
Water volume in engine	m^3	1.0	1.0	1.0	1.0
Low temperature cooling water system					
Pressure at engine, after pump, nom. (PT 451)	kPa	250 + static	250 + static	250 + static	250 + static
Pressure at engine, after pump, max. (PT 451)	kPa	530	530	530	530
Temperature before engine, max. (TE 451)	°C	38	38	38	38
Temperature before engine, min. (TE 451)	°C	25	25	25	25
Capacity of engine driven pump, nom.	m^3/h	115	115	115	115
Pressure drop over charge air cooler	kPa	50	50	50	50
Pressure drop over built-on lube oil cooler	kPa	20	20	20	20
Pressure drop over built-on temp. control valve	kPa	30	30	30	30
Pressure drop in external system, max.	kPa	150	150	150	150
Pressure from expansion tank	kPa	70 ... 150	70 ... 150	70 ... 150	70 ... 150
Water volume in engine	m^3	0.3	0.3	0.3	0.3
Starting air system					
Pressure, nom.	kPa	3000	3000	3000	3000
Pressure, max.	kPa	3000	3000	3000	3000
Low pressure limit in air vessels	kPa	1800	1800	1800	1800
Consumption per start at 20°C (successful start)	Nm^3	6.0	6.0	6.0	6.0
Consumption per start at 20°C, (with slowturn)	Nm^3	7.0	7.0	7.0	7.0

Notes:

Note 1 At ISO 3046-1 conditions (ambient air temperature 25°C, LT-water 25°C) and 100% load. Tolerance 5%.

Note 2 At ISO 3046-1 conditions (ambient air temperature 25°C, LT-water 25°C) and 100% load. Flow tolerance 5% and temperature tolerance 15°C.

Note 3 At ISO 3046-1 conditions (ambient air temperature 25°C, LT-water 25°C) and 100% load. Tolerance for cooling water heat 10%, tolerance for radiation heat 20%. Fouling factors and a margin to be taken into account when dimensioning heat exchangers.

Note 4 According to ISO 3046-1, lower calorific value 42 700 kJ/kg, without engine driven pumps. Tolerance 5%. Load according to propeller law for mechanical propulsion engines (ME).

ME = Engine driving propeller, variable speed
DE = Engine driving generator
CR = Common Rail
Subject to revision without notice.

3.2.2 Wärtsilä 7L46F

Wärtsilä 7L46F		ME	DE	ME-CR	DE-CR
Cylinder output	**kW**	**1250**	**1250**	**1250**	**1250**
Engine speed	**rpm**	**600**	**600**	**600**	**600**
Engine output	kW	8750	8750	8750	8750
Mean effective pressure	MPa	2.59	2.59	2.59	2.59
Combustion air system (Note 1)					
Flow at 100% load	kg/s	15.3	15.3	15.3	15.3
Temperature at turbocharger intake, max. (TE 600)	°C	45	45	45	45
Temperature after air cooler, nom. (TE 601)	°C	50	50	50	50
Exhaust gas system (Note 2)					
Flow at 100% load	kg/s	15.8	15.8	15.8	15.8
Flow at 85% load	kg/s	14.1	14.4	14.1	14.4
Flow at 75% load	kg/s	12.8	13.3	12.8	13.3
Flow at 50% load	kg/s	10.7	11.4	10.7	11.4
Temp. after turbo, 100% load (TE 517)	°C	373	373	373	373
Temp. after turbo, 85% load (TE 517)	°C	322	319	322	319
Temp. after turbo, 75% load (TE 517)	°C	327	317	327	317
Temp. after turbo, 50% load (TE 517)	°C	299	291	299	291
Backpressure, max.	kPa	3.0	3.0	3.0	3.0
Calculated pipe diameter for 35 m/s	mm	1023	1023	1023	1023
Heat balance at 100% load (Note 3)					
Jacket water, HT-circuit	kW	845	845	845	845
Charge air, HT-circuit	kW	2030	2035	2030	2035
Charge air, LT-circuit	kW	875	875	875	875
Lubricating oil, LT-circuit	kW	1095	1095	1095	1095
Radiation	kW	320	330	320	330
Fuel system (Note 4)					
Pressure before injection pumps (PT 101)	kPa	800...1000	800...1000	800...1000	800...1000
Flow to engine, approx.	m^3/h	7.0	7.0	5.2	5.2
HFO viscosity before engine	cSt	16...24	16...24	16...24	16...24
MDF viscosity, min.	cSt	2.0	2.0	2.0	2.0
Max. HFO temperature before engine (TE 101)	°C	135	135	135	135
Clean leak fuel quantity, HFO at 100% load	kg/h	5.2	5.2	2.6	2.6
Clean leak fuel quantity, MDF at 100% load	kg/h	26.5	26.5	13.3	13.3
Clean leak fuel quantity at stop, max.	l	-	-	13	13
Fuel consumption at 100% load	g/kWh	180	180	180	180
Fuel consumption at 85% load	g/kWh	175	176	175	176
Fuel consumption at 75% load	g/kWh	177	178	177	178
Fuel consumption at 50% load	g/kWh	181	185	181	185
Lubricating oil system					
Pressure before bearings, nom. (PT 201)	kPa	450	450	450	450
Pressure after pump, max.	kPa	800	800	800	800
Suction ability of built-on pump, including losses, max.	kPa	400	400	400	400
Priming pressure, nom. (PT 201)	kPa	80	80	80	80
Temperature before bearings, nom. (TE 201)	°C	56	56	56	56
Temperature after engine, approx.	°C	75	75	75	75
Pump capacity (main), engine driven	m^3/h	175	155	175	155
Pump capacity (main), electrically driven	m^3/h	160	160	160	160
Oil flow through engine	m^3/h	150	150	150	150
Priming pump capacity	m^3/h	45	45	45	45
Control oil flow, steady	l/min	-	-	3.7	3.7
Control oil flow, max. momentary	l/min	-	-	110	110
Absolute mesh size of built-on automatic filter	µm	30.0	30.0	30.0	30.0
Absolute mesh size of built-on safety filter	µm	100.0	100.0	100.0	100.0
Oil volume in separate system oil tank	m^3	10.5	10.5	10.5	10.5
Oil consumption at 100% load, approx.	g/kWh	0.7	0.7	0.7	0.7
Crankcase ventilation flow rate at full load	l/min	1600	1600	1600	1600
Crankcase ventilation backpressure, max.	Pa	200	200	200	200
Oil volume in turning device	l	9.5	9.5	9.5	9.5
Oil volume in speed governor	l	1.7	1.7	-	-
High temperature cooling water system					
Pressure at engine, after pump, nom. (PT 401)	kPa	250 + static	250 + static	250 + static	250 + static
Pressure at engine, after pump, max. (PT 401)	kPa	530	530	530	530

Wärtsilä 7L46F		ME	DE	ME-CR	DE-CR
Cylinder output	**kW**	**1250**	**1250**	**1250**	**1250**
Engine speed	**rpm**	**600**	**600**	**600**	**600**
Temperature before cylinders, approx. (TE 401)	°C	74	74	74	74
Temperature after cylinders, nom. (TE 402)	°C	82	82	82	82
Temperature after charge air cooler at 100% load, approx.	°C	91	91	91	91
Capacity of engine driven pump, nom.	m^3/h	150	150	150	150
Pressure drop over engine (including temp. control valve)	kPa	150	150	150	150
Pressure drop in external system, max.	kPa	100	100	100	100
Pressure from expansion tank	kPa	70...150	70...150	70...150	70...150
Water volume in engine	m^3	1.3	1.3	1.3	1.3
Low temperature cooling water system					
Pressure at engine, after pump, nom. (PT 451)	kPa	250 + static	250 + static	250 + static	250 + static
Pressure at engine, after pump, max. (PT 451)	kPa	530	530	530	530
Temperature before engine, max. (TE 451)	°C	38	38	38	38
Temperature before engine, min. (TE 451)	°C	25	25	25	25
Capacity of engine driven pump, nom.	m^3/h	150	150	150	150
Pressure drop over charge air cooler	kPa	50	50	50	50
Pressure drop over built-on lube oil cooler	kPa	20	20	20	20
Pressure drop over built-on temp. control valve	kPa	30	30	30	30
Pressure drop in external system, max.	kPa	150	150	150	150
Pressure from expansion tank	kPa	70 ... 150	70 ... 150	70 ... 150	70 ... 150
Water volume in engine	m^3	0.4	0.4	0.4	0.4
Starting air system					
Pressure, nom.	kPa	3000	3000	3000	3000
Pressure, max.	kPa	3000	3000	3000	3000
Low pressure limit in air vessels	kPa	1800	1800	1800	1800
Consumption per start at 20°C (successful start)	Nm^3	7.0	7.0	7.0	7.0
Consumption per start at 20°C, (with slowturn)	Nm^3	8.0	8.0	8.0	8.0

Notes:

Note 1 At ISO 3046-1 conditions (ambient air temperature 25°C, LT-water 25°C) and 100% load. Tolerance 5%.

Note 2 At ISO 3046-1 conditions (ambient air temperature 25°C, LT-water 25°C) and 100% load. Flow tolerance 5% and temperature tolerance 15°C.

Note 3 At ISO 3046-1 conditions (ambient air temperature 25°C, LT-water 25°C) and 100% load. Tolerance for cooling water heat 10%, tolerance for radiation heat 20%. Fouling factors and a margin to be taken into account when dimensioning heat exchangers.

Note 4 According to ISO 3046-1, lower calorific value 42 700 kJ/kg, without engine driven pumps. Tolerance 5%. Load according to propeller law for mechanical propulsion engines (ME).

ME = Engine driving propeller, variable speed
DE = Engine driving generator
CR = Common Rail
Subject to revision without notice.

3.2.3 Wärtsilä 8L46F

Wärtsilä 8L46F		ME	DE	ME-CR	DE-CR
Cylinder output	**kW**	**1250**	**1250**	**1250**	**1250**
Engine speed	**rpm**	**600**	**600**	**600**	**600**
Engine output	kW	10000	10000	10000	10000
Mean effective pressure	MPa	2.59	2.59	2.59	2.59
Combustion air system (Note 1)					
Flow at 100% load	kg/s	17.5	17.5	17.5	17.5
Temperature at turbocharger intake, max. (TE 600)	°C	45	45	45	45
Temperature after air cooler, nom. (TE 601)	°C	50	50	50	50
Exhaust gas system (Note 2)					
Flow at 100% load	kg/s	18.0	18.0	18.0	18.0
Flow at 85% load	kg/s	16.1	16.4	16.1	16.4
Flow at 75% load	kg/s	14.7	15.2	14.7	15.2
Flow at 50% load	kg/s	12.3	13.1	12.3	13.1
Temp. after turbo, 100% load (TE 517)	°C	373	373	373	373
Temp. after turbo, 85% load (TE 517)	°C	322	319	322	319
Temp. after turbo, 75% load (TE 517)	°C	327	317	327	317
Temp. after turbo, 50% load (TE 517)	°C	299	291	299	291
Backpressure, max.	kPa	3.0	3.0	3.0	3.0
Calculated pipe diameter for 35 m/s	mm	1092	1092	1092	1092
Heat balance at 100% load (Note 3)					
Jacket water, HT-circuit	kW	970	970	970	970
Charge air, HT-circuit	kW	2325	2325	2325	2325
Charge air, LT-circuit	kW	995	995	995	995
Lubricating oil, LT-circuit	kW	1250	1255	1250	1255
Radiation	kW	365	375	365	375
Fuel system (Note 4)					
Pressure before injection pumps (PT 101)	kPa	800...1000	800...1000	800...1000	800...1000
Flow to engine, approx.	m³/h	8.0	8.0	6.0	6.0
HFO viscosity before engine	cSt	16...24	16...24	16...24	16...24
MDF viscosity, min.	cSt	2.0	2.0	2.0	2.0
Max. HFO temperature before engine (TE 101)	°C	135	135	135	135
Clean leak fuel quantity, HFO at 100% load	kg/h	6.0	6.0	3.0	3.0
Clean leak fuel quantity, MDF at 100% load	kg/h	30.0	30.0	15.0	15.0
Clean leak fuel quantity at stop, max.	l	-	-	15	15
Fuel consumption at 100% load	g/kWh	180	180	180	180
Fuel consumption at 85% load	g/kWh	175	176	175	176
Fuel consumption at 75% load	g/kWh	177	178	177	178
Fuel consumption at 50% load	g/kWh	181	185	181	185
Lubricating oil system					
Pressure before bearings, nom. (PT 201)	kPa	450	450	450	450
Pressure after pump, max.	kPa	800	800	800	800
Suction ability of built-on pump, including losses, max.	kPa	400	400	400	400
Priming pressure, nom. (PT 201)	kPa	80	80	80	80
Temperature before bearings, nom. (TE 201)	°C	56	56	56	56
Temperature after engine, approx.	°C	75	75	75	75
Pump capacity (main), engine driven	m³/h	207	191	207	191
Pump capacity (main), electrically driven	m³/h	190	190	190	190
Oil flow through engine	m³/h	170	170	170	170
Priming pump capacity	m³/h	45	45	45	45
Control oil flow, steady	l/min	-	-	4.2	4.2
Control oil flow, max. momentary	l/min	-	-	110	110
Absolute mesh size of built-on automatic filter	µm	30.0	30.0	30.0	30.0
Absolute mesh size of built-on safety filter	µm	100.0	100.0	100.0	100.0
Oil volume in separate system oil tank	m³	12.0	12.0	12.0	12.0
Oil consumption at 100% load, approx.	g/kWh	0.7	0.7	0.7	0.7
Crankcase ventilation flow rate at full load	l/min	1700	1700	1700	1700
Crankcase ventilation backpressure, max.	Pa	200	200	200	200
Oil volume in turning device	l	9.5	9.5	9.5	9.5
Oil volume in speed governor	l	1.7	1.7	-	-
High temperature cooling water system					
Pressure at engine, after pump, nom. (PT 401)	kPa	250 + static	250 + static	250 + static	250 + static
Pressure at engine, after pump, max. (PT 401)	kPa	530	530	530	530

Wärtsilä 8L46F		ME	DE	ME-CR	DE-CR
Cylinder output	**kW**	**1250**	**1250**	**1250**	**1250**
Engine speed	**rpm**	**600**	**600**	**600**	**600**
Temperature before cylinders, approx. (TE 401)	°C	74	74	74	74
Temperature after cylinders, nom. (TE 402)	°C	82	82	82	82
Temperature after charge air cooler at 100% load, approx.	°C	91	91	91	91
Capacity of engine driven pump, nom.	m^3/h	150	150	150	150
Pressure drop over engine (including temp. control valve)	kPa	150	150	150	150
Pressure drop in external system, max.	kPa	100	100	100	100
Pressure from expansion tank	kPa	70...150	70...150	70...150	70...150
Water volume in engine	m^3	1.4	1.4	1.4	1.4
Low temperature cooling water system					
Pressure at engine, after pump, nom. (PT 451)	kPa	250 + static	250 + static	250 + static	250 + static
Pressure at engine, after pump, max. (PT 451)	kPa	530	530	530	530
Temperature before engine, max. (TE 451)	°C	38	38	38	38
Temperature before engine, min. (TE 451)	°C	25	25	25	25
Capacity of engine driven pump, nom.	m^3/h	150	150	150	150
Pressure drop over charge air cooler	kPa	50	50	50	50
Pressure drop over built-on lube oil cooler	kPa	20	20	20	20
Pressure drop over built-on temp. control valve	kPa	30	30	30	30
Pressure drop in external system, max.	kPa	150	150	150	150
Pressure from expansion tank	kPa	70 ... 150	70 ... 150	70 ... 150	70 ... 150
Water volume in engine	m^3	0.4	0.4	0.4	0.4
Starting air system					
Pressure, nom.	kPa	3000	3000	3000	3000
Pressure, max.	kPa	3000	3000	3000	3000
Low pressure limit in air vessels	kPa	1800	1800	1800	1800
Consumption per start at 20°C (successful start)	Nm^3	8.0	8.0	8.0	8.0
Consumption per start at 20°C, (with slowturn)	Nm^3	9.0	9.0	9.0	9.0

Notes:

Note 1 At ISO 3046-1 conditions (ambient air temperature 25°C, LT-water 25°C) and 100% load. Tolerance 5%.

Note 2 At ISO 3046-1 conditions (ambient air temperature 25°C, LT-water 25°C) and 100% load. Flow tolerance 5% and temperature tolerance 15°C.

Note 3 At ISO 3046-1 conditions (ambient air temperature 25°C, LT-water 25°C) and 100% load. Tolerance for cooling water heat 10%, tolerance for radiation heat 20%. Fouling factors and a margin to be taken into account when dimensioning heat exchangers.

Note 4 According to ISO 3046-1, lower calorific value 42 700 kJ/kg, without engine driven pumps. Tolerance 5%. Load according to propeller law for mechanical propulsion engines (ME).

ME = Engine driving propeller, variable speed
DE = Engine driving generator
CR = Common Rail
Subject to revision without notice.

3.2.4 Wärtsilä 9L46F

Wärtsilä 9L46F		ME	DE	ME-CR	DE-CR
Cylinder output	**kW**	**1250**	**1250**	**1250**	**1250**
Engine speed	**rpm**	**600**	**600**	**600**	**600**
Engine output	kW	11250	11250	11250	11250
Mean effective pressure	MPa	2.59	2.59	2.59	2.59
Combustion air system (Note 1)					
Flow at 100% load	kg/s	19.7	19.7	19.7	19.7
Temperature at turbocharger intake, max. (TE 600)	°C	45	45	45	45
Temperature after air cooler, nom. (TE 601)	°C	50	50	50	50
Exhaust gas system (Note 2)					
Flow at 100% load	kg/s	20.3	20.3	20.3	20.3
Flow at 85% load	kg/s	18.2	18.5	18.2	18.5
Flow at 75% load	kg/s	16.5	17.1	16.5	17.1
Flow at 50% load	kg/s	13.8	14.7	13.8	14.7
Temp. after turbo, 100% load (TE 517)	°C	373	373	373	373
Temp. after turbo, 85% load (TE 517)	°C	322	319	322	319
Temp. after turbo, 75% load (TE 517)	°C	327	317	327	317
Temp. after turbo, 50% load (TE 517)	°C	299	291	299	291
Backpressure, max.	kPa	3.0	3.0	3.0	3.0
Calculated pipe diameter for 35 m/s	mm	1159	1159	1159	1159
Heat balance at 100% load (Note 3)					
Jacket water, HT-circuit	kW	1090	1090	1090	1090
Charge air, HT-circuit	kW	2615	2615	2615	2615
Charge air, LT-circuit	kW	1120	1120	1120	1097
Lubricating oil, LT-circuit	kW	1410	1410	1410	1400
Radiation	kW	415	425	415	425
Fuel system (Note 4)					
Pressure before injection pumps (PT 101)	kPa	800...1000	800...1000	800...1000	800...1000
Flow to engine, approx.	m^3/h	9.0	9.0	6.7	6.7
HFO viscosity before engine	cSt	16...24	16...24	16...24	16...24
MDF viscosity, min.	cSt	2.0	2.0	2.0	2.0
Max. HFO temperature before engine (TE 101)	°C	135	135	135	135
Clean leak fuel quantity, HFO at 100% load	kg/h	6.8	6.8	3.4	3.4
Clean leak fuel quantity, MDF at 100% load	kg/h	34.0	34.0	17.0	17.0
Clean leak fuel quantity at stop, max.	l	-	-	17	17
Fuel consumption at 100% load	g/kWh	180	180	180	180
Fuel consumption at 85% load	g/kWh	175	176	175	176
Fuel consumption at 75% load	g/kWh	177	178	177	178
Fuel consumption at 50% load	g/kWh	181	185	181	185
Lubricating oil system					
Pressure before bearings, nom. (PT 201)	kPa	450	450	450	450
Pressure after pump, max.	kPa	800	800	800	800
Suction ability of built-on pump, including losses, max.	kPa	400	400	400	400
Priming pressure, nom. (PT 201)	kPa	80	80	80	80
Temperature before bearings, nom. (TE 201)	°C	56	56	56	56
Temperature after engine, approx.	°C	75	75	75	75
Pump capacity (main), engine driven	m^3/h	228	207	228	207
Pump capacity (main), electrically driven	m^3/h	200	200	200	200
Oil flow through engine	m^3/h	190	190	190	190
Priming pump capacity	m^3/h	50	50	50	50
Control oil flow, steady	l/min	-	-	4.8	4.8
Control oil flow, max. momentary	l/min	-	-	110	110
Absolute mesh size of built-on automatic filter	μm	30.0	30.0	30.0	30.0
Absolute mesh size of built-on safety filter	μm	100.0	100.0	100.0	100.0
Oil volume in separate system oil tank	m^3	13.5	13.5	13.5	13.5
Oil consumption at 100% load, approx.	g/kWh	0.7	0.7	0.7	0.7
Crankcase ventilation flow rate at full load	l/min	1800	1800	1800	1800
Crankcase ventilation backpressure, max.	Pa	200	200	200	200
Oil volume in turning device	l	70.0	70.0	70.0	70.0
Oil volume in speed governor	l	1.7	1.7	-	-
High temperature cooling water system					
Pressure at engine, after pump, nom. (PT 401)	kPa	250 + static	250 + static	250 + static	250 + static
Pressure at engine, after pump, max. (PT 401)	kPa	530	530	530	530

Wärtsilä 9L46F		ME	DE	ME-CR	DE-CR
Cylinder output	**kW**	**1250**	**1250**	**1250**	**1250**
Engine speed	**rpm**	**600**	**600**	**600**	**600**
Temperature before cylinders, approx. (TE 401)	°C	74	74	74	74
Temperature after cylinders, nom. (TE 402)	°C	82	82	82	82
Temperature after charge air cooler at 100% load, approx.	°C	91	91	91	91
Capacity of engine driven pump, nom.	m^3/h	180	180	180	180
Pressure drop over engine (including temp. control valve)	kPa	150	150	150	150
Pressure drop in external system, max.	kPa	100	100	100	100
Pressure from expansion tank	kPa	70...150	70...150	70...150	70...150
Water volume in engine	m^3	1.5	1.5	1.5	1.5
Low temperature cooling water system					
Pressure at engine, after pump, nom. (PT 451)	kPa	250 + static	250 + static	250 + static	250 + static
Pressure at engine, after pump, max. (PT 451)	kPa	530	530	530	530
Temperature before engine, max. (TE 451)	°C	38	38	38	38
Temperature before engine, min. (TE 451)	°C	25	25	25	25
Capacity of engine driven pump, nom.	m^3/h	180	180	180	180
Pressure drop over charge air cooler	kPa	50	50	50	50
Pressure drop over built-on lube oil cooler	kPa	20	20	20	20
Pressure drop over built-on temp. control valve	kPa	30	30	30	30
Pressure drop in external system, max.	kPa	150	150	150	150
Pressure from expansion tank	kPa	70 ... 150	70 ... 150	70 ... 150	70 ... 150
Water volume in engine	m^3	0.5	0.5	0.5	0.5
Starting air system					
Pressure, nom.	kPa	3000	3000	3000	3000
Pressure, max.	kPa	3000	3000	3000	3000
Low pressure limit in air vessels	kPa	1800	1800	1800	1800
Consumption per start at 20°C (successful start)	Nm^3	9.0	9.0	9.0	9.0
Consumption per start at 20°C, (with slowturn)	Nm^3	10.0	10.0	10.0	10.0

Notes:

Note 1 At ISO 3046-1 conditions (ambient air temperature 25°C, LT-water 25°C) and 100% load. Tolerance 5%.

Note 2 At ISO 3046-1 conditions (ambient air temperature 25°C, LT-water 25°C) and 100% load. Flow tolerance 5% and temperature tolerance 15°C.

Note 3 At ISO 3046-1 conditions (ambient air temperature 25°C, LT-water 25°C) and 100% load. Tolerance for cooling water heat 10%, tolerance for radiation heat 20%. Fouling factors and a margin to be taken into account when dimensioning heat exchangers.

Note 4 According to ISO 3046-1, lower calorific value 42 700 kJ/kg, without engine driven pumps. Tolerance 5%. Load according to propeller law for mechanical propulsion engines (ME).

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Subject to revision without notice.

3.3 Exhaust gas and heat balance diagrams

Figure 3.1 Exhaust gas massflow, variable speed

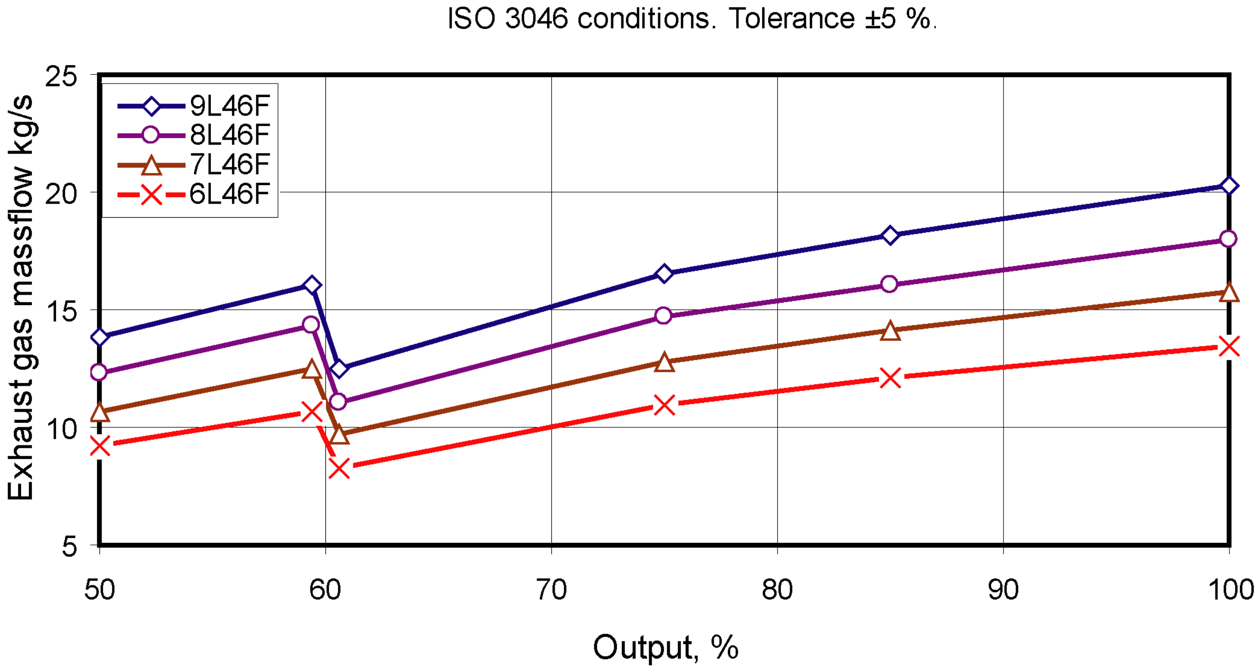
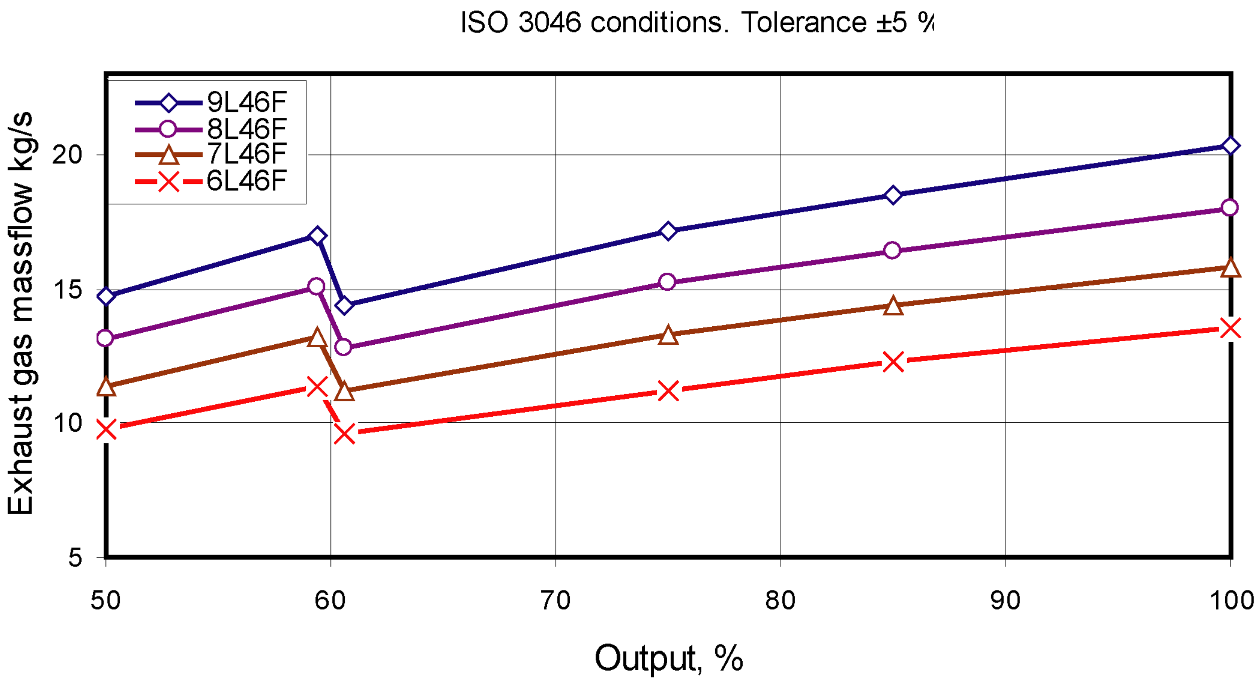


Figure 3.2 Exhaust gas massflow, constant speed



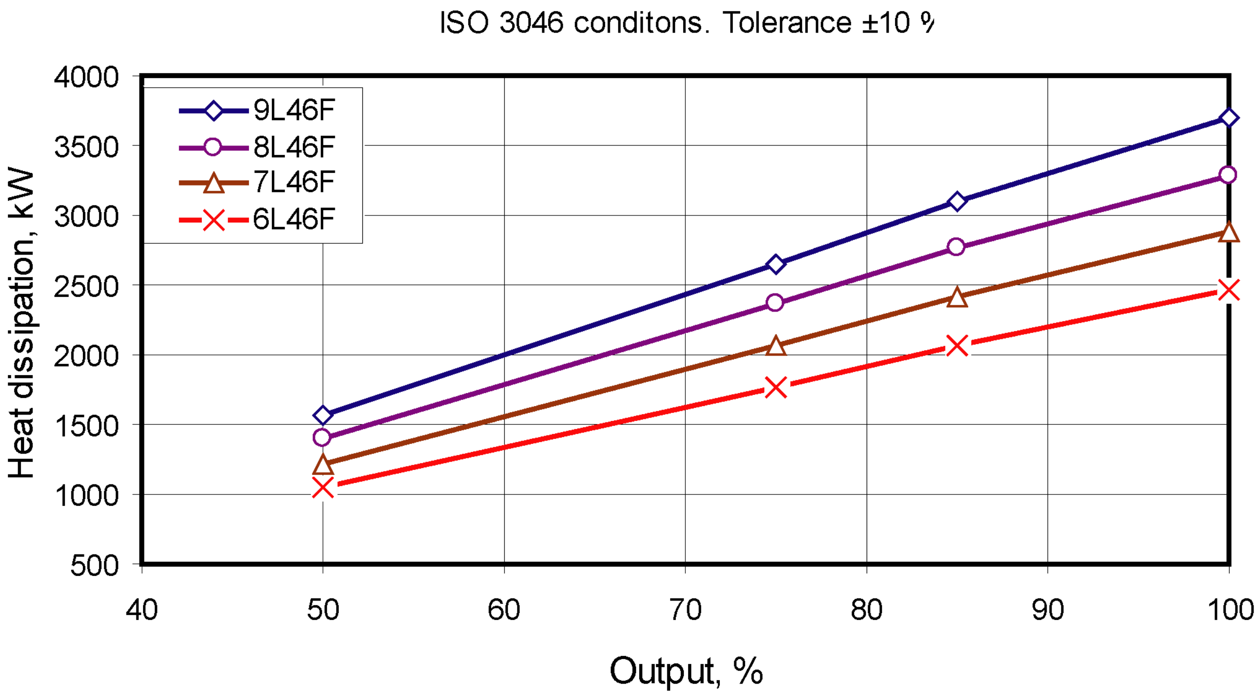


Figure 3.3 HT circuit (cylinder jackets + charge air cooler) heat dissipation, variable speed

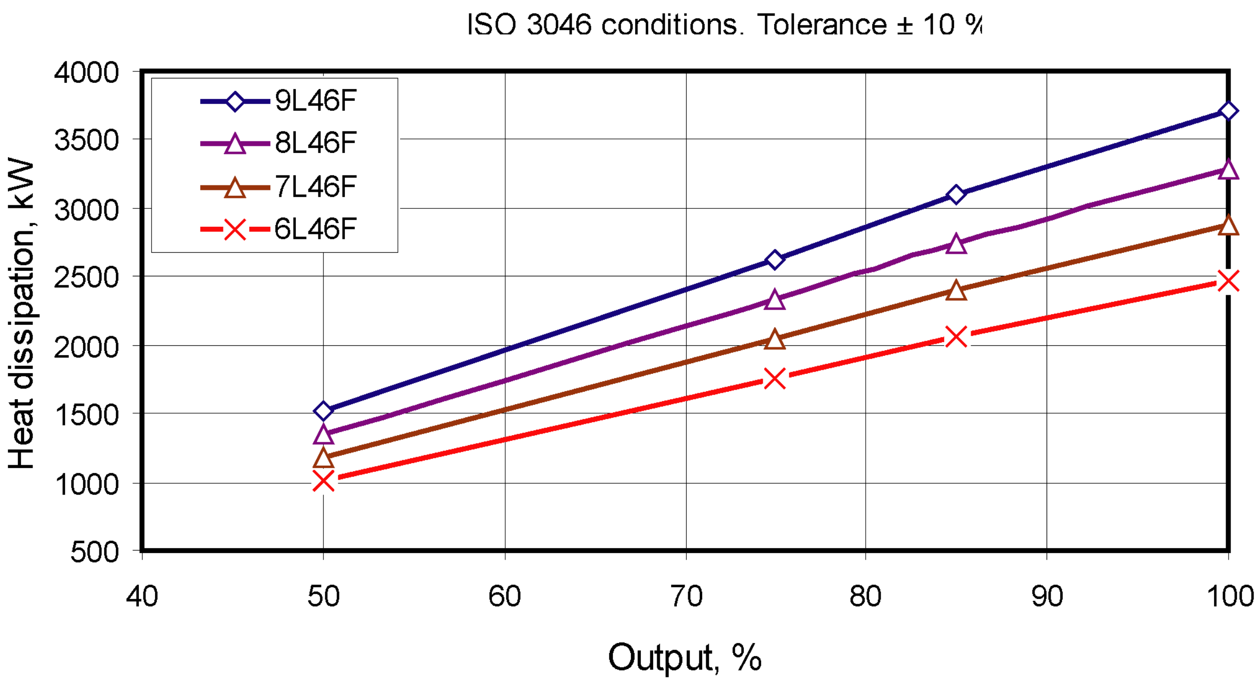


Figure 3.4 HT circuit (cylinder jackets + charge air cooler) heat dissipation, constant speed

Figure 3.5 LT circuit (lubricating oil + charge air cooler) heat dissipation, variable speed

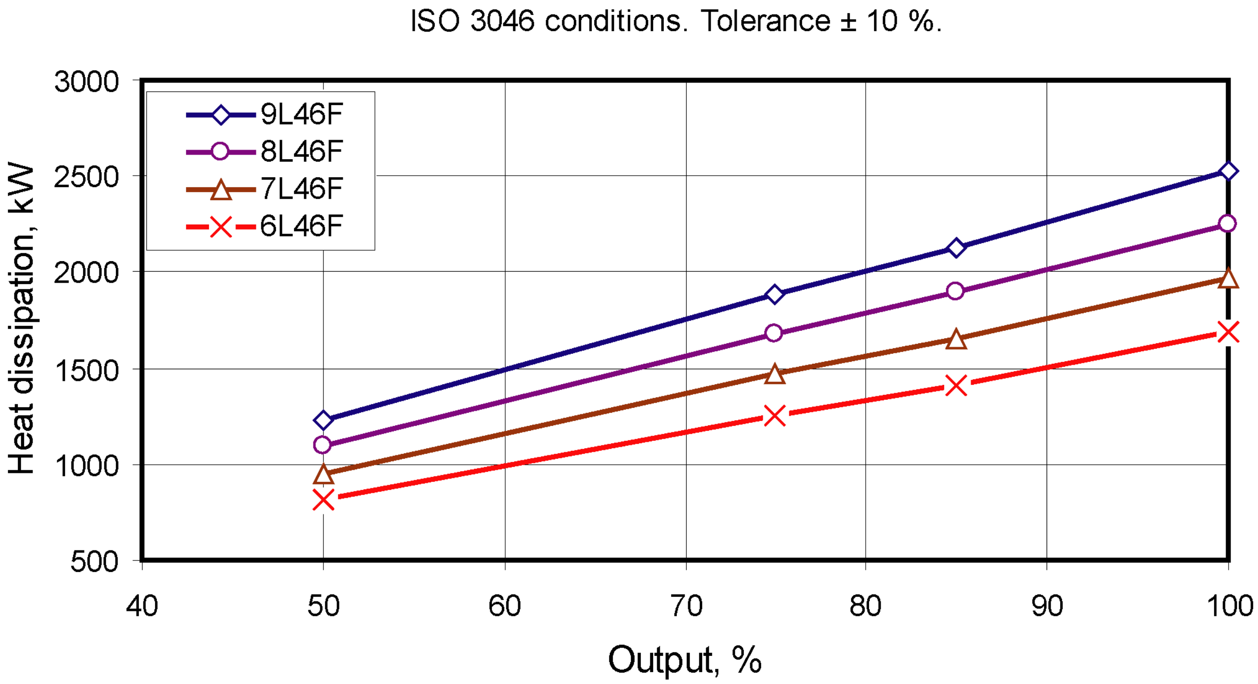


Figure 3.6 LT circuit (lubricating oil + charge air cooler) heat dissipation, constant speed

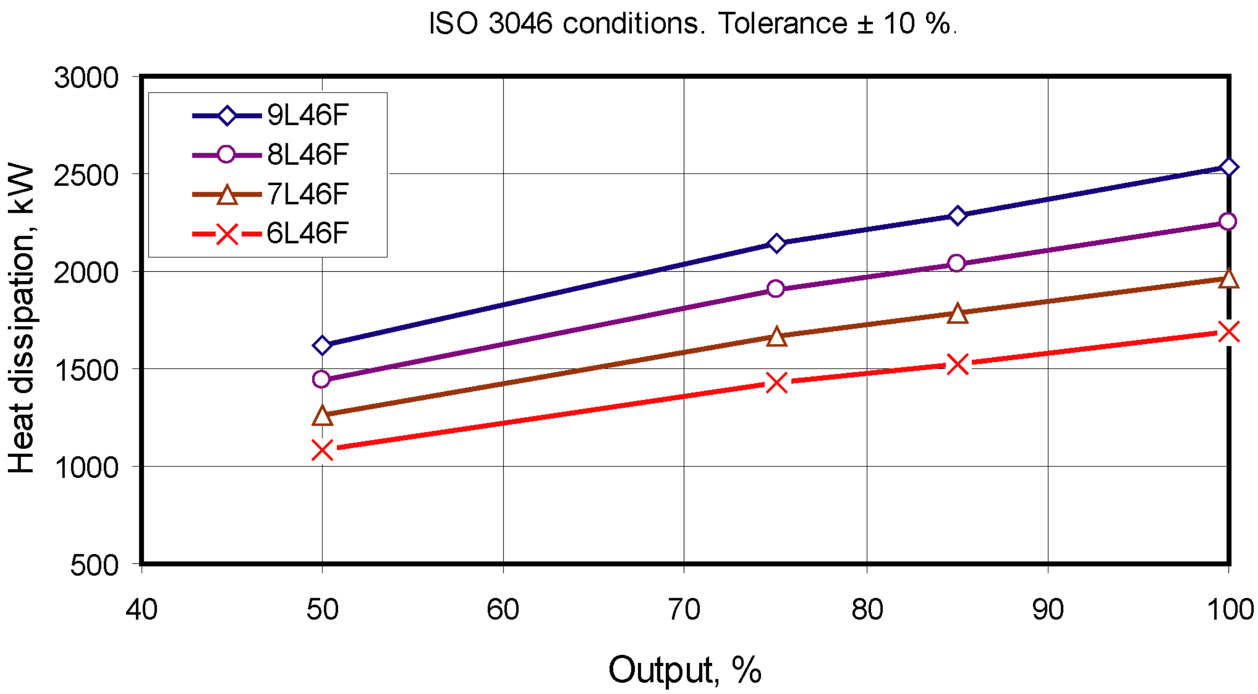


Figure 3.7 Exhaust gas temperature after turbine, variable speed

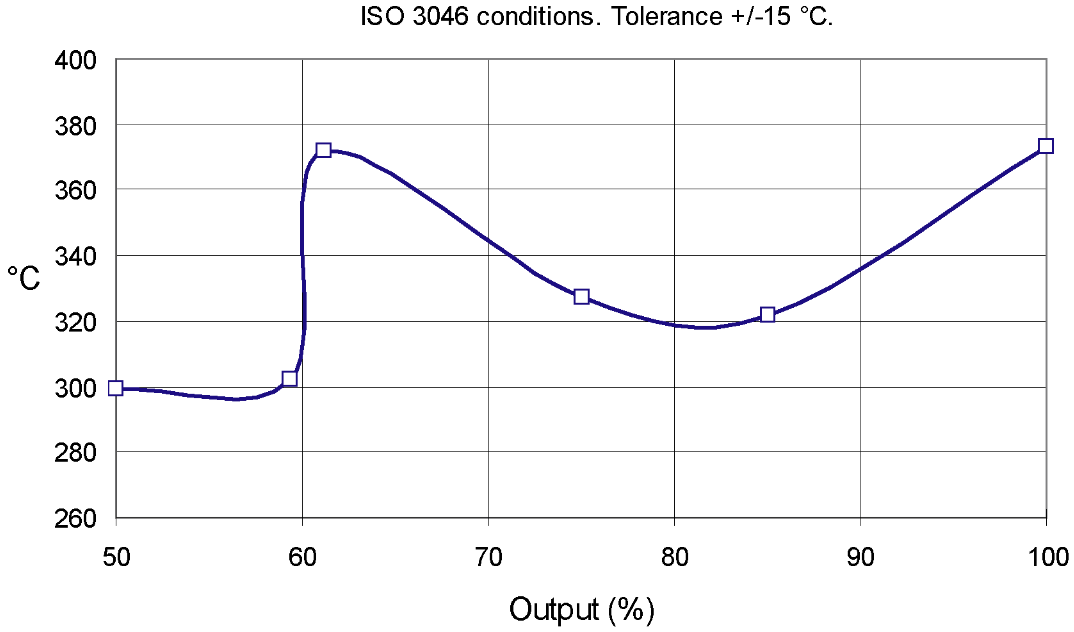
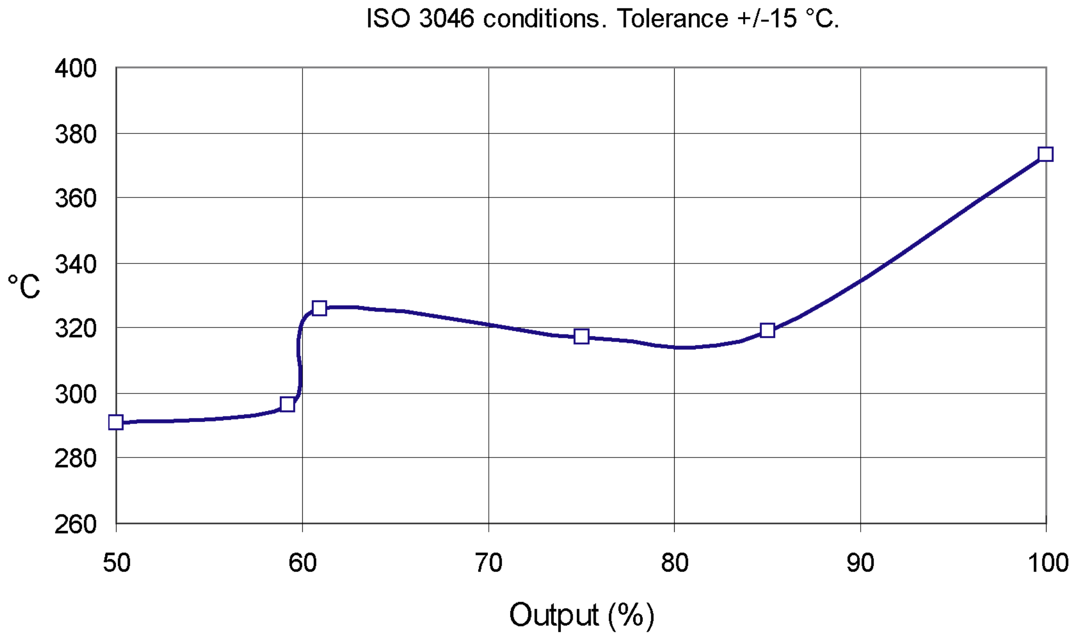


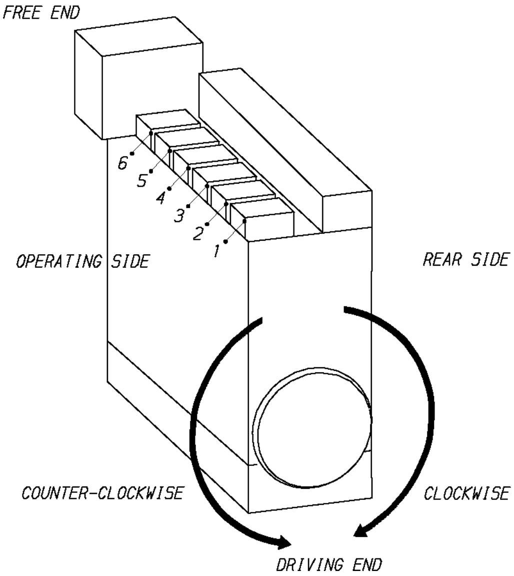
Figure 3.8 Exhaust gas temperature after turbine, constant speed



4. Description of the engine

4.1 Definitions

Figure 4.1 In-line engine (1V93C0029)



4.2 Main components and systems

Main dimensions and weights are presented in the chapter *General data and outputs*.

4.2.1 Engine block

The engine block is made of nodular cast iron and it is cast in one piece.

The block has a stiff and durable design, which makes it suitable for resilient mounting without intermediate foundations.

The engine has an underslung crankshaft supported by main bearing caps made of nodular cast iron. The bearing caps are guided sideways by the engine block, both at the top and at the bottom. Hydraulically tensioned bearing cap screws and horizontal side screws secure the main bearing caps.

At the driving end there is a combined thrust bearing and radial bearing for the camshaft drive and flywheel. The bearing housing of the intermediate gear is integrated in the engine block.

The cooling water is distributed around the cylinder liners with water distribution rings at the lower end of the cylinder collar. There is no wet space in the engine block around the cylinder liner, which eliminates the risk of water leakage into the crankcase.

4.2.2 Crankshaft

Low bearing loads, robust design and a crank gear capable of high cylinder pressures were set out to be the main design criteria for the crankshaft. The moderate bore to stroke ratio is a key element to achieve high rigidity.

The crankshaft line is built up from three-pieces: crankshaft, gear and end piece. The crankshaft itself is forged in one piece. Each crankthrow is individually fully balanced for safe bearing function. Clean steel technology minimizes the amount of slag forming elements and guarantees superior material properties.

All crankshafts can be equipped with a torsional vibration damper at the free end of the engine, if required by the application. Full output is available also from the free end of the engine through a power-take-off (PTO).

The main bearing and crankpin bearing temperatures are continuously monitored.

4.2.3 Connecting rod

The connecting rods are of three-piece design, which makes it possible to pull a piston without opening the big end bearing. Extensive research and development has been made to develop a connecting rod in which the combustion forces are distributed to a maximum area of the big end bearing.

The connecting rod of alloy steel is forged and has a fully machined shank. The lower end is split horizontally to allow removal of piston and connecting rod through the cylinder liner. All connecting rod bolts are hydraulically tightened. The gudgeon pin bearing is solid aluminium bronze.

Oil is led to the gudgeon pin bearing and piston through a bore in the connecting rod.

4.2.4 Main bearings and big end bearings

The main bearings and the big end bearings have steel backs and thin layers for good resistance against fatigue and corrosion. Both tri-metal and bi-metal bearings are used.

4.2.5 Cylinder liner

The centrifugally cast cylinder liner has a high and rigid collar preventing deformations due to the cylinder pressure and pretension forces. A distortion-free liner bore in combination with wear resistant materials and good lubrication provide optimum running conditions for the piston and piston rings. The liner material is a special grey cast iron alloy developed for excellent wear resistance and high strength.

Accurate temperature control is achieved with precisely positioned longitudinal cooling water bores.

An anti-polishing ring removes deposits from piston top land, which eliminates increased lubricating oil consumption due to bore polishing and liner wear.

4.2.6 Piston

The piston is of two-piece design with nodular cast iron skirt and steel crown. Wärtsilä patented skirt lubrication minimizes frictional losses and ensure appropriate lubrication of both the piston skirt and piston rings under all operating conditions.

4.2.7 Piston rings

The piston ring set consists of two compression rings and one spring-loaded conformable oil scraper ring. All piston rings have a wear resistant coating.Two compression rings and one oil scraper ring in combination with pressure lubricated piston skirt give low friction and high seizure resistance. Both compression ring grooves are hardened for good wear resistance.

4.2.8 Cylinder head

A rigid box/cone-like design ensures even circumferential contact pressure and permits high cylinder pressure. Only four hydraulically tightened cylinder head studs simplify the maintenance and leaves more room for optimisation of the inlet and outlet port flow characteristics.

The exhaust valve seats are water cooled. Closed seat rings without water pocket between the seat and the cylinder head ensure long lifetime for valves and seats. Both inlet and exhaust valves are equipped with valve rotators.

4.2.9 Camshaft and valve mechanism

The camshaft is built of forged pieces with integrated cams, one section per cylinder. The camshaft sections are connected through separate bearing journals, which makes it possible to remove single camshaft sections sideways. The bearing housings are integrated in the engine block casting and thus completely closed.

4.2.10 Camshaft drive

The camshaft is driven by the crankshaft through a gear train. The gear wheel on the crankshaft is clamped between the crankshaft and the end piece with expansion bolts.

4.2.11 Fuel injection equipment

The Wärtsilä 46F engine is available with conventional fuel injection or electronically controlled common rail fuel injection. Even the conventional injection system offers timing control according to the prevailing operating condition, thanks to twin plunger injection pumps.

The low pressure fuel lines consist of drilled channels in cast parts that are firmly clamped to the engine block. The entire fuel system is enclosed in a fully covered compartment for maximum safety. All leakages from injection valves, pumps and pipes are collected in a closed system. The pumps are completely sealed off from the camshaft compartment and provided with drain for leakage oil.

The injection nozzles are cooled by lubricating oil.

Conventional fuel injection

Engines with conventional fuel injection are equipped with twin plunger pumps that enable control of the injection timing. In addition to the timing control, the twin plunger solution also combines high mechanical strength with cost efficient design.

One plunger controls the start of injection, i.e. the timing, while the other plunger controls when the injection ends, thus the quantity of injected fuel. Timing is controlled according to engine revolution speed and load level (also other options), while the quantity is controlled as normally by the speed control.

Common rail fuel injection

The common rail system comprises pressurizing fuel pumps, fuel accumulators and electronically controlled fuel injectors. The fuel pumps are driven by the camshaft and each pump and accumulator serve two cylinders. Adjacent accumulators are connected with small bore piping in order to reduce the risk of pulsation in the rail. The engine can operate with one or two fuel pumps disconnected, if this should ever be necessary. A safety feature of the system is that there is no pressure on the injection nozzles between injections. All functions are controlled by the embedded control system on the engine. The main advantage of the common rail system is that the injection pressure can be kept at a sufficiently high level over the whole load range, which gives smokeless operation also at low load.

The electrically controlled fuel injectors are actuated using control oil. The control oil pump is engine driven and engine lubricating oil is used as control oil.

Upgrading of engines with conventional fuel injection to common rail technology has been taken into account in the design.

4.2.12 Lubricating oil system

The engine is equipped with a dry oil sump.

In the standard configuration the engine is also equipped with an engine driven lubricating oil pump, located in free end, and a lubricating oil module located in the opposite end to the turbocharger. The lubricating oil module consists of an oil cooler with temperature control valves and an automatic filter. A centrifugal filter on the engine serves as an indication filter.

The pre-lubricating oil pump is to be installed in the external system.

4.2.13 Cooling water system

The fresh water cooling system is divided into a high temperature (HT) and a low temperature (LT) circuit. The HT-water cools cylinder liners, cylinder heads and the first stage of the charge air cooler. The LT-water cools the second stage of the charge air cooler and the lubricating oil.

In the most complete configuration the HT and LT cooling water pumps are both engine driven, and the electrically actuated temperature control valves are built on the engine. When desired, it is however possible to configure the engine without engine driven LT-pump, or even without both cooling water pumps.

The temperature control valves are equipped with a hand wheel for emergency operation.

4.2.14 Turbocharging and charge air cooling

The SPEX (Single Pipe Exhaust) turbocharging system is designed to combine the good part load performance of a pulse charging system with the simplicity and good high load efficiency of a constant pressure system. In order to further enhance part load performance and prevent excessive charge air pressure at high load, all engines are equipped with a wastegate on the exhaust side. The wastegate arrangement permits a part of the exhaust gas to bypass the turbine in the turbocharger at high engine load.

Variable speed engines are additionally equipped with a by-pass valve to increase the flow through the turbocharger at low engine speed and low engine load. Part of the charge air is conducted directly into the exhaust gas manifold (without passing through the engine), which increases the speed of the turbocharger. The net effect is increased charge air pressure at low engine speed and low engine load, despite the apparent waste of air.

All engines are provided with devices for water cleaning of the turbine and the compressor. The cleaning is performed during operation of the engine.

The engines have a transversely installed turbocharger. The turbocharger can be located at either end of the engine and the exhaust gas outlet can be vertical, or inclined 45 degrees in the longitudinal direction of the engine.

A two-stage charge air cooler is standard. Heat is absorbed with high temperature (HT) cooling water in the first stage, while low temperature (LT) cooling water is used for the final air cooling in the second stage. The engine has two separate cooling water circuits. The flow of LT cooling water through the charge air cooler is controlled to maintain a constant charge air temperature.

4.2.15 Automation system

Wärtsilä 46F is equipped with a modular embedded automation system, Wärtsilä Unified Controls - UNIC, which is available in three different versions. The basic functionality is the same in all versions, but the functionality can be easily expanded to cover different applications. UNIC 1 and UNIC 2 are applicable for engines with conventional fuel injection, while UNIC 3 includes also fuel injection control for engines with common rail fuel injection.

UNIC 1 has a completely hardwired signal interface with the external systems, whereas UNIC 2 and UNIC 3 have hardwired interface for control functions and a bus communication interface for alarm and monitoring.

All versions have en engine safety module and a local control panel mounted on the engine. The engine safety module handles fundamental safety, for example overspeed and low lubricating oil pressure shutdown. The safety module also performs fault detection on critical signals and alerts the alarm system about detected failures. The local control panel has push buttons for local start/stop and shutdown reset, as well as a display showing the most important operating parameters. Speed control is included in the automation system on the engine (all versions).

The major additional features of UNIC2 and UNIC 3 are: all necessary engine control functions are handled by the equipment on the engine, bus communication to external systems, a more comprehensive local display unit, and fuel injection control for common rail engines.

Conventional heavy duty cables are used on the engine and the number of connectors are minimised. Power supply, bus communication and safety-critical functions are doubled on the engine. All cables to/from external systems are connected to terminals in the main cabinet on the engine.

4.2.16 Variable Inlet valve Closure, optional

Variable Inlet valve Closure (VIC), which is available as an option, offers flexibility to apply early inlet valve closure at high load for lowest NOx levels, while good part-load performance is ensured by adjusting the advance to zero at low load. The inlet valve closure can be adjusted up to 30° crank angle.

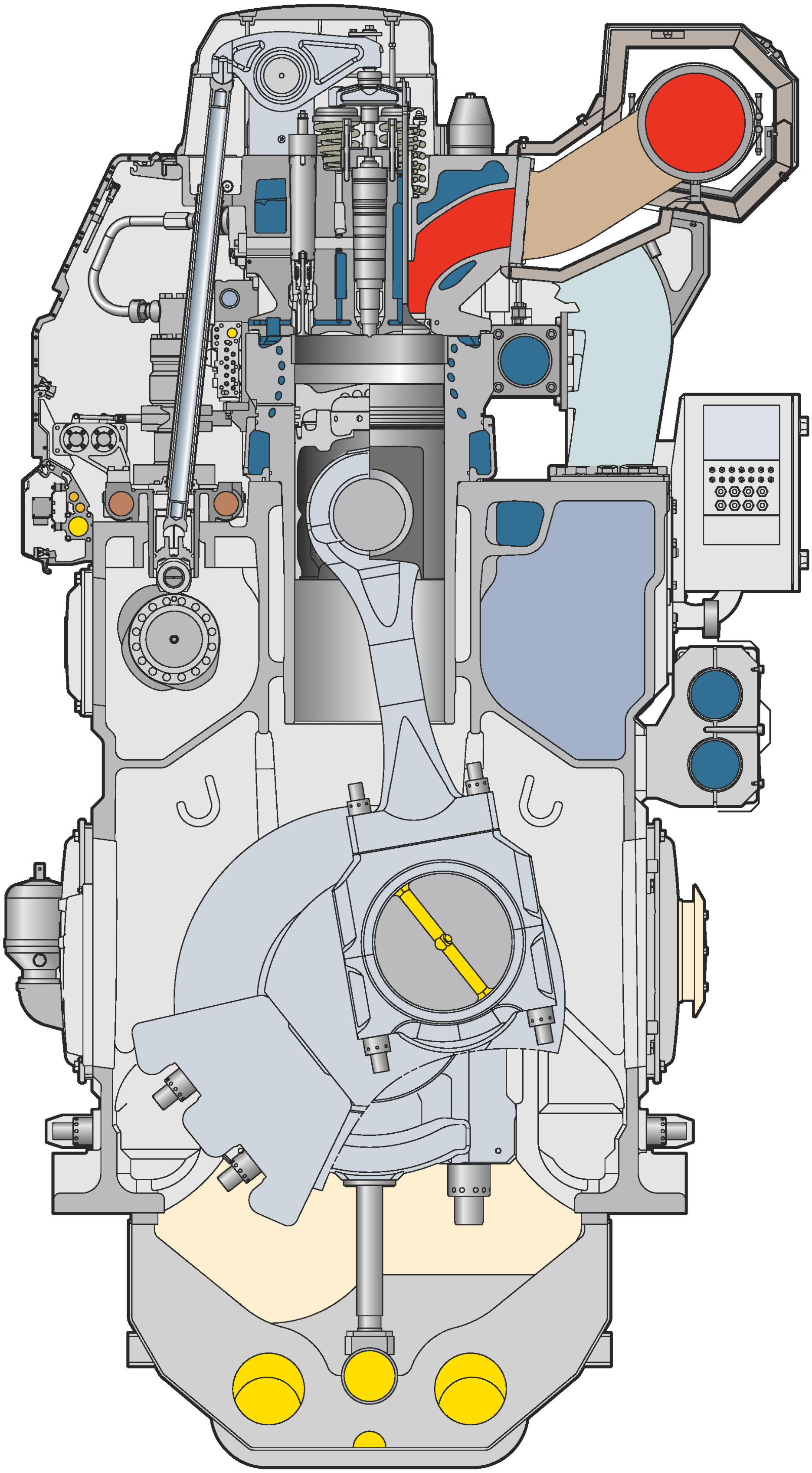
The operating principle is based on a hydraulic device between the valve tappet and the pushrod. Briefly, the device can be described as two hydraulic cylinders connected through two passages. The flow through one passage is controlled by the position of the tappet, while the other passage is controlled with a valve. The tappet acts on one of the hydraulic pistons and the other piston acts on the pushrod. The pushrod can move only when oil is flowing between the two cylinders. When the VIC control valve is open, the pushrod follows the tappet immediately, which results in early valve closure. When the control valve is closed, the downward movement of the pushrod is delayed until the piston actuated by the tappet reveals the passage between the two cylinders. Engine oil is used as the hydraulic medium.

4.2.17 Humidification of charge air (Wetpac H), optional

The new NO_x reduction technology developed by Wärtsilä is named Wetpac H. The principle of Wetpac H is to introduce water with the intake air to reduce the combustion temperature and thereby the formation of NO_x. Pressurized water is injected directly after the compressor of the turbocharger. The high temperature of the compressed air evaporates the water, which enters the cylinders as steam. A water mist catcher prevents water in liquid state from entering the cylinders. The NO_x reduction is up to 50%, and the water consumption is about two times the fuel oil consumption. Wetpac H is available as an option for fuels with sulphur contents less than 1.5%.

4.3 Cross section of the engine

Figure 4.2 Cross section of the in-line engine



4.4 Overhaul intervals and expected life times

The following overhaul intervals and lifetimes are for guidance only. Achievable lifetimes depend on operating conditions, average loading of the engine, fuel quality used, fuel handling system, performance of maintenance etc.

Table 4.1 Time between inspection or overhaul and expected lifetime [h] (DAAE009253)

Component	Maintenance interval (h)	Expected lifetime (h)
Twin pump fuel injection		
- Injection nozzle	-	6 000
- Injection pump element	12 000	24 000
Common rail fuel injection		
- Injection nozzle	-	6 000
- Shuttle valve	6 000	12 000
- Accumulator (inspection)	36 000	60 000
- Accumulator, flow fuse	12 000	24 000
- Start-up and safety valve	12 000	24 000
- High pressure pump	12 000	36 000
- High pressure pump, inlet check valve	6 000	12 000
- High pressure pump, delivery valve	6 000	12 000
- High pressure pump, flow control valve	6 000	24 000
- Control oil pump	-	36 000
Cylinder head	12 000	60 000
Inlet valve seat	12 000	36 000
Inlet valve, guide and rotator	12 000	24 000
Exhaust valve seat	12 000	36 000
Exhaust valve, guide and rotator	12 000	24 000
Piston skirt/crown dismantling	12 000	-
Piston crown, including one reconditioning	-	36 000
Piston skirt	-	60 000
Piston rings	12 000	12 000
Cylinder liner	12 000	84 000
Anti-polishing ring	-	12 000
Gudgeon pin (inspection)	12 000	60 000
Gudgeon pin bearing (inspection)	12 000	36 000
Big end bearing, inspection of one	12 000	36 000
Main bearing, inspection of one	18 000	36 000
Camshaft bearing, inspection of one	36 000	60 000
Turbocharger, inspection and cleaning	12 000	-
Charger air cooler	6 000	36 000
Resilient mounting	6 000	-
Resilient mounting, rubber element	6 000	60 000

5. Piping design, treatment and installation

5.1 General

This chapter provides general guidelines for the design, construction and installation of piping systems, however, not excluding other solutions of at least equal standard.

Fuel, lubricating oil, fresh water and compressed air piping is usually made in seamless carbon steel (DIN 2448) and seamless precision tubes in carbon or stainless steel (DIN 2391), exhaust gas piping in welded pipes of corten or carbon steel (DIN 2458). Pipes on the freshwater side of the cooling water system must not be galvanized. Sea-water piping should be made in hot dip galvanised steel, aluminium brass, cunifer or with rubber lined pipes.

Attention must be paid to fire risk aspects. Fuel supply and return lines shall be designed so that they can be fitted without tension. Flexible hoses must have an approval from the classification society. If flexible hoses are used in the compressed air system, a purge valve shall be fitted in front of the hose(s).

The following aspects shall be taken into consideration:

- Pockets shall be avoided. When not possible, drain plugs and air vents shall be installed
- Leak fuel drain pipes shall have continuous slope
- Vent pipes shall be continuously rising
- Flanged connections shall be used, cutting ring joints for precision tubes

Maintenance access and dismounting space of valves, coolers and other devices shall be taken into consideration. Flange connections and other joints shall be located so that dismounting of the equipment can be made with reasonable effort.

5.2 Pipe dimensions

When selecting the pipe dimensions, take into account:

- The pipe material and its resistance to corrosion/erosion.
- Allowed pressure loss in the circuit vs delivery head of the pump.
- Required net positive suction head (NPSH) for pumps (suction lines).
- In small pipe sizes the max acceptable velocity is usually somewhat lower than in large pipes of equal length.
- The flow velocity should not be below 1 m/s in sea water piping due to increased risk of fouling and pitting.
- In open circuits the velocity in the suction pipe is typically about 2/3 of the velocity in the delivery pipe.

Recommended maximum fluid velocities on the delivery side of pumps are given as guidance in table *5.1*.

Table 5.1 Recommended maximum velocities on pump delivery side for guidance

Piping	Pipe material	Max velocity [m/s]
Fuel piping (MDF and HFO)	Black steel	1.0
Lubricating oil piping	Black steel	1.5
Fresh water piping	Black steel	2.5
Sea water piping	Galvanized steel	2.5
	Aluminium brass	2.5
	10/90 copper-nickel-iron	3.0
	70/30 copper-nickel	4.5
	Rubber lined pipes	4.5

NOTE! The diameter of gas fuel and compressed air piping depends only on the allowed pressure loss in the piping, which has to be calculated project specifically.

5.3 Trace heating

The following pipes shall be equipped with trace heating (steam, thermal oil or electrical). It shall be possible to shut off the trace heating.

- All heavy fuel pipes
- All leak fuel and filter flushing pipes carrying heavy fuel

5.4 Operating and design pressure

The pressure class of the piping shall be equal to or higher than the maximum operating pressure, which can be significantly higher than the normal operating pressure.

A design pressure is defined for components that are not categorized according to pressure class, and this pressure is also used to determine test pressure. The design pressure shall also be equal to or higher than the maximum pressure.

The pressure in the system can:

- Originate from a positive displacement pump
- Be a combination of the static pressure and the pressure on the highest point of the pump curve for a centrifugal pump
- Rise in an isolated system if the liquid is heated

Within this Project Guide there are tables attached to drawings, which specify pressure classes of connections. The pressure class of a connection can be higher than the pressure class required for the pipe.

Example 1:

The fuel pressure before the engine should be 1.0 MPa (10 bar). The safety filter in dirty condition may cause a pressure loss of 0.1 MPa (1 bar). The viscosimeter, heater and piping may cause a pressure loss of 0.2 MPa (2 bar). Consequently the discharge pressure of the circulating pumps may rise to 1.3 MPa (13 bar), and the safety valve of the pump shall thus be adjusted e.g. to 1.4 MPa (14 bar).

- The minimum design pressure is 1.4 MPa (14 bar).
- The nearest pipe class to be selected is PN16.
- Piping test pressure is normally 1.5 x the design pressure = 2.1 MPa (21 bar).

Example 2:

The pressure on the suction side of the cooling water pump is 0.1 MPa (1 bar). The delivery head of the pump is 0.3 MPa (3 bar), leading to a discharge pressure of 0.4 MPa (4 bar). The highest point of the pump curve (at or near zero flow) is 0.1 MPa (1 bar) higher than the nominal point, and consequently the discharge pressure may rise to 0.5 MPa (5 bar) (with closed or throttled valves).

- The minimum design pressure is 0.5 MPa (5 bar).
- The nearest pressure class to be selected is PN6.
- Piping test pressure is normally 1.5 x the design pressure = 0.75 MPa (7.5 bar).

Standard pressure classes are PN4, PN6, PN10, PN16, PN25, PN40, etc.

5.5 Pipe class

Classification societies categorize piping systems in different classes (DNV) or groups (ABS) depending on pressure, temperature and media. The pipe class can determine:

- Type of connections to be used
- Heat treatment
- Welding procedure

- Test method

Systems with high design pressures and temperatures and hazardous media belong to class I (or group I), others to II or III as applicable. Quality requirements are highest in class I.

Examples of classes of piping systems as per DNV rules are presented in the table below.

Table 5.2 Classes of piping systems as per DNV rules

Media	Class I		Class II		Class III	
	MPa (bar)	°C	MPa (bar)	°C	MPa (bar)	°C
Steam	> 1.6 (16)	or > 300	< 1.6 (16)	and < 300	< 0.7 (7)	and < 170
Flammable fluid	> 1.6 (16)	or > 150	< 1.6 (16)	and < 150	< 0.7 (7)	and < 60
Other media	> 4 (40)	or > 300	< 4 (40)	and < 300	< 1.6 (16)	and < 200

5.6 Insulation

The following pipes shall be insulated:

- All trace heated pipes
- Exhaust gas pipes
- Exposed parts of pipes with temperature > 60°C

Insulation is also recommended for:

- Pipes between engine or system oil tank and lubricating oil separator
- Pipes between engine and jacket water preheater

5.7 Local gauges

Local thermometers should be installed wherever a new temperature occurs, i.e. before and after heat exchangers, etc.

Pressure gauges should be installed on the suction and discharge side of each pump.

5.8 Cleaning procedures

Instructions shall be given to manufacturers and fitters of how different piping systems shall be treated, cleaned and protected before delivery and installation. All piping must be checked and cleaned from debris before installation. Before taking into service all piping must be cleaned according to the methods listed below.

Table 5.3 Pipe cleaning

System	Methods
Fuel oil	A,B,C,D,F
Lubricating oil	A,B,C,D,F
Starting air	A,B,C
Cooling water	A,B,C
Exhaust gas	A,B,C
Charge air	A,B,C

A = Washing with alkaline solution in hot water at 80°C for degreasing (only if pipes have been greased)

B = Removal of rust and scale with steel brush (not required for seamless precision tubes)

C = Purging with compressed air

D = Pickling

F = Flushing

5.8.1 Pickling

Pipes are pickled in an acid solution of 10% hydrochloric acid and 10% formaline inhibitor for 4-5 hours, rinsed with hot water and blown dry with compressed air.

After the acid treatment the pipes are treated with a neutralizing solution of 10% caustic soda and 50 grams of trisodiumphosphate per litre of water for 20 minutes at 40...50°C, rinsed with hot water and blown dry with compressed air.

5.8.2 Flushing

More detailed recommendations on flushing procedures are when necessary described under the relevant chapters concerning the fuel oil system and the lubricating oil system. Provisions are to be made to ensure that necessary temporary bypasses can be arranged and that flushing hoses, filters and pumps will be available when required.

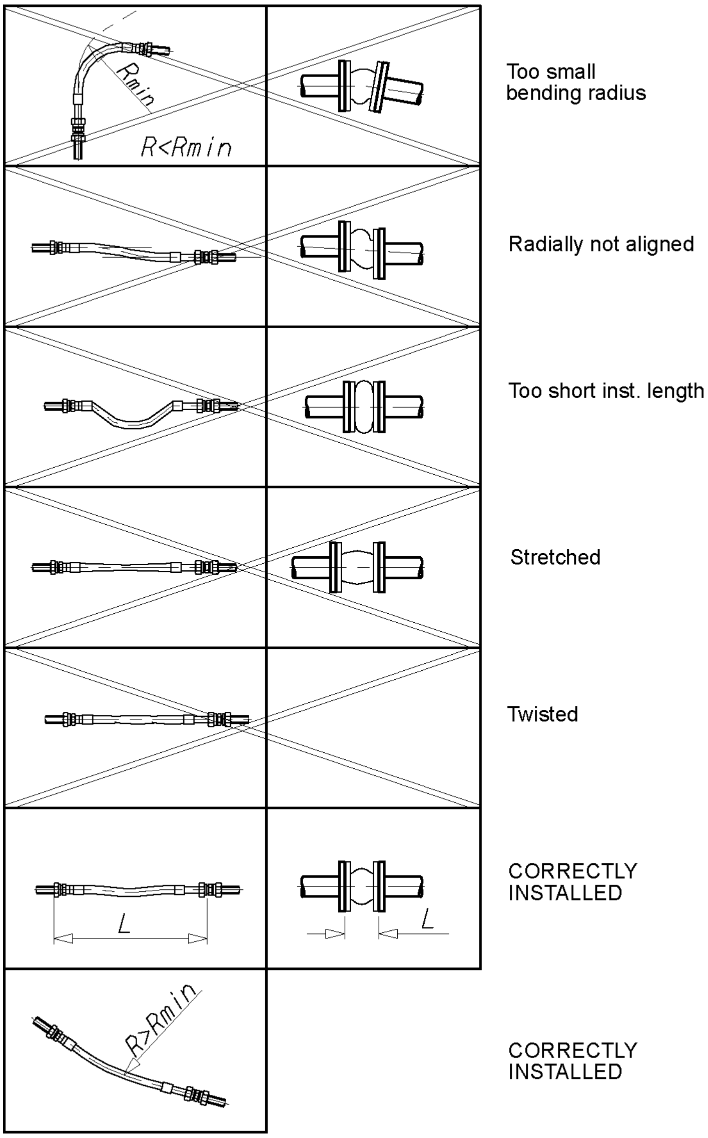
5.9 Flexible pipe connections

Pressurized flexible connections carrying flammable fluids or compressed air have to be type approved.

Great care must be taken to ensure proper installation of flexible pipe connections between resiliently mounted engines and ship’s piping.

- Flexible pipe connections must not be twisted
- Installation length of flexible pipe connections must be correct
- Minimum bending radius must respected
- Piping must be concentrically aligned
- When specified the flow direction must be observed
- Mating flanges shall be clean from rust, burrs and anticorrosion coatings
- Bolts are to be tightened crosswise in several stages
- Flexible elements must not be painted
- Rubber bellows must be kept clean from oil and fuel
- The piping must be rigidly supported close to the flexible piping connections.

Figure 5.1 Flexible hoses (4V60B0100a)



5.10 Clamping of pipes

It is very important to fix the pipes to rigid structures next to flexible pipe connections in order to prevent damage caused by vibration. The following guidelines should be applied:

- Pipe clamps and supports next to the engine must be very rigid and welded to the steel structure of the foundation.
- The first support should be located as close as possible to the flexible connection. Next support should be 0.3-0.5 m from the first support.
- First three supports closest to the engine or generating set should be fixed supports. Where necessary, sliding supports can be used after these three fixed supports to allow thermal expansion of the pipe.
- Supports should never be welded directly to the pipe. Either pipe clamps or flange supports should be used for flexible connection.

Examples of flange support structures are shown in Figure *5.2*. A typical pipe clamp for a fixed support is shown in Figure *5.3*. Pipe clamps must be made of steel; plastic clamps or similar may not be used.

Figure 5.2 Flange supports of flexible pipe connections (4V60L0796)

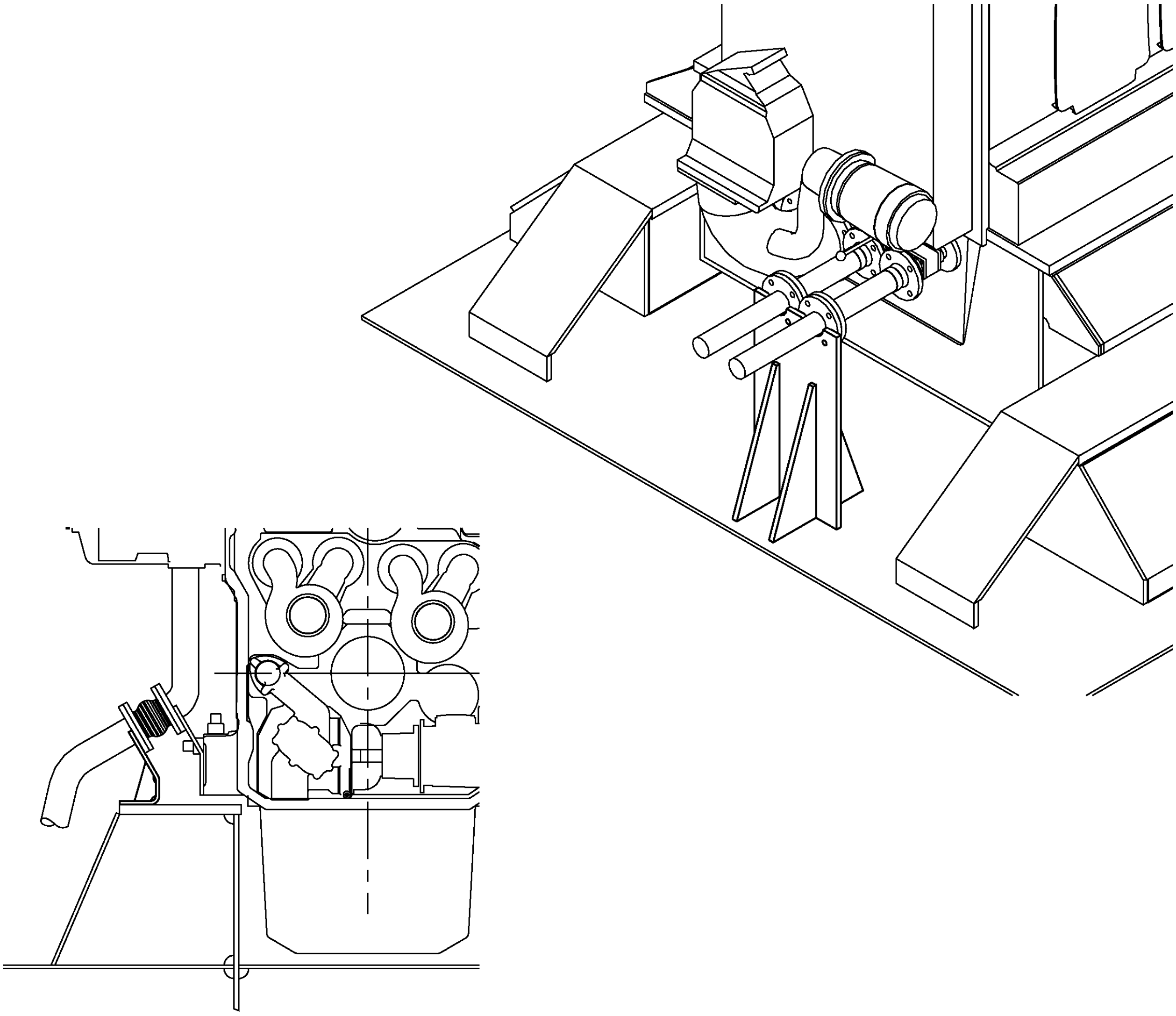
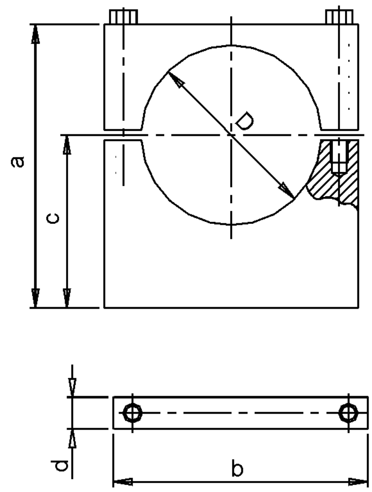


Figure 5.3 Pipe clamp for fixed support (4V61H0842)



DN	d_u [mm]	D [mm]	a [mm]	b [mm]	c [mm]	d [mm]	BOLTS
25	33.7	35	150	80	120	25	M10x50
32	42.4	43	150	75	120	25	M10x50
40	48.3	48	154.5	100	115	25	M12x60
50	60.3	61	185	100	145	25	M12x60
65	76.1	76.5	191	115	145	25	M12x70
80	88.9	90	220	140	150	30	M12x90
100	114.3	114.5	196	170	121	25	M12x100
125	139.7	140	217	200	132	30	M16x120
150	168.3	170	237	240	132	30	M16x140
200	219.1	220	295	290	160	30	M16x160
250	273.0	274	355	350	190	30	M16x200

d_u = Pipe outer diameter

6. Fuel oil system

6.1 Acceptable fuel characteristics

The fuel specifications are based on the ISO 8217:2005 (E) standard. Observe that a few additional properties not included in the standard are listed in the tables.

Distillate fuel grades are ISO-F-DMX, DMA, DMB, DMC. These fuel grades are referred to as MDF (Marine Diesel Fuel).

Residual fuel grades are referred to as HFO (Heavy Fuel Oil). The fuel specification HFO 2 covers the categories ISO-F-RMA 30 to RMK 700. Fuels fulfilling the specification HFO 1 permit longer overhaul intervals of specific engine components than HFO 2.

Table 6.1 MDF specifications

Property	Unit	ISO-F-DMX	ISO-F-DMA	ISO-F-DMB	ISO-F-DMC [1]	Test method ref.
Appearance		Clear and bright		-	-	Visual inspection
Viscosity, before injection pumps, min. [2]	cSt	2.0	2.0	2.0	2.0	ISO 3104
Viscosity, before injection pumps, max. [2]	cSt	24	24	24	24	ISO 3104
Viscosity at 40°C, max.	cSt	5.5	6.0	11.0	14.0	ISO 3104
Density at 15°C, max.	kg/m³	—	890	900	920	ISO 3675 or 12185
Cetane index, min.		45	40	35	—	ISO 4264
Water, max.	% volume	—	—	0.3	0.3	ISO 3733
Sulphur, max.	% mass	1.0	1.5	2.0 [3]	2.0 [3]	ISO 8574 or 14596
Ash, max.	% mass	0.01	0.01	0.01	0.05	ISO 6245
Vanadium, max.	mg/kg	—	—	—	100	ISO 14597 or IP 501 or 470
Sodium before engine, max. [2]	mg/kg	—	—	—	30	ISO 10478
Aluminium + Silicon, max	mg/kg	—	—	—	25	ISO 10478 or IP 501 or 470
Aluminium + Silicon before engine, max. [2]	mg/kg	—	—	—	15	ISO 10478 or IP 501 or 470
Carbon residue on 10 % volume distillation bottoms, max.	% mass	0.30	0.30	—	—	ISO 10370
Carbon residue, max.	% mass	—	—	0.30	2.50	ISO 10370
Flash point (PMCC), min.	°C	60 [2]	60	60	60	ISO 2719
Pour point, winter quality, max.	°C	—	-6	0	0	ISO 3016
Pour point, summer quality, max	°C	—	0	6	6	ISO 3016
Cloud point, max.	°C	-16	—	—	—	ISO 3015
Total sediment existent, max.	% mass	—	—	0.1	0.1	ISO 10307-1
Used lubricating oil, calcium, max. [4]	mg/kg	—	—	—	30	IP 501 or 470
Used lubricating oil, zinc, max. [4]	mg/kg	—	—	—	15	IP 501 or 470
Used lubricating oil, phosphorus, max. [4]	mg/kg	—	—	—	15	IP 501 or 500

Remarks:

1) Use of ISO-F-DMC category fuel is allowed provided that the fuel treatment system is equipped with a fuel centrifuge.

2) Additional properties specified by the engine manufacturer, which are not included in the ISO specification or differ from the ISO specification.

3) A sulphur limit of 1.5% mass will apply in SO_x emission controlled areas designated by IMO (International Maritime Organization). There may also be other local variations.

4) A fuel shall be considered to be free of used lubricating oil (ULO), if one or more of the elements calcium, zinc, and phosphorus are below or at the specified limits. All three elements shall exceed the same limits before a fuel shall be deemed to contain ULO's.

Table 6.2 HFO specifications

Property	Unit	Limit HFO 1	Limit HFO 2	Test method ref.
Viscosity at 100°C, max. Viscosity at 50°C, max. Viscosity at 100°F, max	cSt cSt Redwood No. 1 s	55 700 7200	55 700 7200	ISO 3104
Viscosity, before injection pumps 4)	cSt	16...24	16...24	
Density at 15°C, max.	kg/m³	991 / 1010 1)	991 / 1010 1)	ISO 3675 or 12185
CCAI, max.4)		850	870 2)	ISO 8217, Annex B
Water, max.	% volume	0.5	0.5	ISO 3733
Water before engine, max.4)	% volume	0.3	0.3	ISO 3733
Sulphur, max.	% mass	1.5	4.5 5)	ISO 8754 or 14596
Ash, max.	% mass	0.05	0.15	ISO 6245
Vanadium, max. 3)	mg/kg	100	600 3)	ISO 14597 or IP 501 or 470
Sodium, max. 3,4)	mg/kg	50	50	ISO 10478
Sodium before engine, max.3,4)	mg/kg	30	30	ISO 10478
Aluminium + Silicon, max.	mg/kg	30	80	ISO 10478 or IP 501 or 470
Aluminium + Silicon before engine, max.4)	mg/kg	15	15	ISO 10478 or IP 501 or 470
Carbon residue, max.	% mass	15	22	ISO 10370
Asphaltenes, max.4)	% mass	8	14	ASTM D 3279
Flash point (PMCC), min.	°C	60	60	ISO 2719
Pour point, max.	°C	30	30	ISO 3016
Total sediment potential, max.	% mass	0.10	0.10	ISO 10307-2
Used lubricating oil, calcium, max. 6)	mg/kg	30	30	IP 501 or 470
Used lubricating oil, zinc, max. 6)	mg/kg	15	15	IP 501 or 470
Used lubricating oil, phosphorus, max. 6)	mg/kg	15	15	IP 501 or 500

Remarks:

1) Max. 1010 kg/m³ at 15°C provided the fuel treatment system can remove water and solids.

2) Straight run residues show CCAI values in the 770 to 840 range and have very good ignition quality. Cracked residues delivered as bunkers may range from 840 to - in exceptional cases - above 900. Most bunkers remain in the max. 850 to 870 range at the moment.

3) Sodium contributes to hot corrosion on exhaust valves when combined with high sulphur and vanadium contents. Sodium also contributes strongly to fouling of the exhaust gas turbine at high loads. The aggressiveness of the fuel depends not only on its proportions of sodium and vanadium but also on the total amount of ash constituents. Hot corrosion and deposit formation are, however, also influenced by other ash constituents. It is therefore difficult to set strict limits based only on the sodium and vanadium content of the fuel. Also a fuel with lower sodium and vanadium contents that specified above, can cause hot corrosion on engine components.

4) Additional properties specified by the engine manufacturer, which are not included in the ISO specification.

5) A sulphur limit of 1.5% mass will apply in SO_x emission controlled areas designated by IMO (International Maritime Organization). There may also be other local variations.

6) A fuel shall be considered to be free of used lubricating oil (ULO), if one or more of the elements calcium, zinc, and phosphorus are below or at the specified limits. All three elements shall exceed the same limits before a fuel shall be deemed to contain ULO's.

The limits above concerning HFO 2 also correspond to the demands of the following standards:

- BS MA 100: 1996, RMH 55 and RMK 55
- CIMAC 2003, Grade K 700
- ISO 8217: 2005(E), ISO-F-RMK 700

The fuel shall not contain any added substances or chemical waste, which jeopardizes the safety of installations or adversely affects the performance of the engines or is harmful to personnel or contributes overall to air pollution.

6.1.1 Liquid bio fuels

The engine can be operated on liquid bio fuels, according to the specification below, without reduction in the rated output. However, since liquid bio fuels have typically lower heating value than fossil fuels, the capacity of the fuel injection system must be checked for each installation. Biodiesels that fulfil standards like ASTM D 6751-02 or DIN EN 14214 can be used as fuel oil as long as the specification is fulfilled.

The specification is valid for raw vegetable based liquid bio fuels, like palm oil, coconut oil, copra oil, rape seed oil, etc. but is not valid for animal based bio fuels.

Table 6.3 Liquid bio fuel specification

Property	Unit	Limit	Test method ref.
Viscosity at 40°C, max.[1)]	cSt	100	ISO 3104
Viscosity, before injection pumps, min.	cSt	2.8	
Viscosity, before injection pumps, max.	cSt	24	
Density at 15°C, max.	kg/m³	991	ISO 3675 or 12185
Ignition properties [2)]			FIA test
Sulphur, max.	% mass	0.05	ISO 8574
Total sediment existent, max.	% mass	0.05	ISO 10307-1
Water before engine, max.	% volume	0.20	ISO 3733
Micro carbon residue, max.	% mass	0.30	ISO 10370
Ash, max.	% mass	0.05	ISO 6245
Phosphorus, max.	mg/kg	100	ISO 10478
Silicon, max.	mg/kg	10	ISO 10478
Alkali content (Na+K), max.	mg/kg	30	ISO 10478
Flash point (PMCC), min.	°C	60	ISO 2719
Pour point, max.	°C	[3)]	ISO 3016
Cloud point, max.	°C	[3)]	ISO 3015
Cold filter plugging point, max.	°C	[3)]	IP 309
Copper strip corrosion (3h at 50°C), max.		1b	ASTM D130
Steel corrosion (24/72h at 20, 60 and 120°C), max.		No signs of corrosion	LP 2902
Acid number, max.	mg KOH/g	5.0	ASTM D664
Strong acid number, max.	mg KOH/g	0.0	ASTM D664
Iodine number, max.		120	ISO 3961

Remarks:

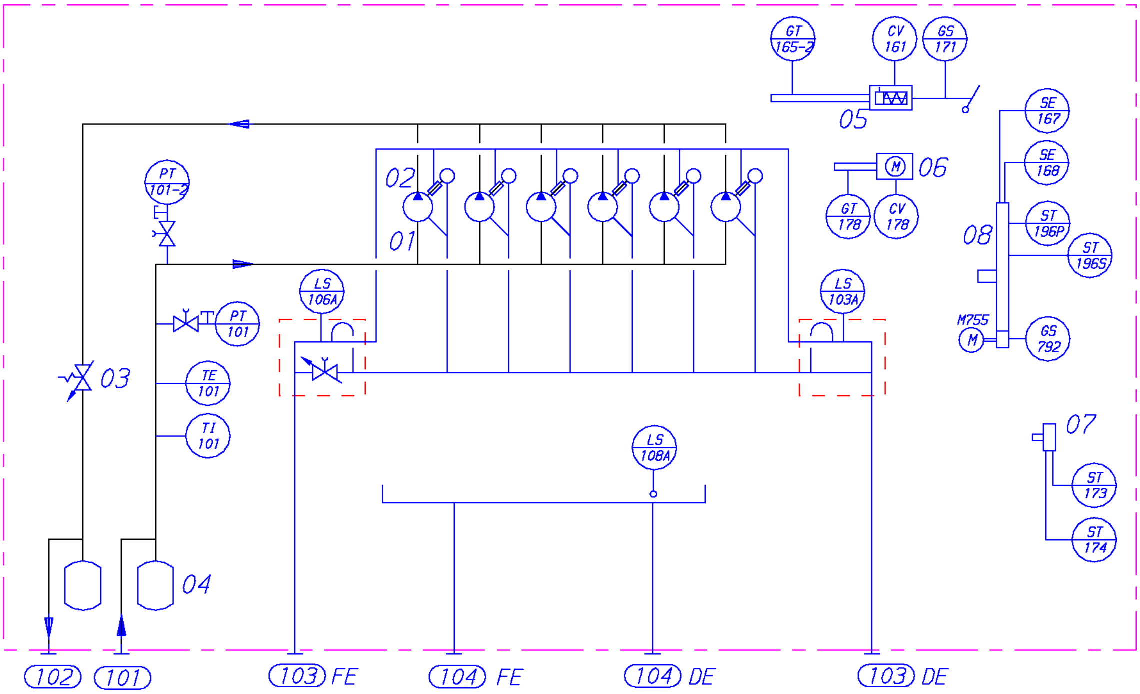
1) If injection viscosity of max. 24 cSt cannot be achieved with an unheated fuel, fuel oil system has to be equipped with a heater.

2) Ignition properties have to be equal to or better than requirements for fossil fuels, i.e. CN min. 35 for MDF and CCAI max. 870 for HFO.

3) Pour point and cloud point / cold filter plugging point have to be at least 10°C below the fuel injection temperature.

6.2 Internal fuel oil system

Figure 6.1 Internal fuel system, conventional fuel injection (DAAE017289a)



System components

01	Injection pump	05	Fuel rack actuator
02	Injection valve	06	Timing rack actuator
03	Pressure control valve	07	Camshaft
04	Pulse damper	08	Flywheel

Sensors and indicators

PT101	Fuel pressure, engine inlet	GT178	Timing rack position
PT101-2	Fuel pressure, engine inlet (for local indication)	GS171	Stop lever in stop position
TE101	Fuel temperature, engine inlet	GS792	Turning gear engaged
TI101	Fuel temperature, engine inlet (thermometer)	SE167	Engine speed 1, if external speed control
LS103A	Fuel leakage, injection pipe	SE168	Engine speed 2, if external speed control
LS106A	Fuel leakage, clean fuel	ST173	Engine speed 1 (safety)
LS108A	Fuel leakage, dirty fuel	ST174	Engine speed 2 (safety)
CV161	Fuel rack control	ST196P	Engine speed, prime (speed control)
CV178	Timing rack control	ST196S	Engine speed, back-up (speed control)
GT165-2	Fuel rack position, if CPP	M755	Electric motor for turning gear

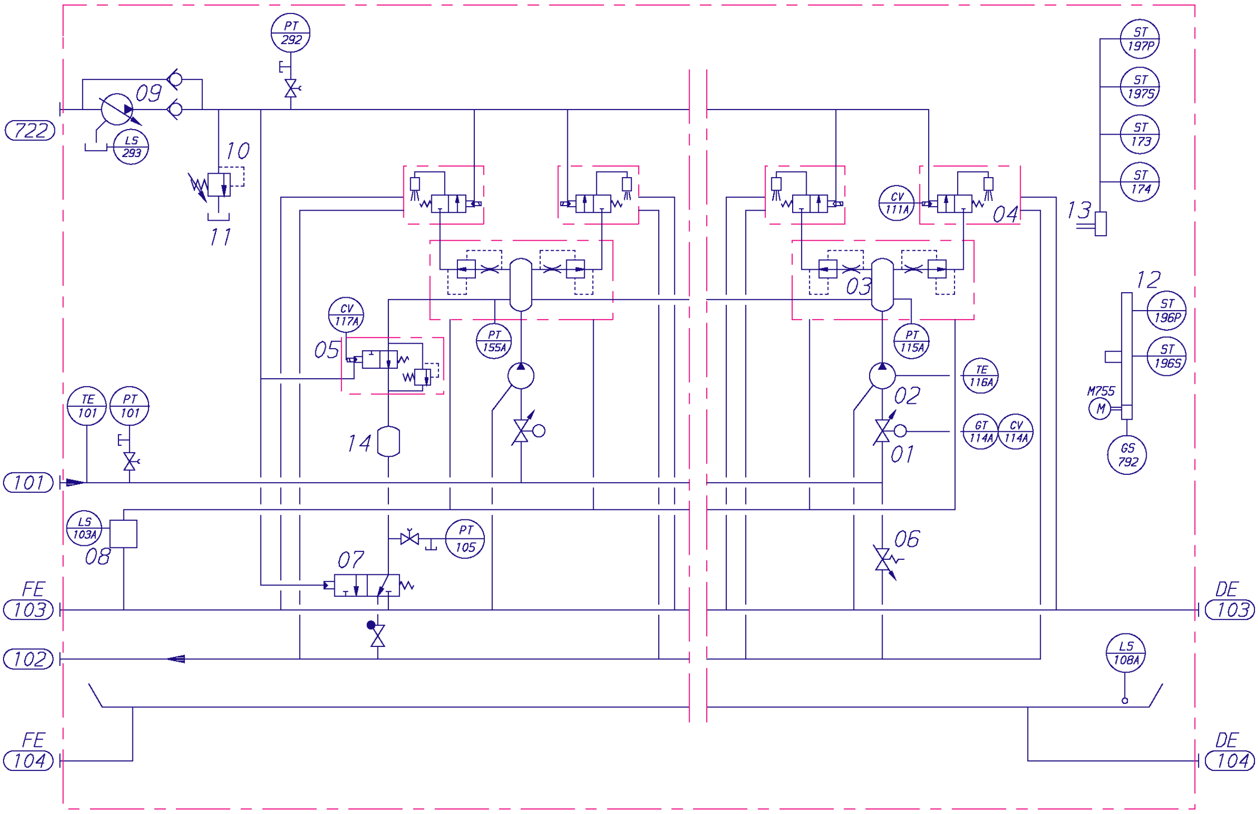
Pipe connections		Size	Pressure class	Standard
101	Fuel inlet	DN32	PN40	ISO 7005-1
102	Fuel outlet	DN32	PN40	ISO 7005-1
103	Leak fuel drain, clean fuel	DN25	PN40	ISO 7005-1
104	Leak fuel drain, dirty fuel	OD48		

Abbreviations:

FE = Free end

DE = Driving end

Figure 6.2 Internal fuel system for common rail (DAAE023789b)



System components

01	Flow control valve (throttle valve)	08	Fuel oil leakage collector
02	High pressure pump	09	Control oil pump
03	Accumulator with flow fuses	10	Pressure relief valve
04	Fuel injector	11	Lubricating oil pump
05	Start and safety valve	12	Flywheel
06	Pressure control valve	13	Camshaft
07	3-way valve	14	SSV drain volume

Sensors and indicators

PT101	Fuel pressure, engine inlet	CV114A	Throttle valve control (114A...1x4A)
PT105	Fuel pressure, return / pressure relief line	CV117A	Start and safety valve control
PT115A	Rail pressure, driving end	GT114A	Throttle valve position (114A...1x4A)
PT155A	Rail pressure, free end	GS792	Turning gear engaged
PT292	Control oil pressure	ST173	Engine speed 1 (safety)
TE101	Fuel temperature, engine inlet	ST174	Engine speed 2 (safety)
TE116A	High pressure pump temperature (116A...1x6A)	ST196P	Engine speed / top dead centre, prime
LS103A	Fuel leakage, injection pipe	ST196S	Engine speed / top dead centre, back-up
LS108A	Fuel leakage, dirty fuel	ST197P	Engine phase, prime
LS293	Control oil leakage	ST197S	Engine phase, back-up
CV111A	Fuel injector control (111A...1n1A)	M755	Electric motor for turning gear
	(x = fuel pump number) (n = cylinder number)		

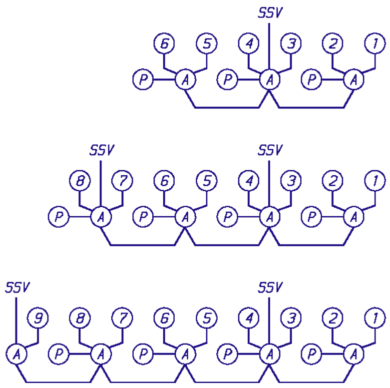
Pipe connections		Size	Pressure class	Standard
101	Fuel inlet	DN32	PN40	ISO 7005-1
102	Fuel outlet	DN32	PN40	ISO 7005-1
103	Leak fuel drain, clean fuel	DN25	PN40	ISO 7005-1
104	Leak fuel drain, dirty fuel	OD48		
722	Control oil from external filter	DN40	PN25	ISO 7005-1

Abbreviations:

FE = Free end

DE = Driving end

Location of components depending on cylinder configuration:



P = Pump
A = Accumulator
SSV = Start and safety valve

The engine is designed for continuous operation on heavy fuel oil (HFO). On request the engine can be built for operation exclusively on marine diesel fuel (MDF). It is however possible to operate HFO engines on MDF intermittently without any alternations. Continuous operation on HFO is recommended as far as possible.

If the operation of the engine is changed from HFO to continuous operation on MDF, then a change of exhaust valves from Nimonic to Stellite is recommended.

A pressure control valve in the fuel return line on the engine maintains desired pressure before the injection pumps.

6.2.1 Leak fuel system

Clean leak fuel from the injection valves and the injection pumps is collected on the engine and drained by gravity through a clean leak fuel connection. The clean leak fuel can be re-used without separation. The quantity of clean leak fuel is given in chapter *Technical data*.

The fuel rail on common rail engines is depressurized by discharging fuel into the clean leak fuel line when the engine is to be stopped. An amount of fuel is therefore discharged into the clean leak fuel line at every stop.

Other possible leak fuel and spilled water and oil is separately drained from the hot-box through dirty fuel oil connections and it shall be led to a sludge tank.

6.3 External fuel oil system

The design of the external fuel system may vary from ship to ship, but every system should provide well cleaned fuel of correct viscosity and pressure to each engine. Temperature control is required to maintain stable and correct viscosity of the fuel before the injection pumps (see *Technical data*). 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 greatest importance, and therefore the recommendations of the separator manufacturer must be closely followed. Poorly centrifuged fuel is harmful to the engine and a high content of water may also damage the fuel feed system.

The fuel pipe connections on the engine are smaller than the required pipe diameter on the installation side.

Injection pumps generate pressure pulses into the fuel feed and return piping. The fuel pipes between the feed unit and the engine must be properly clamped 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*.

A connection for compressed air should be provided before the engine, together with a drain from the fuel return line to the clean leakage fuel or overflow tank. With this arrangement it is possible to blow out fuel from the engine prior to maintenance work, to avoid spilling.

NOTE! 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. 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.

6.3.1 Fuel heating requirements HFO

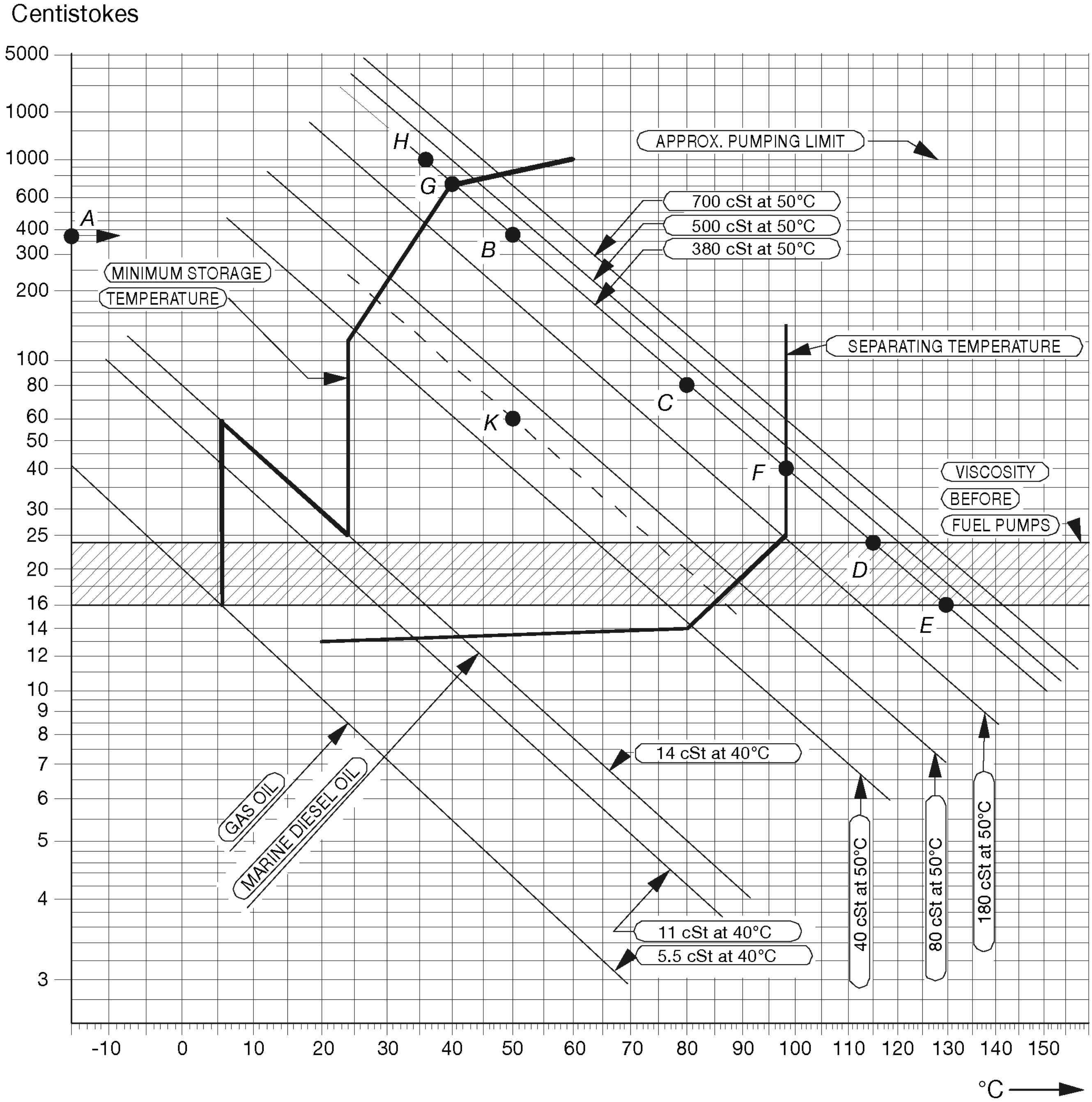
Heating is required for:

- Bunker tanks, settling tanks, day tanks
- Pipes (trace heating)
- Separators
- Fuel feeder/booster units

To enable pumping the temperature of bunker tanks must always be maintained 5...10°C above the pour point, typically at 40...50°C. The heating coils can be designed for a temperature of 60°C.

The tank heating capacity is determined by the heat loss from the bunker tank and the desired temperature increase rate.

Figure 6.3 Fuel oil viscosity-temperature diagram for determining the pre-heating temperatures of fuel oils (4V92G0071b)



Example 1: A fuel oil with a viscosity of 380 cSt (A) at 50°C (B) or 80 cSt at 80°C (C) must be pre-heated to 115 - 130°C (D-E) before the fuel injection pumps, to 98°C (F) at the separator and to minimum 40°C (G) in the storage tanks. The fuel oil may not be pumpable below 36°C (H).

To obtain temperatures for intermediate viscosities, draw a line from the known viscosity/temperature point in parallel to the nearest viscosity/temperature line in the diagram.

Example 2: Known viscosity 60 cSt at 50°C (K). The following can be read along the dotted line: viscosity at 80°C = 20 cSt, temperature at fuel injection pumps 74 - 87°C, separating temperature 86°C, minimum storage tank temperature 28°C.

6.3.2 Fuel tanks

The fuel oil is first transferred from the bunker tanks to settling tanks for initial separation of sludge and water. After centrifuging the fuel oil is transferred to day tanks, from which fuel is supplied to the engines.

Settling tank, HFO (1T02) and MDF (1T10)

Separate settling tanks for HFO and MDF are recommended.

To ensure sufficient time for settling (water and sediment separation), the capacity of each tank should be sufficient for min. 24 hours operation at maximum fuel consumption.

The tanks should be provided with internal baffles to achieve efficient settling and have a sloped bottom for proper draining.

The temperature in HFO settling tanks should be maintained between 50°C and 70°C, which requires heating coils and insulation of the tank. Usuallly MDF settling tanks do not need heating or insulation, but the tank temperature should be in the range 20...40°C.

Day tank, HFO (1T03) and MDF (1T06)

Two day tanks for HFO are to be provided, each with a capacity sufficient for at least 8 hours operation at maximum fuel consumption.

A separate tank is to be provided for MDF. The capacity of the MDF tank should ensure fuel supply for 8 hours.

Settling tanks may not be used instead of day tanks.

The day tank must be designed so that accumulation of sludge near the suction pipe is prevented and the bottom of the tank should be sloped to ensure efficient draining.

HFO day tanks shall be provided with heating coils and insulation. It is recommended that the viscosity is kept below 140 cSt in the day tanks. Due to risk of wax formation, fuels with a viscosity lower than 50 cSt at 50°C must be kept at a temperature higher than the viscosity would require. Continuous separation is nowadays common practice, which means that the HFO day tank temperature normally remains above 90°C.

The temperature in the MDF day tank should be in the range 20...40°C.

The level of the tank must ensure a positive static pressure on the suction side of the fuel feed pumps. If black-out starting with MDF from a gravity tank is foreseen, then the tank must be located at least 15 m above the engine crankshaft.

Leak fuel tank, clean fuel (1T04)

Clean leak fuel is drained by gravity from the engine. The fuel should be collected in a separate clean leak fuel tank, from where it can be pumped to the day tank and reused without separation. The pipes from the engine to the clean leak fuel tank should be arranged continuosly sloping. The tank and the pipes must be heated and insulated, unless the installation is designed for operation on MDF only.

The leak fuel piping should be fully closed to prevent dirt from entering the system.

NOTE! The fuel rail on common rail engines is depressurized by discharging fuel into the clean leak fuel line. It is therefore very important that the leak fuel system can accommodate this volume at all times. The maximum volume discharged at an emergency stop is stated in chapter *Technical data*. Fuel will also be discharged into the clean leak fuel system in case of a malfunction causing excessive rail pressure. On common rail engines the clean leak fuel outlets at both ends of the engine must be connected to the leak fuel tank.

Leak fuel tank, dirty fuel (1T07)

In normal operation no fuel should leak out from the components of the fuel system. In connection with maintenance, or due to unforeseen leaks, fuel or water may spill in the hot box of the engine. The spilled liquids are collected and drained by gravity from the engine through the dirty fuel connection.

Dirty leak fuel shall be led to a sludge tank. The tank and the pipes must be heated and insulated, unless the installation is designed for operation exclusively on MDF.

6.3.3 Fuel treatment

Separation

Heavy fuel (residual, and mixtures of residuals and distillates) must be cleaned in an efficient centrifugal separator before it is transferred to the day tank.

Classification rules require the separator arrangement to be redundant so that required capacity is maintained with any one unit out of operation.

All recommendations from the separator manufacturer must be closely followed.

Centrifugal disc stack separators are recommended also for installations operating on MDF only, to remove water and possible contaminants. The capacity of MDF separators should be sufficient to ensure the fuel supply at maximum fuel consumption. Would a centrifugal separator be considered too expensive for a MDF installation, then it can be accepted to use coalescing type filters instead. A coalescing filter is usually installed on the suction side of the circulation pump in the fuel feed system. The filter must have a low pressure drop to avoid pump cavitation.

Separator mode of operation

The best separation efficiency is achieved when also the stand-by separator is in operation all the time, and the throughput is reduced according to actual consumption.

Separators with monitoring of cleaned fuel (without gravity disc) operating on a continuous basis can handle fuels with densities exceeding 991 kg/m^3 at 15°C. In this case the main and stand-by separators should be run in parallel.

When separators with gravity disc are used, then each stand-by separator should be operated in series with another separator, so that the first separator acts as a purifier and the second as clarifier. This arrangement can be used for fuels with a density of max. 991 kg/m^3 at 15°C. The separators must be of the same size.

Separation efficiency

The term Certified Flow Rate (CFR) has been introduced to express the performance of separators according to a common standard. CFR is defined as the flow rate in l/h, 30 minutes after sludge discharge, at which the separation efficiency of the separator is 85%, when using defined test oils and test particles. CFR is defined for equivalent fuel oil viscosities of 380 cSt and 700 cSt at 50°C. More information can be found in the CEN (European Committee for Standardisation) document CWA 15375:2005 (E).

The separation efficiency is measure of the separator's capability to remove specified test particles. The separation efficiency is defined as follows:

$$n = 100 \times \left(1 - \frac{C_{out}}{C_{in}}\right)$$

where:

n = separation efficiency [%]

C_{out} = number of test particles in cleaned test oil

C_{in} = number of test particles in test oil before separator

Separator unit (1N02/1N05)

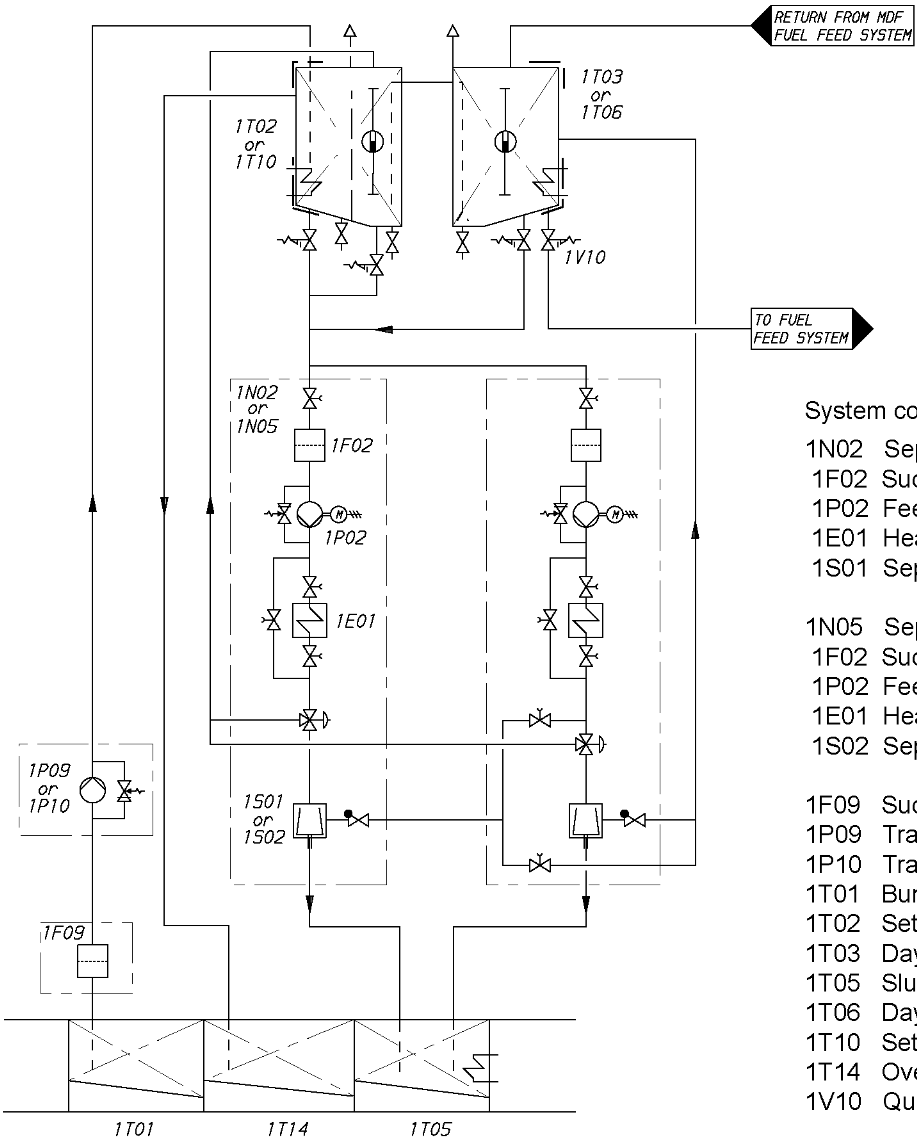
Separators are usually supplied as pre-assembled units designed by the separator manufacturer.

Typically separator modules are equipped with:

- Suction strainer (1F02)
- Feed pump (1P02)
- Pre-heater (1E01)
- Sludge tank (1T05)
- Separator (1S01/1S02)

- Sludge pump
- Control cabinets including motor starters and monitoring

Figure 6.4 Fuel transfer and separating system (3V76F6626d)



System components:

1N02	Separator unit (HFO)
1F02	Suction strainer
1P02	Feed pump
1E01	Heater
1S01	Separator (HFO)
1N05	Separator unit (MDF)
1F02	Suction strainer
1P02	Feed pump
1E01	Heater
1S02	Separator (MDF)
1F09	Suction strainer
1P09	Transfer pump (HFO)
1P10	Transfer pump (MDF)
1T01	Bunker tank
1T02	Settling tank (HFO)
1T03	Day tank (HFO)
1T05	Sludge tank
1T06	Day tank (MDF)
1T10	Settling tank (MDF)
1T14	Overflow tank
1V10	Quick closing valve (Fuel oil tank)

Separator feed pumps (1P02)

Feed pumps should be dimensioned for the actual fuel quality and recommended throughput of the separator. The pump should be protected by a suction strainer (mesh size about 0.5 mm)

An approved system for control of the fuel feed rate to the separator is required.

Design data:	HFO	MDF
Design pressure	0.5 MPa (5 bar)	0.5 MPa (5 bar)
Design temperature	100°C	50°C
Viscosity for dimensioning electric motor	1000 cSt	100 cSt

Separator pre-heater (1E01)

The pre-heater is dimensioned according to the feed pump capacity and a given settling tank temperature.

The surface temperature in the heater must not be too high in order to avoid cracking of the fuel. The temperature control must be able to maintain the fuel temperature within ± 2°C.

Recommended fuel temperature after the heater depends on the viscosity, but it is typically 98°C for HFO and 20...40°C for MDF. The optimum operating temperature is defined by the sperarator manufacturer.

The required minimum capacity of the heater is:

$$P = \frac{Q \times \Delta T}{1700}$$

where:

P = heater capacity [kW]

Q = capacity of the separator feed pump [l/h]

ΔT = temperature rise in heater [°C]

For heavy fuels ΔT = 48°C can be used, i.e. a settling tank temperature of 50°C. Fuels having a viscosity higher than 5 cSt at 50°C require pre-heating before the separator.

The heaters to be provided with safety valves and drain pipes to a leakage tank (so that the possible leakage can be detected).

Separator (1S01/1S02)

Based on a separation time of 23 or 23.5 h/day, the service throughput Q [l/h] of the separator can be estimated with the formula:

$$Q = \frac{P \times b \times 24[h]}{\rho \times t}$$

where:

P = max. continuous rating of the diesel engine(s) [kW]

b = specific fuel consumption + 15% safety margin [g/kWh]

ρ = density of the fuel [kg/m^3]

t = daily separating time for self cleaning separator [h] (usually = 23 h or 23.5 h)

The flow rates recommended for the separator and the grade of fuel must not be exceeded. The lower the flow rate the better the separation efficiency.

Sample valves must be placed before and after the separator.

MDF separator in HFO installations (1S02)

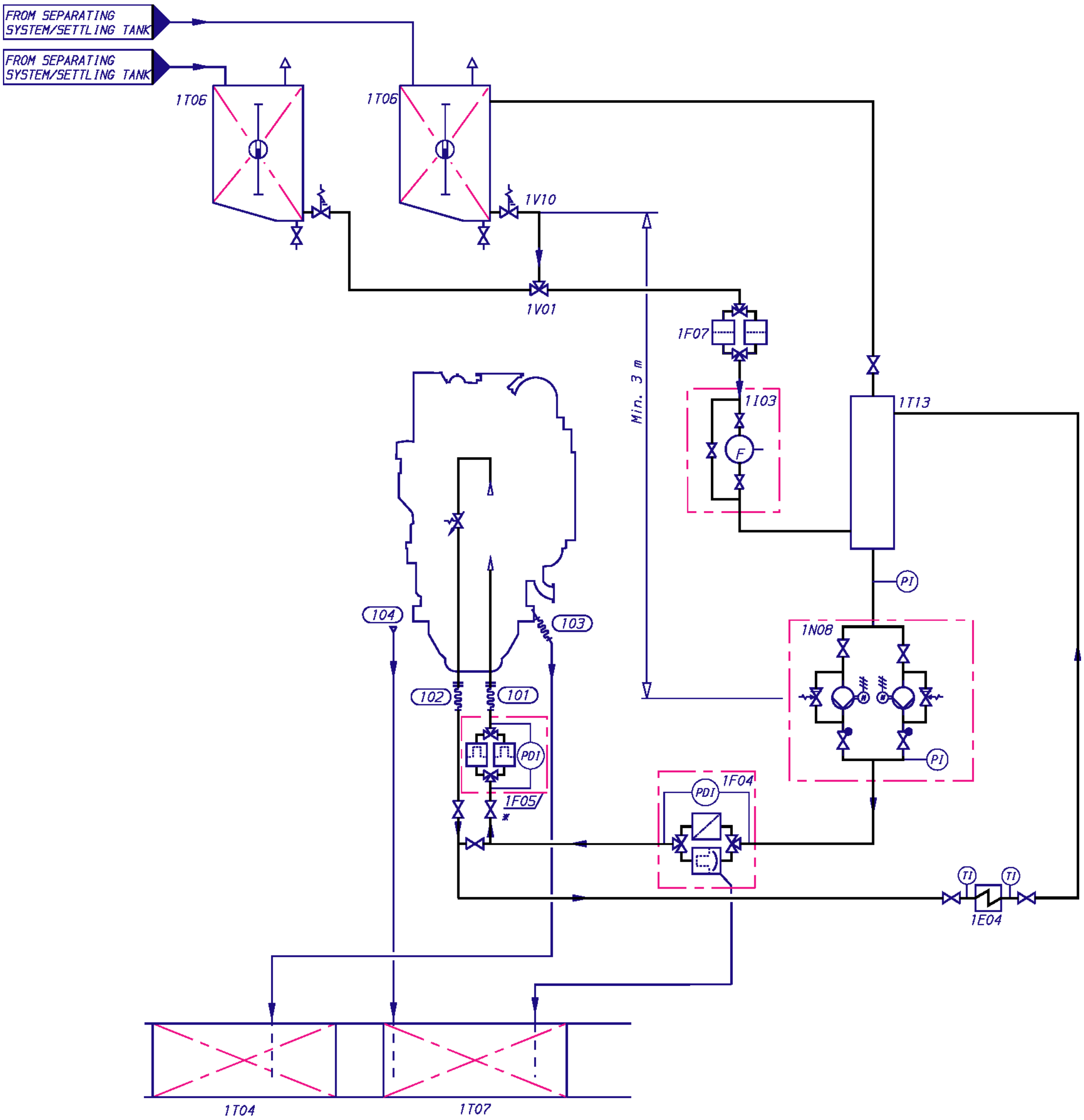
A separator for MDF is recommended also for installations operating primarily on HFO. The MDF separator can be a smaller size dedicated MDF separator, or a stand-by HFO separator used for MDF.

Sludge tank (1T05)

The sludge tank should be located directly beneath the separators, or as close as possible below the separators, unless it is integrated in the separator unit. The sludge pipe must be continuously falling.

6.3.4 Fuel feed system - MDF installations

Figure 6.5 Example of fuel oil system, MDF, single engine installation (DAAE022042b)



* To be remotely operated if located < 5 m from engine.

System components		Pipe connections	
1E04	Cooler (MDF return line)	101	Fuel inlet
1F04	Automatic filter (MDF)	102	Fuel outlet
1F05	Fine filter (MDF)	103	Leak fuel drain, clean fuel
1F07	Suction strainer (MDF)	104	Leak fuel drain, dirty fuel
1I03	Flow meter (MDF)		
1N08	Fuel feed pump unit (MDF)		
1T04	Leak fuel tank, clean fuel		
1T06	Day tank (MDF)		
1T07	Leak fuel tank, dirty fuel		
1T13	Return fuel tank		
1V01	Change-over valve		
1V10	Quick closing valve		

If the engines are to be operated on MDF only, heating of the fuel is normally not necessary. In such case it is sufficient to install the equipment listed below. Some of the equipment listed below is also to be installed in the MDF part of a HFO fuel oil system.

Circulation pump, MDF (1P03)

The circulation pump maintains the pressure at the injection pumps and circulates the fuel in the system. It is recommended to use a screw pump as circulation pump. A suction strainer with a fineness of 0.5 mm should be installed before each pump. There must be a positive static pressure of about 30 kPa on the suction side of the pump.

Design data:	
Capacity:	
- conventional fuel injection	4 x the total consumption of the connected engines and the flush quantity of a possible automatic filter
- common rail fuel injection	3 x the total consumption of the connected engines and the flush quantity of a possible automatic filter
Design pressure	1.6 MPa (16 bar)
Max. total pressure (safety valve)	1.2 MPa (12 bar)
Design temperature	50°C
Viscosity for dimensioning of electric motor	90 cSt

Flow meter, MDF (1I03)

If the return fuel from the engine is conducted to a return fuel tank instead of the day tank, one consumption meter is sufficient for monitoring of the fuel consumption, provided that the meter is installed in the feed line from the day tank (before the return fuel tank). A fuel oil cooler is usually required with a return fuel tank.

The total resistance of the flow meter and the suction strainer must be small enough to ensure a positive static pressure of about 30 kPa on the suction side of the circulation pump.

There should be a by-pass line around the consumption meter, which opens automatically in case of excessive pressure drop.

Automatic filter, MDF (1F04)

The use of an automatic back-flushing filter is recommended, normally as a duplex filter with an insert filter as the stand-by half. The circulating pump capacity must be sufficient to prevent pressure drop during the flushing operation.

Design data:	
Fuel viscosity	according to fuel specification
Design temperature	50°C
Design flow	Equal to feed/circulation pump capacity
Design pressure	1.6 MPa (16 bar)
Fineness, conventional fuel injection:	
- automatic filter	35 μm (absolute mesh size)
- bypass filter	35 μm (absolute mesh size)
Fineness, common rail fuel injection:	
- automatic filter	10 μm (absolute mesh size)
- bypass filter	25 μm (absolute mesh size)
Maximum permitted pressure drops at 14 cSt:	
- clean filter, 35 μm	20 kPa (0.2 bar)
- clean filter, 10 μm	30 kPa (0.3 bar)
- alarm	80 kPa (0.8 bar)

Fine filter, MDF (1F05)

The fuel oil fine filter is a full flow duplex type filter with steel net. This filter must be installed as near the engine as possible.

The diameter of the pipe between the fine filter and the engine should be the same as the diameter before the filters.

Design data:	
Fuel viscosity	according to fuel specifications
Design temperature	50°C
Design flow	Equal to feed/circulation pump capacity
Design pressure	1.6 MPa (16 bar)
Fineness, conventional fuel injection	37 μm (absolute mesh size)
Fineness, common rail fuel injection	25 μm (absolute mesh size)
Maximum permitted pressure drops at 14 cSt:	
- clean filter	20 kPa (0.2 bar)
- alarm	80 kPa (0.8 bar)

Pressure control valve, MDF (1V02)

The pressure control valve is installed when the installation includes a feeder/booster unit for HFO and there is a return line from the engine to the MDF day tank. The purpose of the valve is to increase the pressure in the return line so that the required pressure at the engine is achieved.

Design data:	
Capacity	Equal to circulation pump
Design temperature	50°C
Design pressure	1.6 MPa (16 bar)
Set point	0.4...0.7 MPa (4...7 bar)

MDF cooler (1E04)

The fuel viscosity may not drop below the minimum value stated in *Technical data*. When operating on MDF, the practical consequence is that the fuel oil inlet temperature must be kept below 45...50°C. Very light fuel grades may require even lower temperature.

Sustained operation on MDF usually requires a fuel oil cooler. The cooler is to be installed in the return line after the engine(s). LT-water is normally used as cooling medium.

Design data:	
Heat to be dissipated	4 kW/cyl at full load and 0.5 kW/cyl at idle
Max. pressure drop, fuel oil	80 kPa (0.8 bar)
Max. pressure drop, water	60 kPa (0.6 bar)
Margin (heat rate, fouling)	min. 15%

Return fuel tank (1T13)

The return fuel tank shall be equipped with a vent valve needed for the vent pipe to the MDF day tank. The volume of the return fuel tank should be at least 100 l.

Black out start

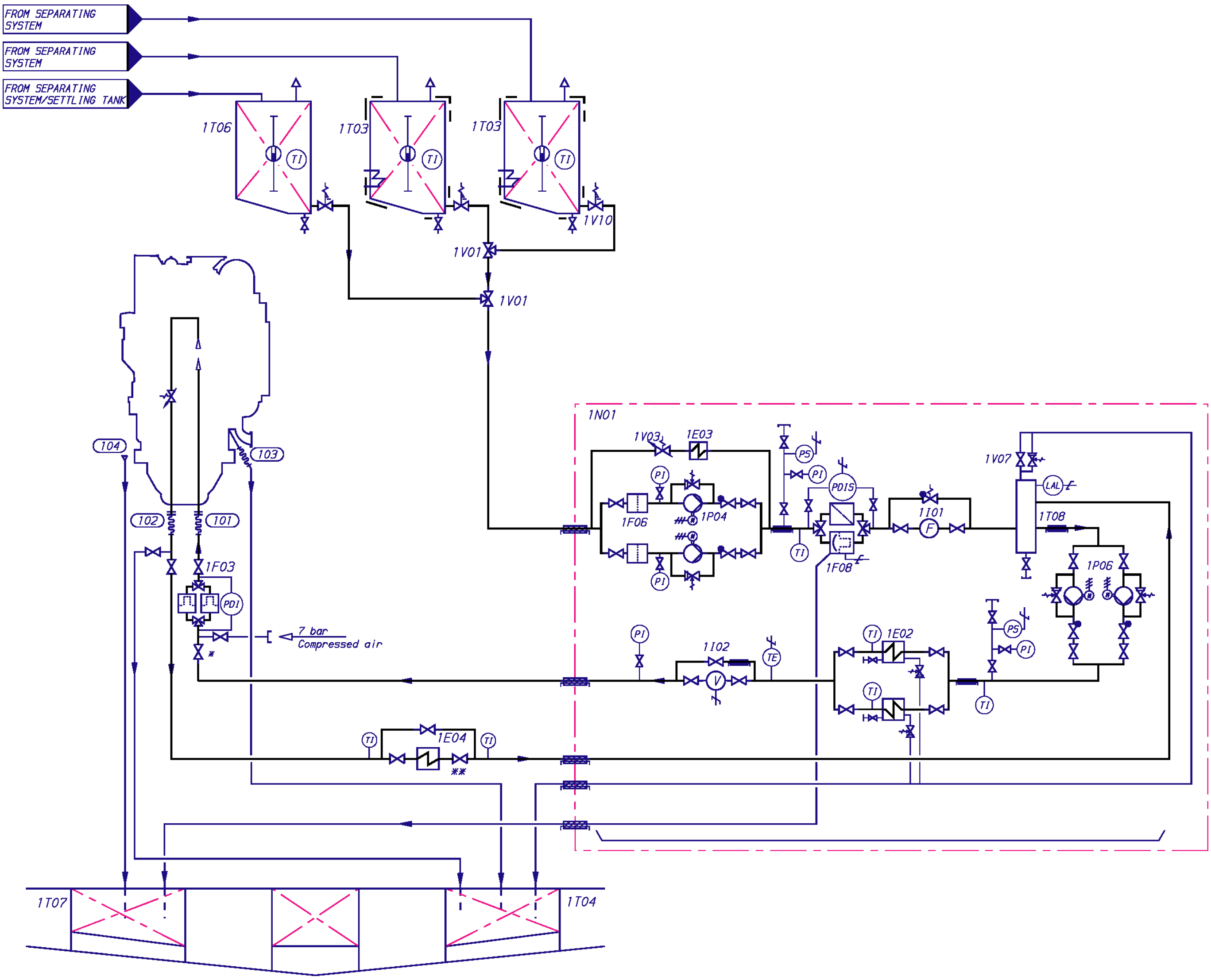
Diesel generators serving as the main source of electrical power must be able to resume their operation in a black out situation by means of stored energy. Depending on system design and classification regulations, it may in some cases be permissible to use the emergency generator. Sufficient fuel pressure to enable black out start can be achieved by means of:

- A gravity tank located min. 15 m above the crankshaft

- A pneumatically driven fuel feed pump (1P11)
- An electrically driven fuel feed pump (1P11) powered by an emergency power source

6.3.5 Fuel feed system - HFO installations

Figure 6.6 Example of fuel oil system, HFO, single engine installation (DAAE022041b)



* To be remotely operated if located < 5 m from engine.

** Required for frequent or sustained operation on MDF

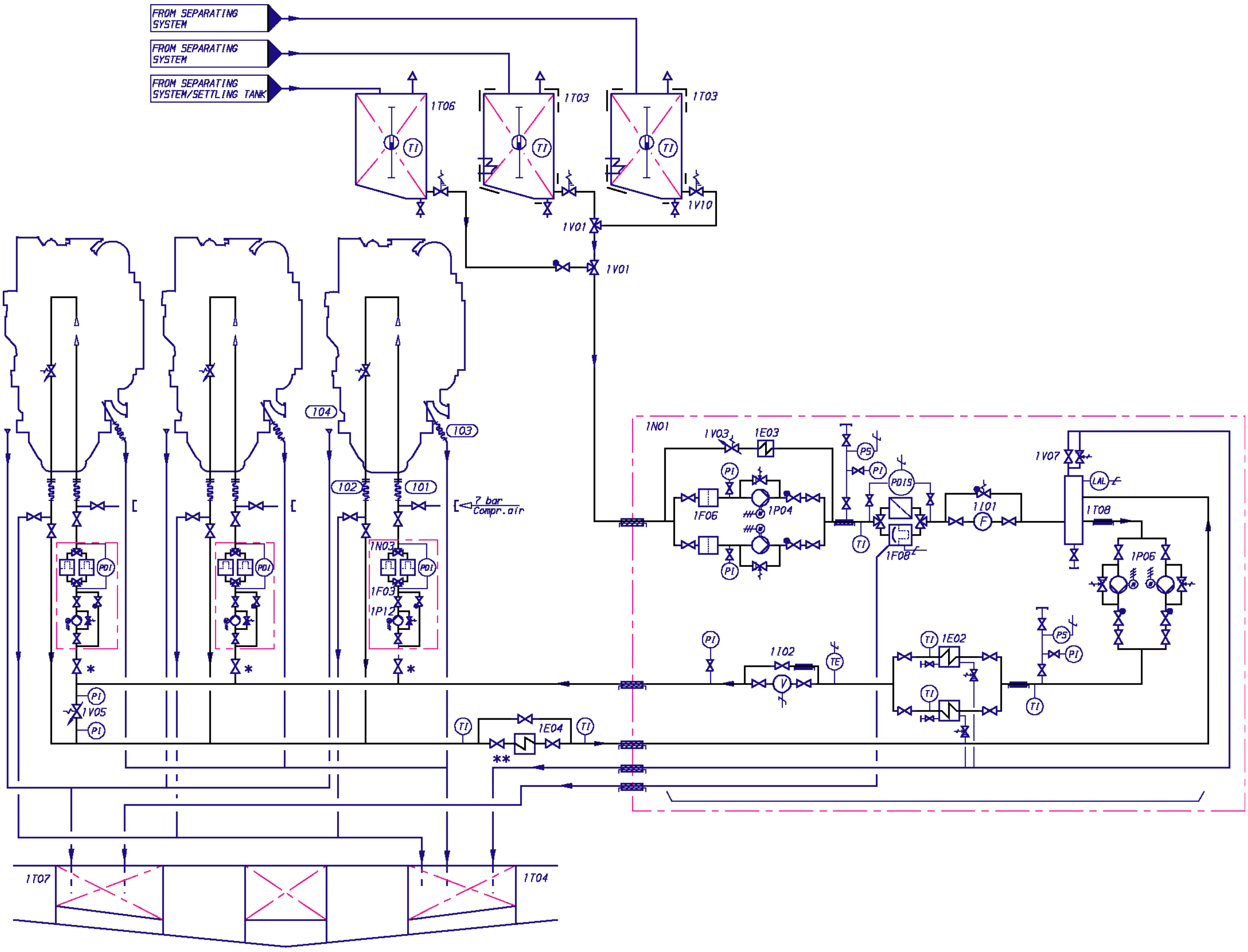
System components

1E02	Heater	1P06	Circulation pump
1E03	Cooler	1T03	Day tank (HFO)
1E04	Cooler (MDF return line)	1T04	Leak fuel tank, clean fuel
1F03	Safety filter (HFO)	1T06	Day tank (MDF)
1F06	Suction filter	1T07	Leak fuel tank, dirty fuel
1F08	Automatic filter	1T08	De-aeration tank
1I01	Flow meter	1V01	Change-over valve
1I02	Viscosity meter	1V03	Pressure control valve
1N01	Feeder/booster unit	1V07	Venting valve
1P04	Fuel feed pump	1V10	Quick closing valve

Pipe connections

101	Fuel inlet
102	Fuel outlet
103	Leak fuel drain, clean fuel
104	Leak fuel drain, dirty fuel

Figure 6.7 Example of fuel oil system, HFO, multiple engine installation (DAAE057999a)

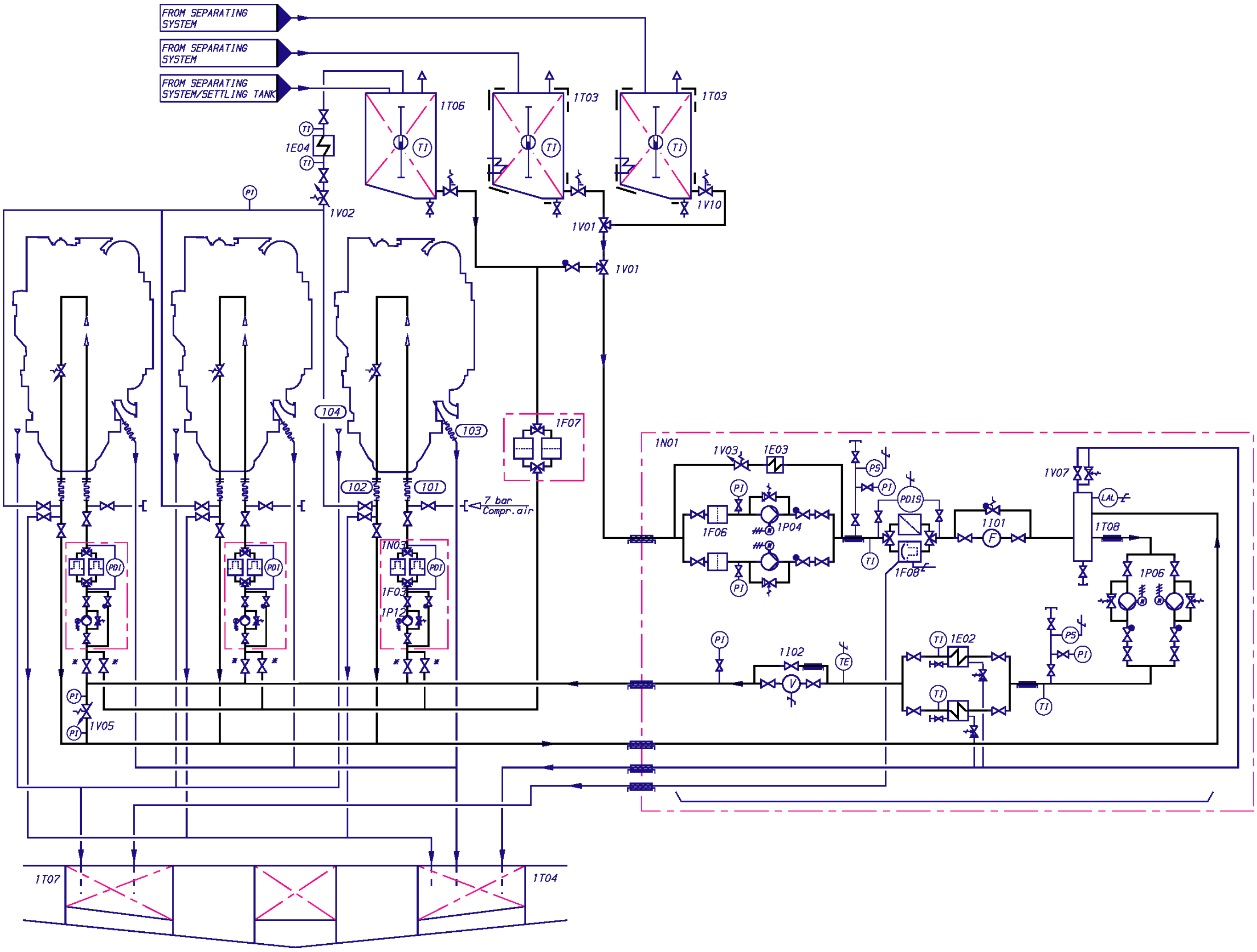


* To be remotely operated if located < 5 m from engine.

** Required for frequent or sustained operation on MDF

System components				Pipe connections	
1E02	Heater	1P12	Circulation pump (HFO/MDF)	101	Fuel inlet
1E03	Cooler	1T03	Day tank (HFO)	102	Fuel outlet
1E04	Cooler (MDF return line)	1T04	Leak fuel tank, clean fuel	103	Leak fuel drain, clean fuel
1F03	Safety filter (HFO)	1T06	Day tank (MDF)	104	Leak fuel drain, dirty fuel
1F06	Suction filter	1T07	Leak fuel tank, dirty fuel		
1F08	Automatic filter	1T08	De-aeration tank		
1I01	Flow meter	1V01	Change-over valve		
1I02	Viscosity meter	1V03	Pressure control valve		
1N01	Feeder/booster unit	1V05	Overflow valve (HFO/MDF)		
1N03	Pump and filter unit (HFO/MDF)	1V07	Venting valve		
1P04	Fuel feed pump	1V10	Quick closing valve		
1P06	Circulation pump (booster unit)				

Figure 6.8 Example of fuel oil system, HFO, multiple engine installation, not suitable for common rail engines due to required filter fineness (DAAE022040b)



* To be remotely operated if located < 5 m from engine.

System components

1E02	Heater	1P12	Circulation pump (HFO/MDF)
1E03	Cooler	1T03	Day tank (HFO)
1E04	Cooler (MDF return line)	1T04	Leak fuel tank, clean fuel
1F03	Safety filter (HFO)	1T06	Day tank (MDF)
1F06	Suction filter	1T07	Leak fuel tank, dirty fuel
1F07	Suction strainer (MDF)	1T08	De-aeration tank
1F08	Automatic filter	1V01	Change-over valve
1I01	Flow meter	1V02	Pressure control valve (MDF)
1I02	Viscosity meter	1V03	Pressure control valve
1N01	Feeder/booster unit	1V05	Overflow valve (HFO/MDF)
1N03	Pump and filter unit (HFO/MDF)	1V07	Venting valve
1P04	Fuel feed pump	1V10	Quick closing valve
1P06	Circulation pump (booster unit)		

Pipe connections

101	Fuel inlet
102	Fuel outlet
103	Leak fuel drain, clean fuel
104	Leak fuel drain, dirty fuel

HFO pipes shall be properly insulated. If the viscosity of the fuel is 180 cSt/50°C or higher, the pipes must be equipped with trace heating. It shall be possible to shut off the heating of the pipes when operating on MDF (trace heating to be grouped logically).

Starting and stopping

The engine can be started and stopped on HFO provided that the engine and the fuel system are pre-heated to operating temperature. The fuel must be continuously circulated also through a stopped engine in order to maintain the operating temperature. Changeover to MDF for start and stop is not recommended.

Prior to overhaul or shutdown of the external system the engine fuel system shall be flushed and filled with MDF.

Changeover from HFO to MDF

The control sequence and the equipment for changing fuel during operation must ensure a smooth change in fuel temperature and viscosity. When MDF is fed through the HFO feeder/booster unit, the volume in the system is sufficient to ensure a reasonably smooth transfer.

When there are separate circulating pumps for MDF, then the fuel change should be performed with the HFO feeder/booster unit before switching over to the MDF circulating pumps. As mentioned earlier, sustained operation on MDF usually requires a fuel oil cooler. The viscosity at the engine shall not drop below the minimum limit stated in chapter *Technical data*.

Number of engines in the same system

When the fuel feed unit serves Wärtsilä 46F engines only, maximum two engines should be connected to the same fuel feed circuit, unless individual circulating pumps before each engine are installed.

Main engines and auxiliary engines should preferably have separate fuel feed units. Individual circulating pumps or other special arrangements are often required to have main engines and auxiliary engines in the same fuel feed circuit. Regardless of special arrangements it is not recommended to supply more than maximum two main engines and two auxiliary engines, or one main engine and three auxiliary engines from the same fuel feed unit.

In addition the following guidelines apply:

- Twin screw vessels with two engines should have a separate fuel feed circuit for each propeller shaft.
- Twin screw vessels with four engines should have the engines on the same shaft connected to different fuel feed circuits. One engine from each shaft can be connected to the same circuit.

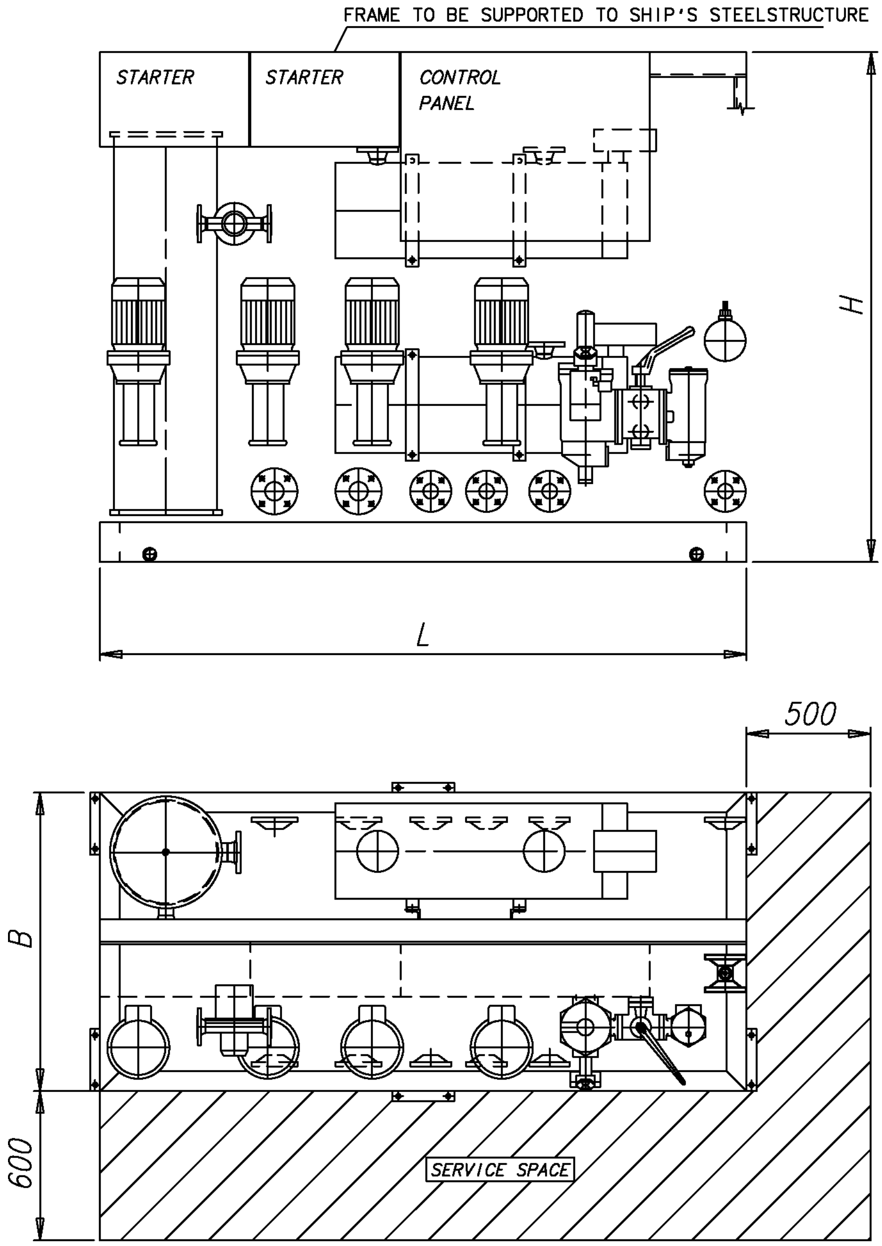
Feeder/booster unit (1N01)

A completely assembled feeder/booster unit can be supplied. This unit comprises the following equipment:

- Two suction strainers
- Two fuel feed pumps of screw type, equipped with built-on safety valves and electric motors
- One pressure control/overflow valve
- One pressurized de-aeration tank, equipped with a level switch operated vent valve
- Two circulating pumps, same type as the fuel feed pumps
- Two heaters, steam, electric or thermal oil (one heater in operation, the other as spare)
- One automatic back-flushing filter with by-pass filter
- One viscosimeter for control of the heaters
- One control valve for steam or thermal oil heaters, a control cabinet for electric heaters
- One thermostatic valve for emergency control of the heaters
- One control cabinet including starters for pumps
- One alarm panel

The above equipment is built on a steel frame, which can be welded or bolted to its foundation in the ship. The unit has all internal wiring and piping fully assembled. All HFO pipes are insulated and provided with trace heating.

Figure 6.9 Feeder/booster unit, example (DAAE006659)



	H	L	B
STEAM	1800	2500	1100
ELECTRICAL	2050	2600	1200

All dimensions in mm.

Fuel feed pump, booster unit (1P04)

The feed pump maintains the pressure in the fuel feed system. It is recommended to use a screw pump as feed pump. The capacity of the feed pump must be sufficient to prevent pressure drop during flushing of the automatic filter.

A suction strainer with a fineness of 0.5 mm should be installed before each pump. There must be a positive static pressure of about 30 kPa on the suction side of the pump.

Design data:

Capacity	Total consumption of the connected engines added with the flush quantity of the automatic filter (1F08)
Design pressure	1.6 MPa (16 bar)
Max. total pressure (safety valve)	0.7 MPa (7 bar)
Design temperature	100°C
Viscosity for dimensioning of electric motor	1000 cSt

Pressure control valve, booster unit (1V03)

The pressure control valve in the feeder/booster unit maintains the pressure in the de-aeration tank by directing the surplus flow to the suction side of the feed pump.

Design data:	
Capacity	Equal to feed pump
Design pressure	1.6 MPa (16 bar)
Design temperature	100°C
Set-point	0.3...0.5 MPa (3...5 bar)

Automatic filter, booster unit (1F08)

It is recommended to select an automatic filter with a manually cleaned filter in the bypass line. The automatic filter must be installed before the heater, between the feed pump and the de-aeration tank, and it should be equipped with a heating jacket. Overheating (temperature exceeding 100°C) is however to be prevented, and it must be possible to switch off the heating for operation on MDF.

Design data:	
Fuel viscosity	According to fuel specification
Design temperature	100°C
Preheating	If fuel viscosity is higher than 25 cSt/100°C
Design flow	Equal to feed pump capacity
Design pressure	1.6 MPa (16 bar)
Fineness, conventional fuel injection:	
- automatic filter	35 μm (absolute mesh size)
- bypass filter	35 μm (absolute mesh size)
Fineness, common rail fuel injection:	
- automatic filter	10 μm (absolute mesh size)
- bypass filter	25 μm (absolute mesh size)
Maximum permitted pressure drops at 14 cSt:	
- clean filter, 35 μm	20 kPa (0.2 bar)
- clean filter, 10 μm	30 kPa (0.3 bar)
- alarm	80 kPa (0.8 bar)

Flow meter, booster unit (1I01)

If a fuel consumption meter is required, it should be fitted between the feed pumps and the de-aeration tank. When it is desired to monitor the fuel consumption of individual engines in a multiple engine installation, two flow meters per engine are to be installed: one in the feed line and one in the return line of each engine.

There should be a by-pass line around the consumption meter, which opens automatically in case of excessive pressure drop.

If the consumption meter is provided with a prefilter, an alarm for high pressure difference across the filter is recommended.

De-aeration tank, booster unit (1T08)

It shall be equipped with a low level alarm switch and a vent valve. The vent pipe should, if possible, be led downwards, e.g. to the overflow tank. The tank must be insulated and equipped with a heating coil. The volume of the tank should be at least 100 l.

Circulation pump, booster unit (1P06)

The purpose of this pump is to circulate the fuel in the system and to maintain the required pressure at the injection pumps, which is stated in the chapter *Technical data*. By circulating the fuel in the system it also maintains correct viscosity, and keeps the piping and the injection pumps at operating temperature.

When more than two engines are connected to the same feeder/booster unit, individual circulation pumps (1P12) must be installed before each engine.

Design data, conventional fuel injection:

Capacity:	
- without circulation pumps (1P12)	4 x the total consumption of the connected engines
- with circulation pumps (1P12)	15% more than total capacity of all circulation pumps
Design pressure	1.6 MPa (16 bar)
Max. total pressure (safety valve)	1.2 MPa (12 bar)
Design temperature	150°C
Viscosity for dimensioning of electric motor	500 cSt

Design data, common rail fuel injection:

Capacity:	
- without circulation pumps (1P12)	3 x the total consumption of the connected engines
- with circulation pumps (1P12)	15% more than total capacity of all circulation pumps
Design pressure	1.6 MPa (16 bar)
Max. total pressure (safety valve)	1.2 MPa (12 bar)
Design temperature	150°C
Viscosity for dimensioning of electric motor	500 cSt

Heater, booster unit (1E02)

The heater must be able to maintain a fuel viscosity of 14 cSt at maximum fuel consumption, with fuel of the specified grade and a given day tank temperature (required viscosity at injection pumps stated in *Technical data*). When operating on high viscosity fuels, the fuel temperature at the engine inlet may not exceed 135°C however.

The power of the heater is to be controlled by a viscosimeter. The set-point of the viscosimeter shall be somewhat lower than the required viscosity at the injection pumps to compensate for heat losses in the pipes. A thermostat should be fitted as a backup to the viscosity control.

To avoid cracking of the fuel the surface temperature in the heater must not be too high. The heat transfer rate in relation to the surface area must not exceed 1.5 W/cm^2.

The required heater capacity can be estimated with the following formula:

$$P = \frac{Q \times \Delta T}{1700}$$

where:

P = heater capacity (kW)

Q = total fuel consumption at full output + 15% margin [l/h]

ΔT = temperature rise in heater [°C]

Viscosimeter, booster unit (1I02)

The heater is to be controlled by a viscosimeter. The viscosimeter should be of a design that can withstand the pressure peaks caused by the injection pumps of the diesel engine.

Design data:

Operating range	0...50 cSt
Design temperature	180°C
Design pressure	4 MPa (40 bar)

Pump and filter unit (1N03)

When more than two engine are connected to the same feeder/booster unit, a circulation pump (1P12) must be installed before each engine. The circulation pump (1P12) and the safety filter (1F03) can be combined in a pump and filter unit (1N03). A safety filter is always required.

There must be a by-pass line over the pump to permit circulation of fuel through the engine also in case the pump is stopped. The diameter of the pipe between the filter and the engine should be the same size as between the feeder/booster unit and the pump and filter unit.

Circulation pump (1P12)

The purpose of the circulation pump is to ensure equal circulation through all engines. With a common circulation pump for several engines, the fuel flow will be divided according to the pressure distribution in the system (which also tends to change over time) and the control valve on the engine has a very flat pressure versus flow curve.

In installations where MDF is fed directly from the MDF tank (1T06) to the circulation pump, a suction strainer (1F07) with a fineness of 0.5 mm shall be installed to protect the circulation pump. The suction strainer can be common for all circulation pumps.

A fuel feed line directly from the MDF day tank is not very attractive in installations with common rail engines, because a pump and filter unit would be required also in the feed line from the day tank due to the required filter fineness (10 µm).

Design data, conventional fuel injection:	
Capacity	4 x the consumption of the engine
Design pressure	1.6 MPa (16 bar)
Max. total pressure (safety valve)	1.2 MPa (12 bar)
Design temperature	150°C
Pressure for dimensioning of electric motor (Δp):	
- if MDF is fed directly from day tank	1.0 MPa (10 bar)
- if all fuel is fed through feeder/booster unit	0.3 MPa (3 bar)
Viscosity for dimensioning of electric motor	500 cSt

Design data, common rail fuel injection:	
Capacity	3 x the consumption of the engine
Design pressure	1.6 MPa (16 bar)
Max. total pressure (safety valve)	1.2 MPa (12 bar)
Design temperature	150°C
Pressure for dimensioning of electric motor (Δp):	
- fuel is fed through feeder/booster unit	0.3 MPa (3 bar)
Viscosity for dimensioning of electric motor	500 cSt

Safety filter (1F03)

The safety filter is a full flow duplex type filter with steel net. The filter should be equipped with a heating jacket. The safety filter or pump and filter unit shall be installed as close as possible to the engine.

Design data:	
Fuel viscosity	according to fuel specification
Design temperature	150°C
Design flow	Equal to circulation pump capacity
Design pressure	1.6 MPa (16 bar)
Fineness, conventional fuel injection	37 µm (absolute mesh size)
Fineness, common rail fuel injection	25 µm (absolute mesh size)
Maximum permitted pressure drops at 14 cSt:	

Design data:	
- clean filter	20 kPa (0.2 bar)
- alarm	80 kPa (0.8 bar)

Overflow valve, HFO (1V05)

When several engines are connected to the same feeder/booster unit an overflow valve is needed between the feed line and the return line. The overflow valve limits the maximum pressure in the feed line, when the fuel lines to a parallel engine are closed for maintenance purposes.

The overflow valve should be dimensioned to secure a stable pressure over the whole operating range.

Design data:	
Capacity	Equal to circulation pump (1P06)
Design pressure	1.6 MPa (16 bar)
Design temperature	150°C
Set-point (Δp)	0.2...0.7 MPa (2...7 bar)

6.3.6 Flushing

The external piping system must be thoroughly flushed before the engines are connected and fuel is circulated through the engines. The piping system must have provisions for installation of a temporary flushing filter.

The fuel pipes at the engine (connections 101 and 102) are disconnected and the supply and return lines are connected with a temporary pipe or hose on the installation side. All filter inserts are removed, except in the flushing filter of course. The automatic filter and the viscosimeter should be bypassed to prevent damage. The fineness of the flushing filter should be 35 μm or finer.

7. Lubricating oil system

7.1 Lubricating oil requirements

7.1.1 Engine lubricating oil

The lubricating oil must be of viscosity class SAE 40 and have a viscosity index (VI) of minimum 95. The lubricating oil alkalinity (BN) is tied to the fuel grade, as shown in the table below. BN is an abbreviation of Base Number. The value indicates milligrams KOH per gram of oil.

Table 7.1 Fuel standards and lubricating oil requirements

Category	Fuel standard		Lubricating oil BN
A	ASTM D 975-01, BS MA 100: 1996 CIMAC 2003 ISO8217: 1996(E)	GRADE NO. 1-D, 2-D DMX, DMA DX, DA ISO-F-DMX, DMA	10...30
B	BS MA 100: 1996 CIMAC 2003 ISO 8217: 1996(E)	DMB DB ISO-F-DMB	15...30
C	ASTM D 975-01, ASTM D 396-04, BS MA 100: 1996 CIMAC 2003 ISO 8217: 1996(E)	GRADE NO. 4-D GRADE NO. 5-6 DMC, RMA10-RMK55 DC, A30-K700 ISO-F-DMC, RMA10-RMK55	30...55

BN 50-55 lubricants are to be selected in the first place for operation on HFO. BN 40 lubricants can also be used with HFO provided that the sulphur content of the fuel is relatively low, and the BN remains above the condemning limit for acceptable oil change intervals. BN 30 lubricating oils should be used together with HFO only in special cases; for example in SCR (Selective Catalyctic Reduction) installations, if better total economy can be achieved despite shorter oil change intervals. Lower BN may have a positive influence on the lifetime of the SCR catalyst.

Crude oils with low sulphur content may permit the use of BN 30 lubricating oils. It is however not unusual that crude oils contain other acidic compounds, which requires a high BN oil although the sulphur content of the fuel is low.

It is not harmful to the engine to use a higher BN than recommended for the fuel grade.

Different oil brands may not be blended, unless it is approved by the oil suppliers. Blending of different oils must also be approved by Wärtsilä, if the engine still under warranty.

An updated list of approved lubricating oils is supplied for every installation.

7.1.2 Oil in speed governor or actuator

An oil of viscosity class SAE 30 or SAE 40 is acceptable in normal operating conditions. Usually the same oil as in the engine can be used. At low ambient temperatures it may be necessary to use a multigrade oil (e.g. SAE 5W-40) to ensure proper operation during start-up with cold oil.

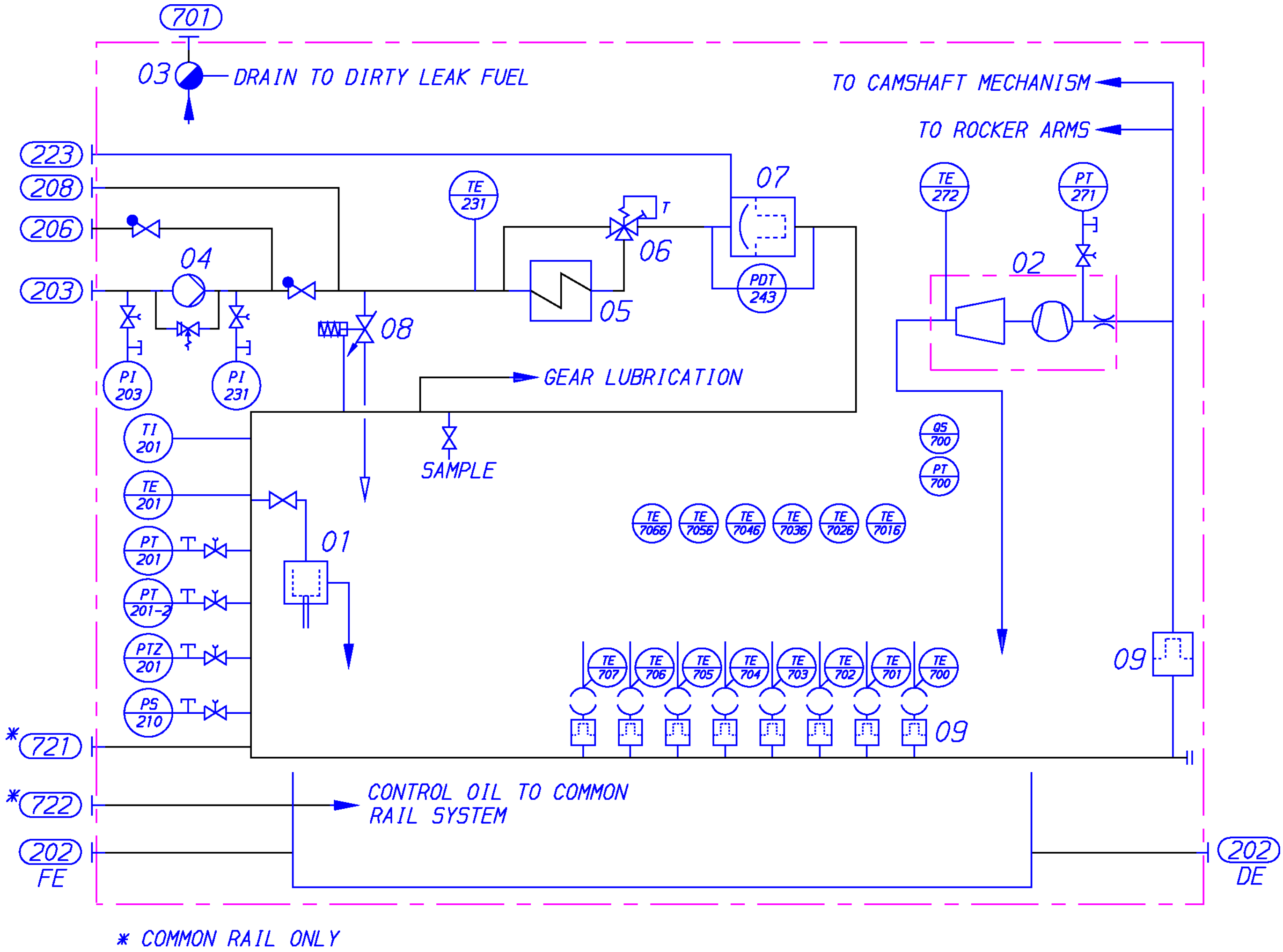
7.1.3 Oil in turning device

It is recommended to use EP-gear oils, viscosity 400-500 cSt at 40°C = ISO VG 460.

An updated list of approved oils is supplied for every installation.

7.2 Internal lubricating oil system

Figure 7.1 Internal lubricating oil system (DAAE017290a)



System components	
01	Centrifugal filter (for indicating)
02	Turbocharger
03	Crankcase breather
04	Main lubricating oil pump (eng. driven)
05	Lubricating oil cooler
06	Temperature control valve
07	Lubricating oil filter (automatic)
08	Pressure control valve
09	Running-in filter (to be removed after commissioning)

Sensors and indicators	
PT201	Lubricating oil pressure before bearings
PT201-2	Lubricating oil pressure before bearings (for local indication)
PT271	Lubricating oil pressure before turbocharger
PTZ201	Low lubricating oil pressure, back-up
PI203	Lubricating oil pressure before pump
PI231	Lubricating oil pressure after pump
PDT243	Pressure difference over lubricating oil filter
PS210	Pressure switch, if stand-by pump
PT700	Crankcase pressure
TI201	Lubricating oil temperature before bearings
TE201	Lubricating oil temperature before bearings
TE231	Lubricating oil temperature before cooler
TE272	Lubricating oil temperature after cooler
TE700	Main bearing temperature (700...70n)
TE7016	Big end bearing temperature (7016...70x6)
QS700	Oil mist in crankcase

n = Main bearing number
x = Cylinder number

Pipe connections		Size	Pressure class	Standard
202 FE	Lubricating oil outlet in free end	DN200	PN10	ISO 7005-1
202 DE	Lubricating oil outlet in driving end	DN200	PN10	ISO 7005-1
203	Lubricating oil to engine driven pump	DN250	PN10	ISO 7005-1
206	Lubricating oil from priming pump	DN80	PN16	ISO 7005-1
208	Lubricating oil from electrically driven pump	DN150	PN16	ISO 7005-1
223	Flushing oil from automatic filter	DN40	PN40	ISO 7005-1
701	Crankcase ventilation	DN125	PN16	ISO 7005-1
721	Control oil to external filter	DN32	PN40	ISO 7005-1
722	Control oil from external filter	DN40	PN25	ISO 7005-1

The oil sump is of dry sump type. There are two oil outlets at each end of the engine. One outlet at each end must be connected to the system oil tank on 6L engines. On other engines one outlet at the free end and both outlets at the driving end should be connected to the system oil tank.

The engine driven lubricating oil pump is of screw type and it is equipped with a pressure control valve. A stand-by pump connection is available as option. Concerning suction height, flow rate and pressure of the engine driven pump, *see Technical Data*. If the system oil tank is located very low, it can be necessary to install an electrically driven pump instead of the engine driven pump.

The built-on lubricating oil module consists of an oil cooler with temperature control valves and an automatic filter. The backflushing oil from the automatic filter has a separate connection. Engines can be delivered without built-on lubricating oil module on request.

The built-on centrifugal filter serves as an indication filter.

All engines are delivered with a running-in filter before each main bearing, before the turbocharger and before the intermediate gears. These filters are to be removed after max. 50 running hours.

7.3 External lubricating oil system

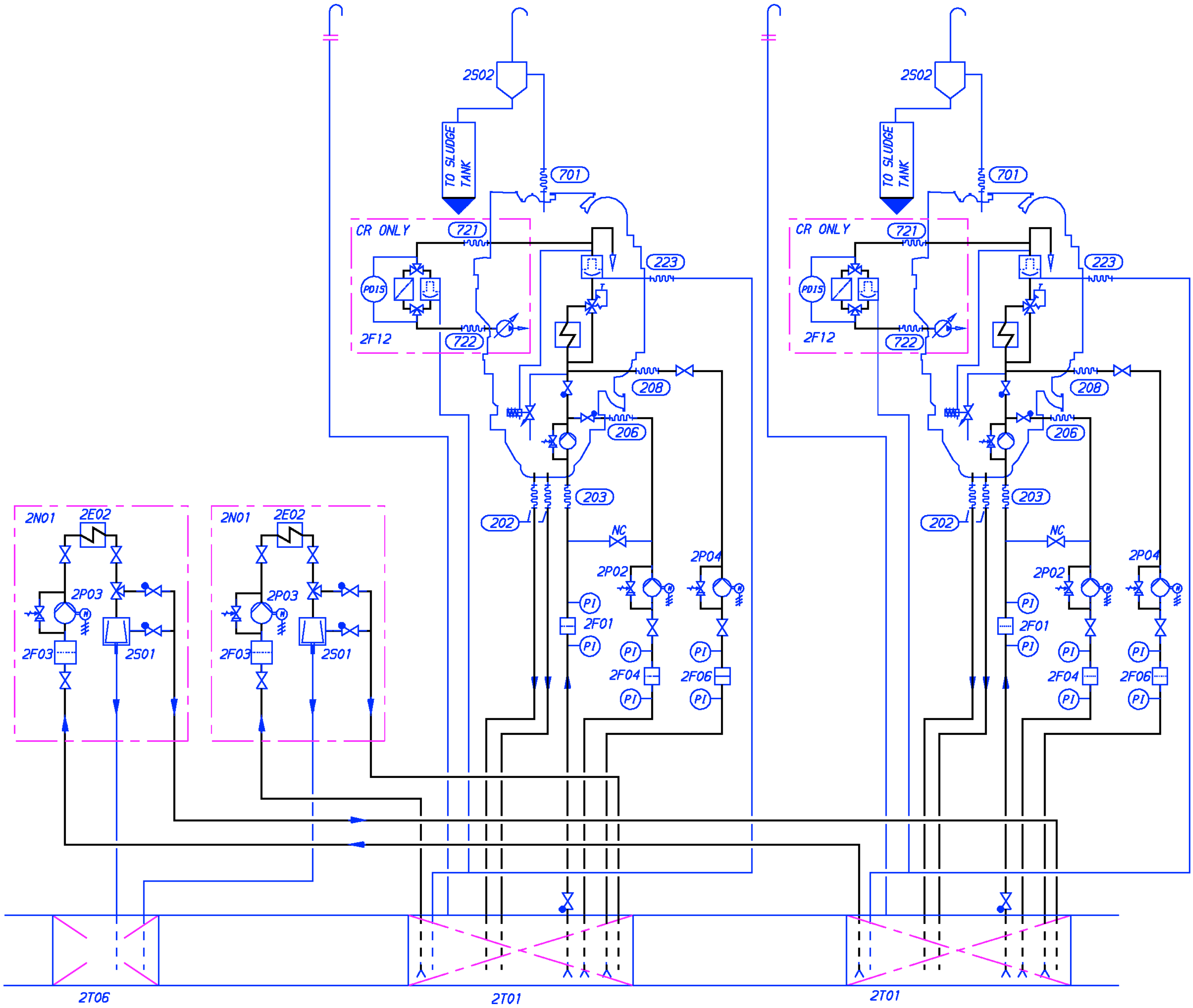


Figure 7.2 External lubricating oil system (DAAE022043b)

System components

2E02	Heater	2F12	Control oil automatic filter	2S01	Separator
2F01	Suction strainer	2N01	Separator unit	2S02	Condensate trap
2F03	Suction strainer	2P02	Pre-lubricating oil pump	2T01	System oil tank
2F04	Suction strainer	2P03	Separator pump	2T06	Sludge tank
2F06	Suction strainer	2P04	Stand-by pump		

Pipe connections

202	Lubricating oil outlet *)	701	Crankcase ventilation
203	Lubricating oil to engine driven pump	721	Control oil to external filter
206	Lubricating oil from pre-lubricating pump	722	Control oil from external filter
208	Lubricating oil from stand-by pump		
223	Flushing oil from automatic filter		

*) Two outlets in each end are available

7.3.1 Separation system

Separator unit (2N01)

Each engine must have a dedicated lubricating oil separator and the separators shall be dimensioned for continuous separating. If the installation is designed to operate on MDF only, then intermittent separating might be sufficient.

Separators are usually supplied as pre-assembled units.

Typically lubricating oil separator units are equipped with:

- Feed pump with suction strainer and safety valve
- Preheater
- Separator
- Control cabinet

The lubricating oil separator unit may also be equipped with an intermediate sludge tank and a sludge pump, which offers flexibility in placement of the separator since it is not necessary to have a sludge tank directly beneath the separator.

Separator feed pump (2P03)

The feed pump must be selected to match the recommended throughput of the separator. Normally the pump is supplied and matched to the separator by the separator manufacturer.

The lowest foreseen temperature in the system oil tank (after a long stop) must be taken into account when dimensioning the electric motor.

Separator preheater (2E02)

The preheater is to be dimensioned according to the feed pump capacity and the temperature in the system oil tank. When the engine is running, the temperature in the system oil tank located in the ship's bottom is normally 65...75°C. To enable separation with a stopped engine the heater capacity must be sufficient to maintain the required temperature without heat supply from the engine.

Recommended oil temperature after the heater is 95°C.

The surface temperature of the heater must not exceed 150°C in order to avoid cooking of the oil.

The heaters should be provided with safety valves and drain pipes to a leakage tank (so that possible leakage can be detected).

Separator (2S01)

The separators should preferably be of a type with controlled discharge of the bowl to minimize the lubricating oil losses.

The service throughput *Q* [*l/h*] of the separator can be estimated with the formula:

$$Q = \frac{1.35 \times P \times n}{t}$$

where:

Q = volume flow [l/h]

P = engine output [kW]

n = number of through-flows of tank volume per day: 5 for HFO, 4 for MDF

t = operating time [h/day]: 24 for continuous separator operation, 23 for normal dimensioning

Sludge tank (2T06)

The sludge tank should be located directly beneath the separators, or as close as possible below the separators, unless it is integrated in the separator unit. The sludge pipe must be continuously falling.

7.3.2 System oil tank (2T01)

Recommended oil tank volume is stated in chapter *Technical data.*

The system oil tank is usually located beneath the engine foundation. The tank may not protrude under the reduction gear or generator, and it must also be symmetrical in transverse direction under the engine. The location must further be such that the lubricating oil is not cooled down below normal operating temperature. Suction height is especially important with engine driven lubricating oil pump. Losses in strainers etc. add to the geometric suction height.

The pipe connection between the engine oil sump and the system oil tank must be flexible to prevent damages due to thermal expansion. The return pipes from the engine oil sump must end beneath the minimum oil level in the tank. Further on the return pipes must not be located in the same corner of the tank as the suction pipe of the pump.

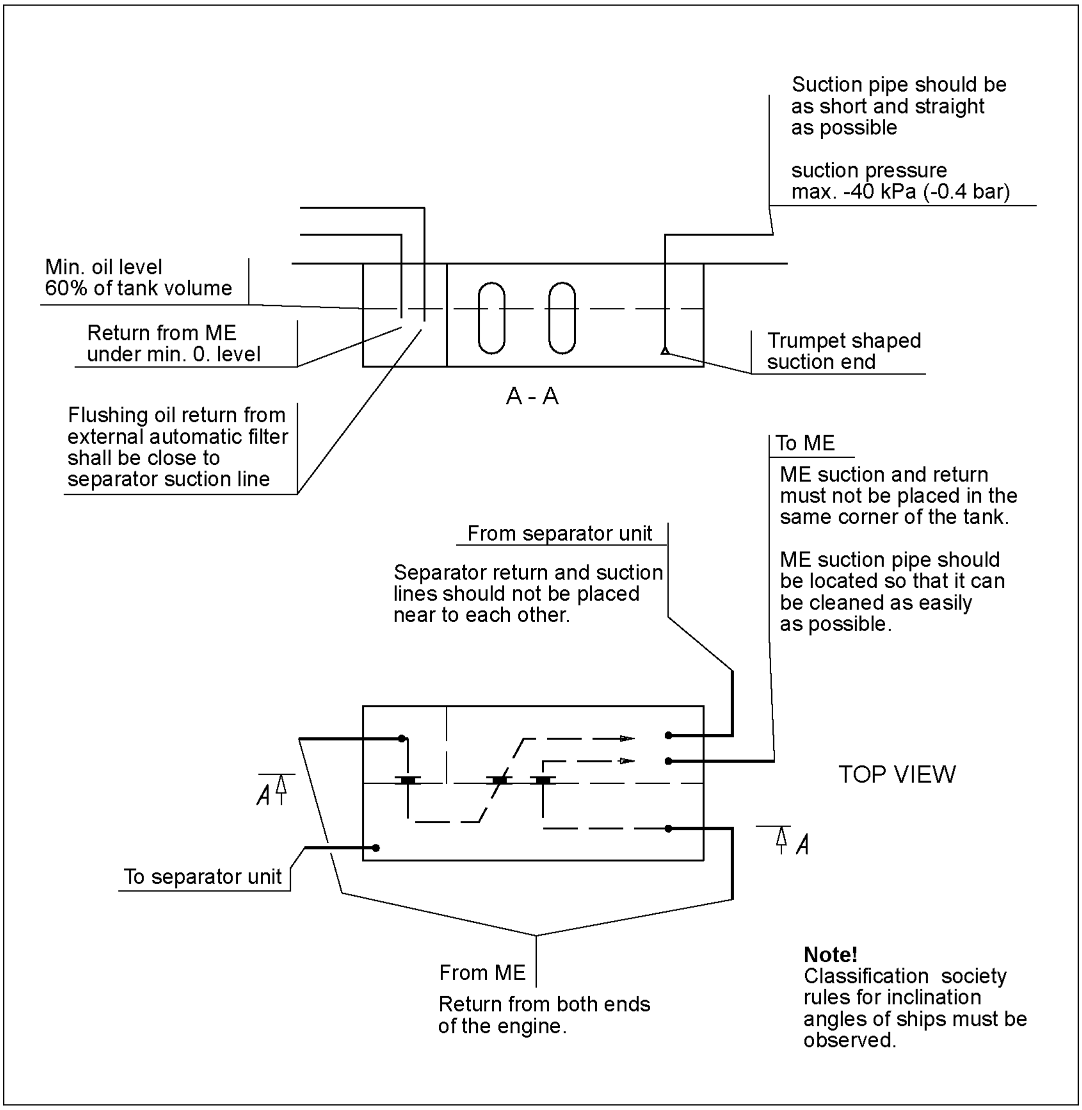
The suction pipe of the pump should have a trumpet shaped or conical inlet to minimise the pressure loss. For the same reason the suction pipe shall be as short and straight as possible and have a sufficient diameter. A pressure gauge shall be installed close to the inlet of the lubricating oil pump. The suction pipe shall further be equipped with a non-return valve of flap type without spring. The non-return valve is particularly important with engine driven pump and it must be installed in such a position that self-closing is ensured.

Suction and return pipes of the separator must not be located close to each other in the tank.

The ventilation pipe from the system oil tank may not be combined with crankcase ventilation pipes.

It must be possible to raise the oil temperature in the tank after a long stop. In cold conditions it can be necessary to have heating coils in the oil tank in order to ensure pumpability. The separator heater can normally be used to raise the oil temperature once the oil is pumpable. Further heat can be transferred to the oil from the preheated engine, provided that the oil viscosity and thus the power consumption of the pre-lubricating oil pump does not exceed the capacity of the electric motor.

Figure 7.3 Example of system oil tank arrangement (DAAE007020d)



Design data:	
Oil volume	1.2...1.5 l/kW, see also *Technical data*
Oil level at service	75 - 80 % of tank volume
Oil level alarm	60% of tank volume.

7.3.3 Gravity tank (2T02)

In installations without engine driven pump it is required to have a lubricating oil gravity tank, to ensure some lubrication during the time it takes for the engine to stop rotating in a blackout situation.

The required height of the tank is about 7 meters above the crankshaft. A minimum pressure of 50 kPa (0.5 bar) must be measured at the inlet to the engine.

Engine type	**Tank volume [m³]**
6L46F	1.0
7L46F, 8L46F, 9L46F	2.0

7.3.4 Suction strainers (2F01, 2F04, 2F06)

It is recommended to install a suction strainer before each pump to protect the pump from damage. The suction strainer and the suction pipe must be amply dimensioned to minimize pressure losses. The suction strainer should always be provided with alarm for high differential pressure.

Design data:	
Fineness	0.5...1.0 mm

7.3.5 Lubricating oil pump (2P01, 2P04)

A lubricating oil pump of screw type is recommended. The pump must be provided with a safety valve.

Some classification societies require that spare pumps are carried onboard even though the ship has multiple engines. Stand-by pumps can in such case be worth considering also for this type of application.

Design data:	
Capacity	see *Technical data*
Design pressure	1.0 MPa (10 bar)
Max. pressure (safety valve)	800 kPa (8 bar)
Design temperature	100°C
Viscosity for dimensioning the electric motor	500 cSt

Example of required power, oil temperature 40°C. The actual power requirement is determined by the type of pump and the flow resistance in the external system.

	6L46F	**7L46F**	**8L46F**	**9L46F**
Pump [kW]	45	50	50	60
Electric motor [kW]	55	55	55	75

7.3.6 Pre-lubricating oil pump (2P02)

The pre-lubricating oil pump is a separately installed scew or gear pump, which is to be equipped with a safety valve.

The installation of a pre-lubricating pump is mandatory. An electrically driven main pump or standby pump (with full pressure) may not be used instead of a dedicated pre-lubricating pump, as the maximum permitted pressure is 200 kPa (2 bar) to avoid leakage through the labyrinth seal in the turbocharger (not a problem when the engine is running). A two speed electric motor for a main or standby pump is not accepted.

The piping shall be arranged so that the pre-lubricating oil pump fills the main oil pump, when the main pump is engine driven.

The pre-lubricating pump should always be running, when the engine is stopped.

Depending on the foreseen oil temperature after a long stop, the suction ability of the pump and the geometric suction height must be specially considered with regards to high viscosity. With cold oil the pressure at the pump will reach the relief pressure of the safety valve.

Design data:	
Capacity	see *Technical data*
Design pressure	1.0 MPa (10 bar)
Max. pressure (safety valve)	350 kPa (3.5 bar)
Design temperature	100°C
Viscosity for dimensioning of the electric motor	500 cSt

Example of required power, oil temperature 40°C.

	6L46F	7L46F	8L46F	9L46F
Pump [kW]	5	6	6	8
Electric motor [kW]	7.5	7.5	7.5	11

Example of required power, oil temperature 20°C.

	6L46F	7L46F	8L46F	9L46F
Pump [kW]	11	14	14	17
Electric motor [kW]	15	15	15	18.5

7.3.7 Common rail engines

Engine lubricating oil is used as control oil. An external automatic filter with finer mesh size than the normal lubricating oil filter is required for the control oil. The control oil automatic filter (2F12) should be installed as close as possible to the engine.

A flushing filter with finer mesh size must be used for the control oil circuit, see *section Flushing instructions*.

Apart from the control oil automatic filter (2F12) and the control oil connection on the engine, the external lubricating oil system can be designed and dimensioned following the same principles as for engines with conventional fuel injection.

Control oil automatic filter (2F12)

It is recommended to select an automatic filter with a manually cleaned filter in the bypass line, to enable easy changeover during maintenance of the automatic filter. A bypass filter must be installed separately if it is not an integrated part of the automatic filter.

A filter type without pressure drop during the flushing operation must be selected.

Design data:	
Oil viscosity	50 cSt (SAE 40, VI 95, appox. 63°C)
Design flow	see *Technical data* 1)
Design temperature	100°C
Design pressure	1.0 MPa (10 bar)
Fineness:	
- automatic filter	10 µm (absolute mesh size)
- insert filter	25 µm (absolute mesh size)
Max permitted pressure drops at 50 cSt:	
- clean filter	30 kPa (0.3 bar)
- alarm	80 kPa (0.8 bar)

1) The maximum temporary flow can occur during a few seconds when the engine is started. The filter must be able to withstand the maximum momentary flow without risk of damage (pressure drop is not essential for the momentary flow).

7.4 Crankcase ventilation system

The purpose of the crankcase ventilation is to evacuate gases from the crankcase in order to keep the pressure in the crankcase within acceptable limits.

Each engine must have its own vent pipe into open air. The crankcase ventilation pipes may not be combined with other ventilation pipes, e.g. vent pipes from the system oil tank.

The diameter of the pipe shall be large enough to avoid excessive back pressure. Other possible equipment in the piping must also be designed and dimensioned to avoid excessive flow resistance.

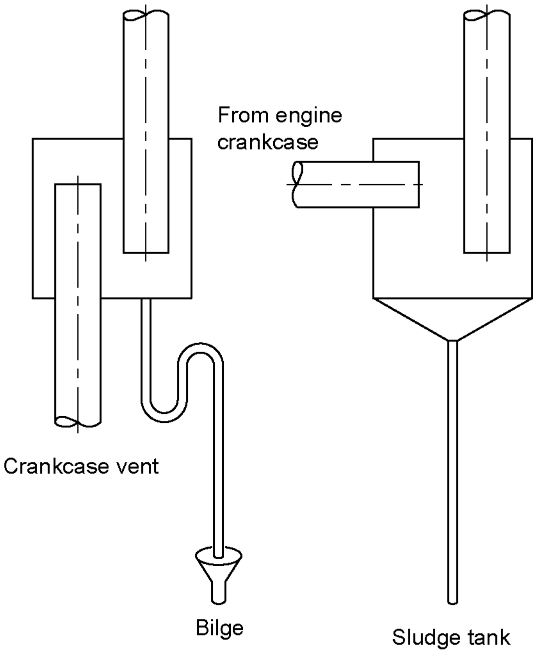
A condensate trap must be fitted on the vent pipe near the engine.

The connection between engine and pipe is to be flexible.

Design data:

Flow	see *Technical data*
Backpressure, max.	see *Technical data*
Temperature	80°C

Figure 7.4 Condensate trap (DAAE032780)



Minimum size of the ventilation pipe after the condensate trap is:

W L46F: DN100

The max. back-pressure must also be considered when selecting the ventilation pipe size.

7.5 Flushing instructions

The external piping system must be thoroughly flushed before it is connected to the engine. Provisions for installation of a temporary flushing filter are therefore required. The fineness of the flushing filter shall be 35 µm or finer.

If an electrically driven standby or main lubricating oil pump is installed, this pump can be used for the flushing. Otherwise it must be possible to install a temporary pump of approximately the same capacity as the engine driven pump. The oil inlet to the engine is disconnected and the oil is discharged through a crankcase door into the engine oil sump. All filter inserts are removed, except in the flushing filter.

Lubricating oil separators should be in operation prior to and during the flushing. The flushing is more effective if a dedicated flushing oil of low viscosity is used. The oil is to be heated so that the system reaches at least normal operating temperature. Engine lubricating oil can also be used, but it is not permitted to use the flushing oil later, not even after separation.

The minimum recommended flushing time is 24 hours. During this time the welds in the piping should be gently knocked at with a hammer to release slag. The flushing filter is to be inspected and cleaned at regular intervals. Flushing is continued until no particles are collected in the filter.

7.5.1 Common rail engines

The piping between the control oil automatic filter (2F12) and the control oil inlet on the engine (connection 722) must be flushed with very clean oil. An additional flushing filter is therefore required for the control oil circuit. This flushing filter shall be 10 µm or finer and it shall be installed next to the normal control oil automatic filter (2F12). Connection 722 is open during the flushing and the oil is discharged into the crankcase. See system diagram in section *External lubricating oil system*.

8. Compressed air system

Compressed air is used to start engines and to provide actuating energy for safety and control devices. The use of starting air for other purposes is limited by the classification regulations.

To ensure the functionality of the components in the compressed air system, the compressed air has to be free from solid particles and oil.

8.1 Instrument air quality

The quality of instrument air, from the ships instrument air system, for safety and control devices must fulfill the following requirements.

Instrument air specification:	
Design pressure	1 MPa (10 bar)
Nominal pressure	0.7 MPa (7 bar)
Dew point temperature	+3°C
Max. oil content	1 mg/m^3
Max. particle size	3 µm

8.2 Internal compressed air system

All engines are started by means of compressed air with a nominal pressure of 3 MPa (30 bar). The start is performed by direct injection of air into the cylinders through the starting air valves in the cylinder heads. The master starting valve is built on the engine and can be operated both manually and electrically.

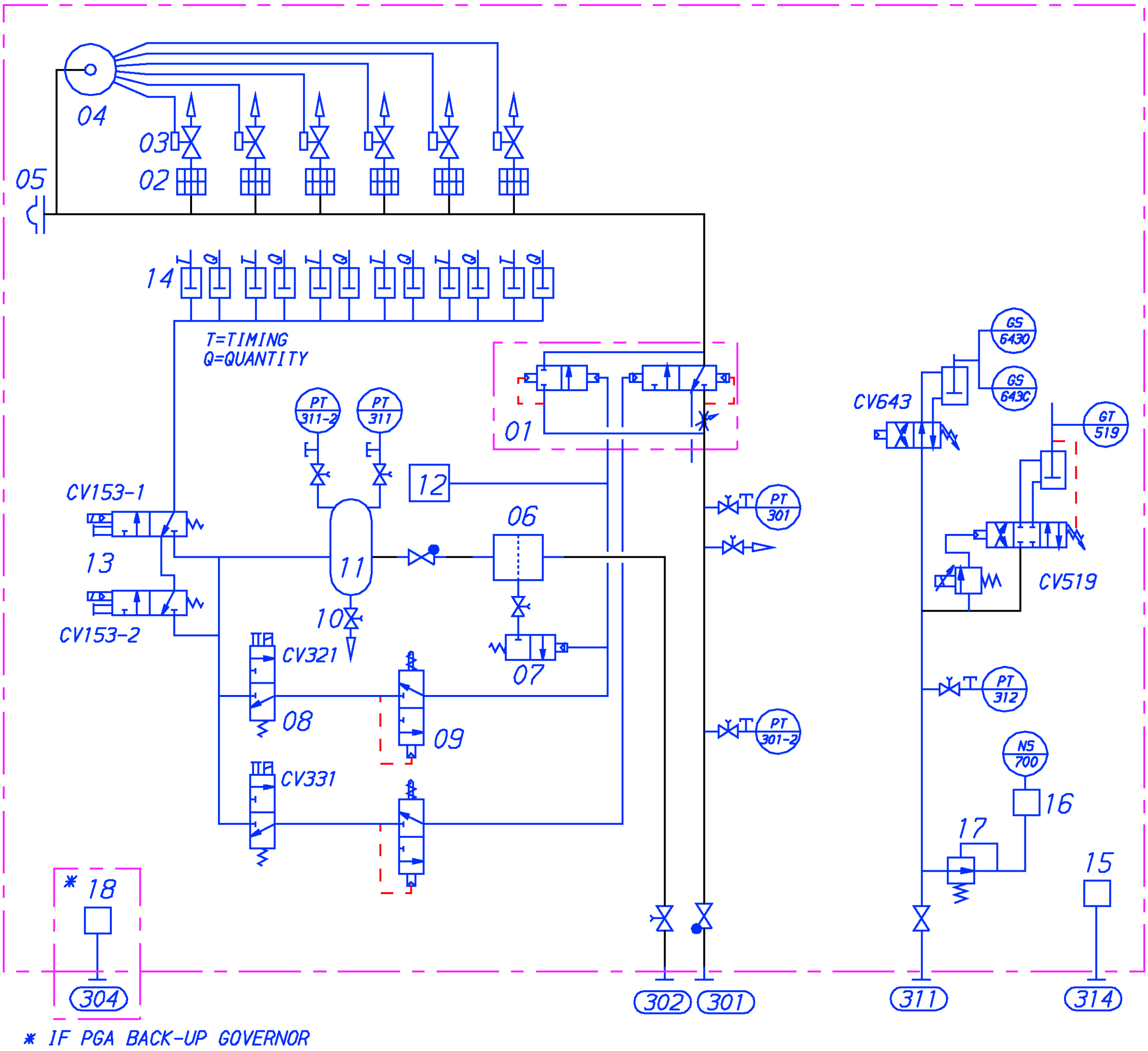
All engines have built-on non-return valves and flame arrestors. The engine can not be started when the turning gear is engaged.

The starting air system is equipped with a slow turning valve, which rotates the engine slowly without fuel injection for a few turns before start. Slow turning is not performed if the engine has been running max. 30 minutes earlier, or if slow turning is automatically performed every 30 minutes.

In addition to the starting system, the compressed air system is also used for a number of control functions. There are separate connections to the external system for these functions.

To ensure correct operation of the engine the compressed air supply, high-pressure or low-pressure, must not be closed during operation.

Figure 8.1 Internal compressed air system (DAAE017291a)



System components

01	Main starting valve	10	Drain valve
02	Flame arrestor	11	Air container
03	Starting air valve in cylinder head	12	Starting booster for governor (not Common Rail)
04	Starting air distributor	13	Stop valves (not Common Rail)
05	Rupturing disc (break pressure 4.0 MPa)	14	Stop cylinders at each injection pump (not Common Rail)
06	Air filter	15	Turbocharger cleaning valves
07	Valve for automatic draining	16	Oil mist detector
08	Valves for starting and slow turning	17	Pressure control valve
09	Blocking valve of turning gear	18	Speed governor (not Common Rail)

Sensors and indicators

PT301	Starting air pressure, engine inlet	CV321	Starting
PT301-2	Starting air pressure, engine inlet (for local indication)	CV331	Slow turning
PT311	Control air pressure	CV519	Exhaust wastegate valve control
PT311-2	Control air pressure (for local indication)	CV643	Charge air by-pass valve control

Sensors and indicators			
PT312	Instrument air pressure	GS643O	Charge air by-pass valve open
NS700	Oil mist detector failure	GS643C	Charge air by-pass valve closed
CV153-1	Stop/shutdown 1 (not Common Rail)	GT519	Exhaust wastegate valve position
CV153-2	Stop/shutdown 2 (not Common Rail)		

Pipe connections		Size	Pressure class	Standard
301	Starting air inlet, 3 MPa	DN50	PN40	ISO 7005-1
302	Control air inlet, 3 MPa	M26 x 1.5 male		
304	Control air to speed governor	OD6		
311	Control air to by-pass/waste-gate valve, 0.4 - 0.8 MPa	M26 x 1.5 male		
314	Air supply to compressor and turbine cleaning device, 0.4 - 0.8 MPa	G3/4 female		DIN ISO 228

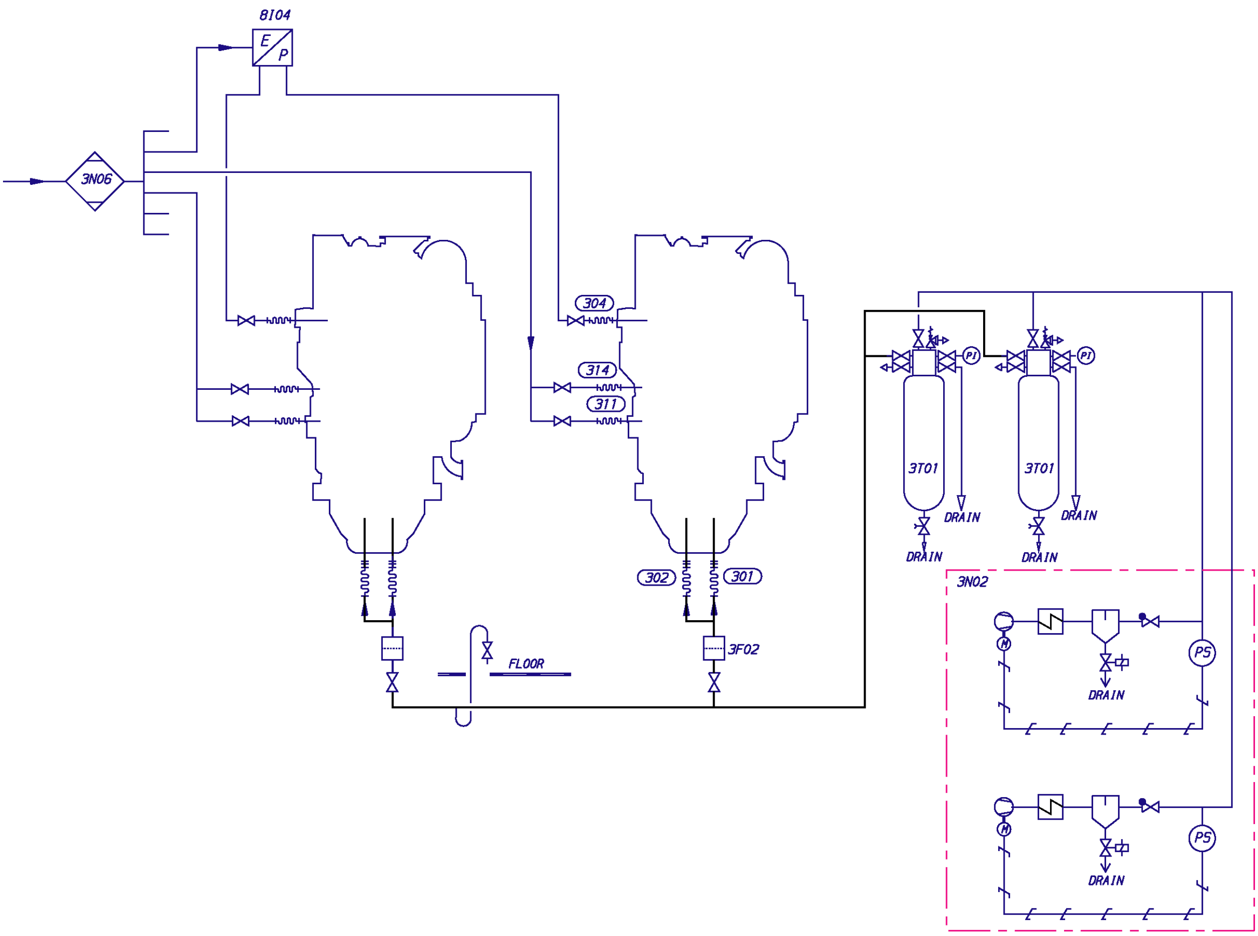
8.3 External compressed air system

The design of the starting air system is partly determined by classification regulations. Most classification societies require that the total capacity is divided into two equally sized starting air receivers and starting air compressors. The requirements concerning multiple engine installations can be subject to special consideration by the classification society.

The starting air pipes should always be slightly inclined and equipped with manual or automatic draining at the lowest points.

Instrument air to safety and control devices must be treated in an air dryer.

Figure 8.2 Example of external compressed air system (DAAE0220459)



System components

3F02	Air filter (starting air inlet)	3T01	Starting air vessel
3N02	Starting air compressor unit	8I04	E/P converter
3N06	Air dryer unit		

Pipe connections

301	Starting air inlet
302	Control air inlet
304	Control air to speed governor (if PGA back-up governor)
311	Control air to by-pass/waste-gate valve
314	Air supply to compressor and turbine cleaning device

The recommended size for the piping is based on pressure losses in a piping with a length of 40 m.

Table 8.1 Recommended main starting air pipe size

Engine	Size
6L, 7L	DN65
8L, 9L	DN80

8.3.1 Starting air compressor unit (3N02)

At least two starting air compressors must be installed. It is recommended that the compressors are capable of filling the starting air vessel from minimum (1.8 MPa) to maximum pressure in 15...30 minutes. For exact determination of the minimum capacity, the rules of the classification societies must be followed.

8.3.2 Oil and water separator (3S01)

An oil and water separator should always be installed in the pipe between the compressor and the air vessel. Depending on the operation conditions of the installation, an oil and water separator may be needed in the pipe between the air vessel and the engine.

8.3.3 Starting air vessel (3T01)

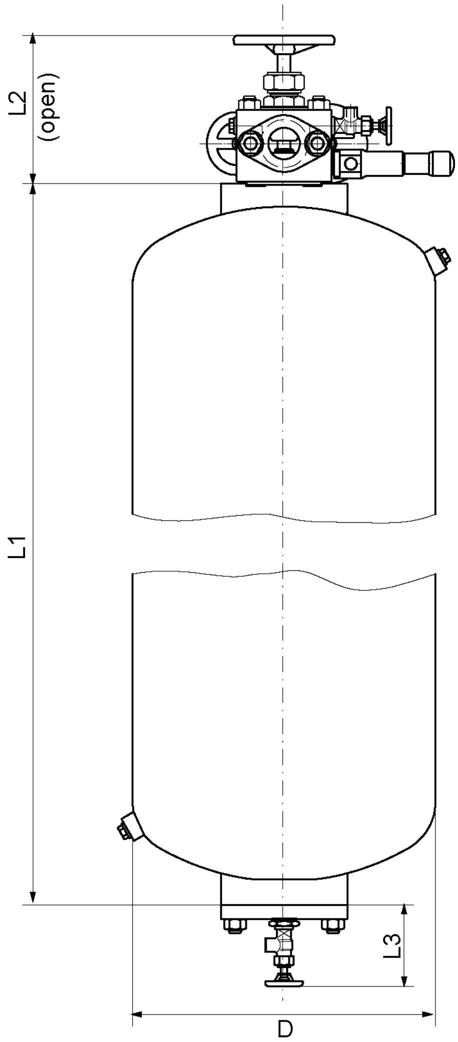
The starting air vessels should be dimensioned for a nominal pressure of 3 MPa.

The number and the capacity of the air vessels for propulsion engines depend on the requirements of the classification societies and the type of installation.

It is recommended to use a minimum air pressure of 1.8 MPa, when calculating the required volume of the vessels.

The starting air vessels are to be equipped with at least a manual valve for condensate drain. If the air vessels are mounted horizontally, there must be an inclination of 3...5° towards the drain valve to ensure efficient draining.

Figure 8.3 Starting air vessel



Size [Litres]	Dimensions [mm]				Weight [kg]
	L1	L2 1)	L3 1)	D	
500	3204	243	133	480	450
1000	3560	255	133	650	810
1250	2930	255	133	800	980
1500	3460	255	133	800	1150
1750	4000	255	133	800	1310
2000	4610	255	133	800	1490

1) Dimensions are approximate.

The starting air consumption stated in technical data is for a successful start. During a remote start the main starting valve is kept open until the engine starts, or until the max. time for the starting attempt has elapsed. A failed remote start can consume two times the air volume stated in technical data. If the ship has a class notation for unattended machinery spaces, then the starts are to be demonstrated as remote starts, usually so that only the last starting attempt is successful.

The required total starting air vessel volume can be calculated using the formula:

$$V_R = \frac{p_E \times V_E \times n}{p_{R\max} - p_{R\min}}$$

where:

V_R = total starting air vessel volume [m^3]

p_E = normal barometric pressure (NTP condition) = 0.1 MPa

V_E = air consumption per start [Nm^3] See *Technical data*

n = required number of starts according to the classification society

p_{Rmax} = maximum starting air pressure = 3 MPa

p_{Rmin} = minimum starting air pressure = 1.8 MPa

NOTE! The total vessel volume shall be divided into at least two equally sized starting air vessels.

8.3.4 Starting air filter (3F02)

Significant condense formation can occur after the water separator, especially in tropical conditions. Depending on the materials used, this can result in abrasive rust particles from the piping, fittings and vessels. It is therefore recommended to install a filter strainer in the external starting air system just before the engine.

The recommended mesh opening size is 400 μm. The open flow area of the straining element shall be at least 250% of the cross sectional area of the pipe, when it is related to the recommended pipe diameter.

9. Cooling water system

9.1 Water quality

Only treated fresh water containing approved corrosion inhibitors may be circulated through the engines. It is important that water of acceptable quality and approved corrosion inhibitors are used directly when the system is filled after completed installation.

The fresh water in the cooling water system of the engine must fulfil the following requirements:

pH	min. 6.5
Hardness	max. 10 °dH
Chlorides	max. 80 mg/l
Sulphates	max. 150 mg/l

Good quality tap water can be used, but shore water is not always suitable. It is recommended to use water produced by an onboard evaporator. Fresh water produced by reverse osmosis plants often has higher chloride content than permitted. Rain water is unsuitable as cooling water due to the high content of oxygen and carbon dioxide.

9.1.1 Corrosion inhibitors

The use of an approved cooling water additive is mandatory. An updated list of approved products is supplied for every installation and it can also be found in the Instruction manual of the engine, together with dosage and further instructions.

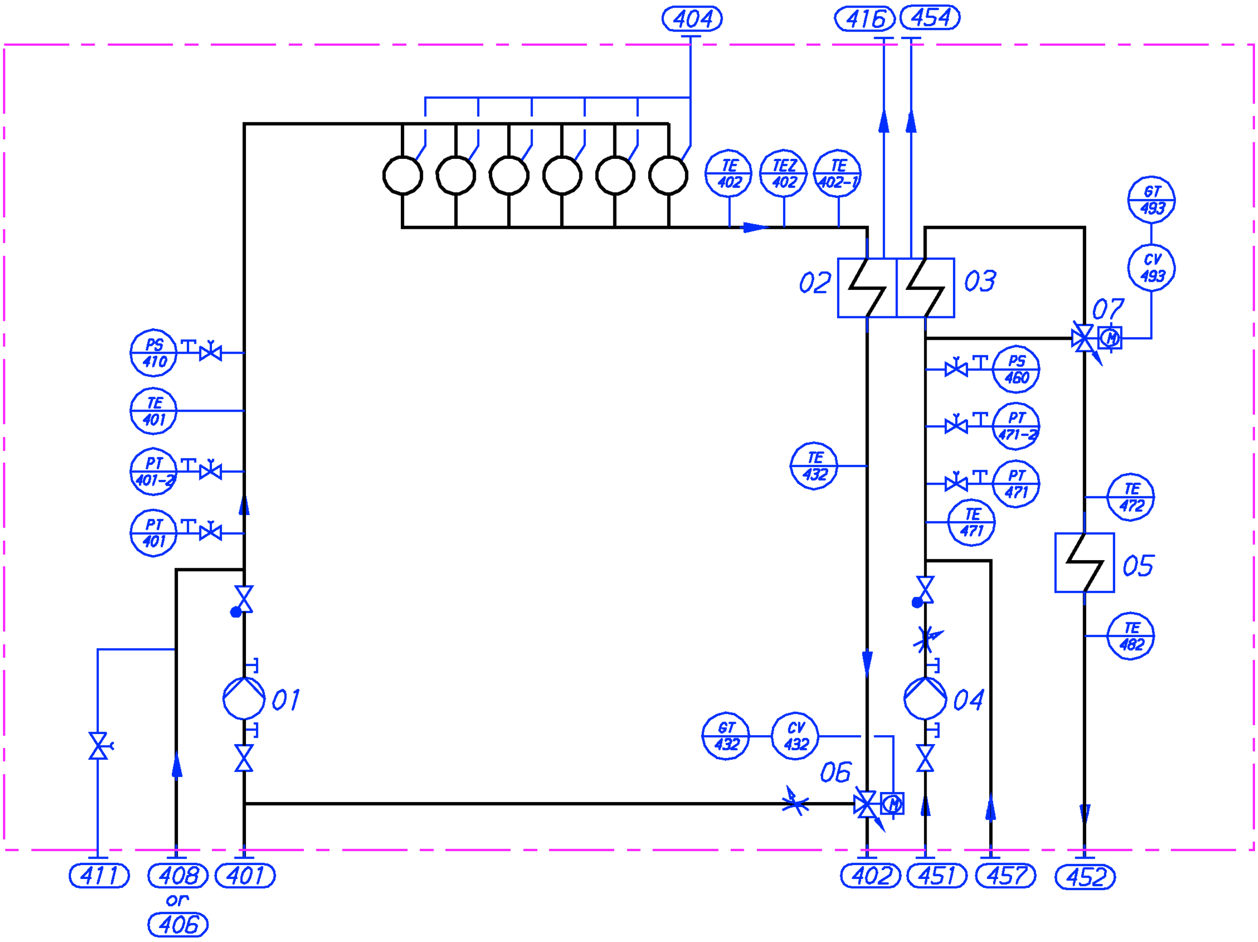
9.1.2 Glycol

Use of glycol in the cooling water is not recommended unless it is absolutely necessary. Starting from 20% glycol the engine is to be de-rated 0.23 % per 1% glycol in the water. Max. 50% glycol is permitted.

Corrosion inhibitors shall be used regardless of glycol in the cooling water.

9.2 Internal cooling water system

Figure 9.1 Internal cooling water system (DAAE017292a)



System components

01	HT-water pump (engine driven)
02	Charge air cooler (HT)
03	Charge air cooler (LT)
04	LT-water pump (engine driven)
05	Lubricating oil cooler
06	HT-temperature control valve
07	CAC temperature control valve

Abbreviations:

HT =	High temperature
LT =	Low temperature
CAC =	Charge air cooler
LOC =	Lubricating oil cooler

Sensors and indicators

PT401	HT-water pressure before cylinder jackets
PT401-2	HT-water pressure before cylinder jackets (for local indication)
PT471	LT-water pressure before CAC
PT471-2	LT-water pressure before CAC (for local indication)
PS410	Pressure switch, if stand-by HT pump
PS460	Pressure switch, if stand-by LT pump
TE401	HT-water temperature before cylinder jackets
TE402	HT-water temperature after cylinder jackets
TE402-1	HT-water temperature after cylinder jackets (for temp. control)
TE432	HT-water temperature after CAC
TE471	LT-water temperature before CAC
TE472	LT-water temperature before LOC
TE482	LT-water temperature after LOC
TEZ402	HT-water temperature after cylinder jackets
CV432	HT-water temperature control
CV493	CAC temperature control
GT432	HT-water temperature control valve position
GT493	CAC temperature control valve position

Pipe connections		Size	Pressure class	Standard
401	HT-water inlet	DN150	PN16	ISO 7005-1
402	HT-water outlet	DN150	PN16	ISO 7005-1
404	HT-water air vent	OD12		
406	Water from preheater to HT-circuit	DN40	PN40	ISO 7005-1
408	HT-water from stand-by pump	DN150	PN16	ISO 7005-1
411	HT-water drain	M26 x 1.5 male		
416	HT-water air vent from air cooler	OD12		
451	LT-water inlet	DN150	PN16	ISO 7005-1
452	LT-water outlet	DN150	PN16	ISO 7005-1
454	LT-water air vent from air cooler	OD12		
457	LT-water from stand-by pump	DN150	PN16	ISO 7005-1

The fresh water cooling system is divided into a high temperature (HT) and a low temperature (LT) circuit. The HT water circulates through cylinder jackets, cylinder heads and the 1st stage of the charge air cooler. The HT water passes through the cylinder jackets before it enters the HT-stage of the charge air cooler. The LT water cools the 2nd stage of the charge air cooler and the lubricating oil. A two-stage charge air cooler enables more efficient heat recovery and heating of cold combustion air.

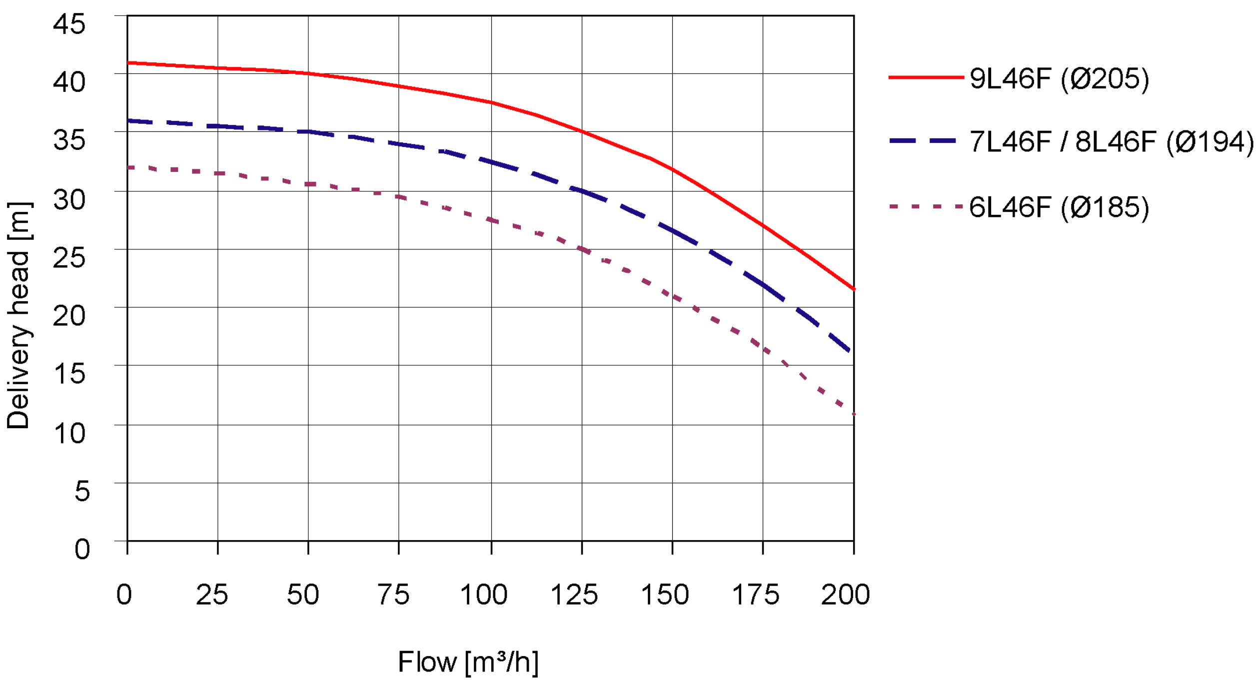
The cooling water temperature after the cylinder heads is controlled in the HT circuit, while the charge air temperature is maintained on a constant level with the arrangement of the LT circuit. The LT water partially bypasses the charge air cooler depending on the operating condition to maintain a constant air temperature after the cooler.

9.2.1 Engine driven circulating pumps

The LT and HT cooling water pumps are usually engine driven. In some installations it can however be desirable to have separate LT pumps, and therefore engines are also available without built-on LT pump. Engine driven pumps are located at the free end of the engine. Connections for stand-by pumps are available with engine driven pumps (option).

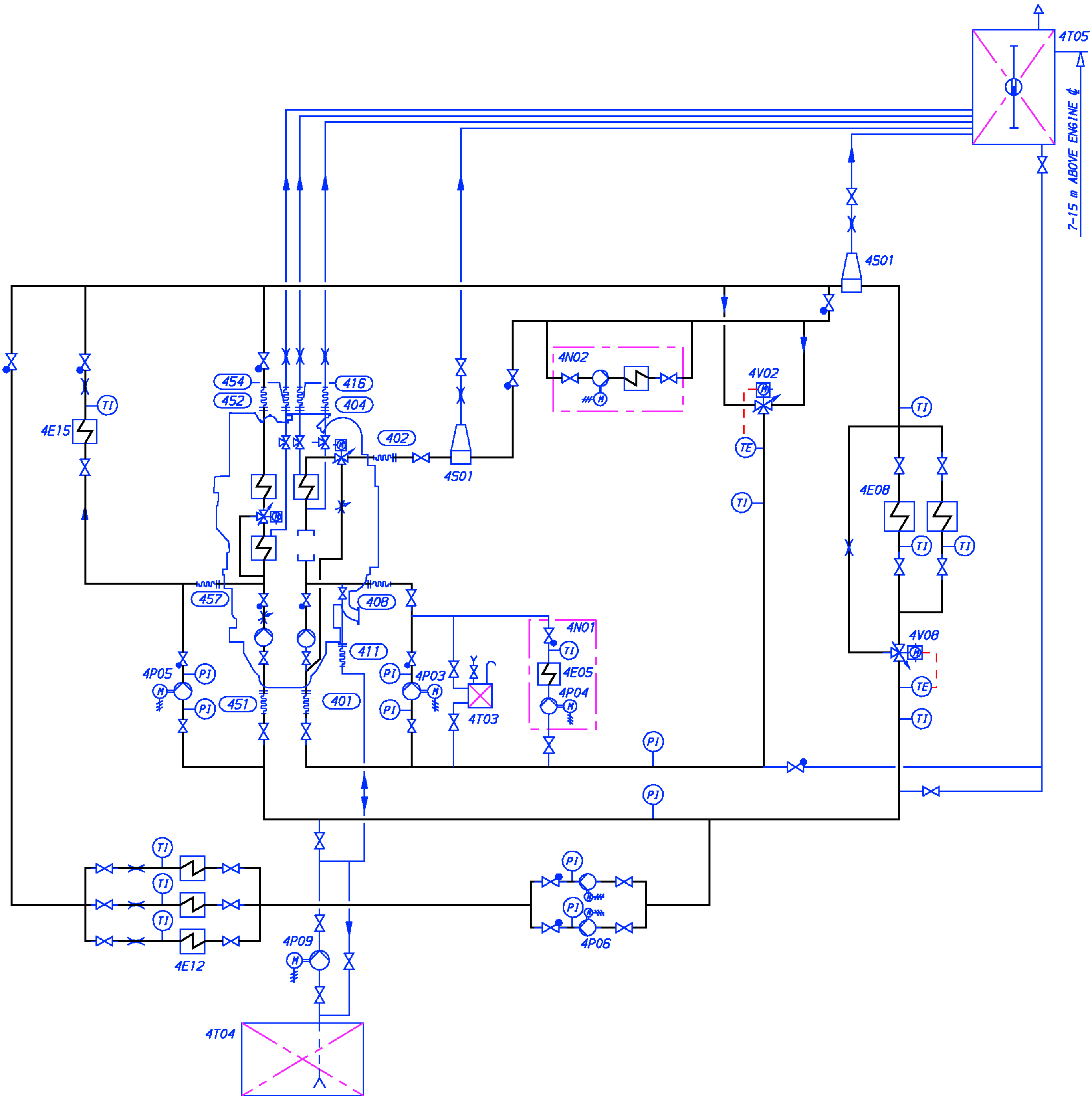
Pump curves for engine driven pumps are shown in the diagram. The nominal pressure and capacity can be found in the chapter *Technical data*.

Figure 9.2 Engine driven HT and LT pumps at 600 rpm.



9.3 External cooling water system

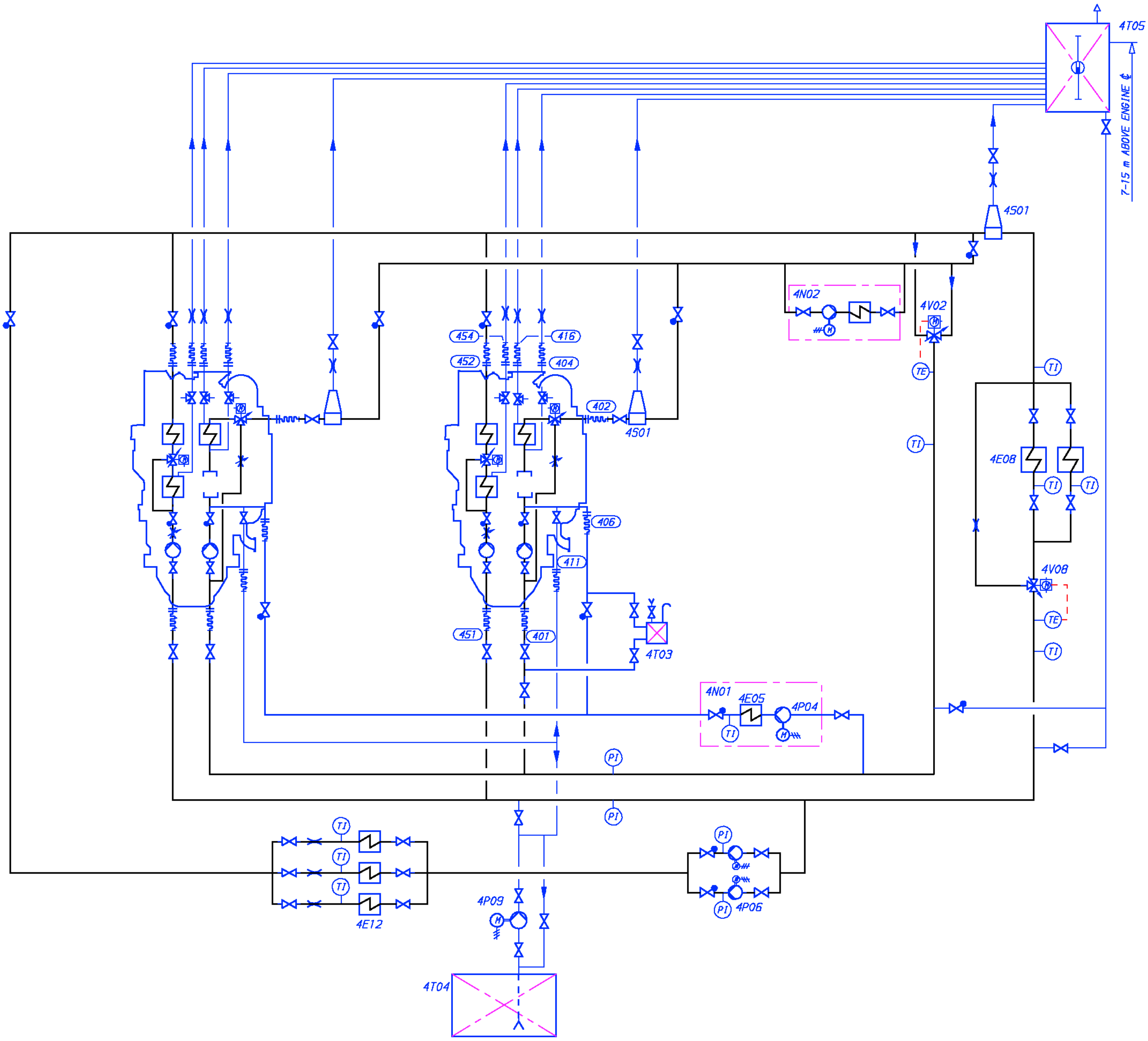
Figure 9.3 External cooling water system 1 x Wärtsilä L46F (DAAE022048a)



System components				Pipe connections	
4E05	Heater (pre-heating unit)	4P06	Circulation pump	401	HT-water inlet
4E08	Central cooler	4S01	Air venting	402	HT-water outlet
4E12	Cooler (installation equipment)	4T03	Additive dosing tank	404	HT-water air vent
4E15	Cooler (generator)	4T04	Drain tank	408	HT-water from stand-by pump
4N01	Pre-heating unit	4T05	Expansion tank	411	HT-water drain
4N02	Evaporator unit	4V02	Temperature control valve (heat recovery)	416	HT-water air vent from air cooler
4P03	Stand-by pump (HT)	4V08	Temperature control valve (central cooler)	451	LT-water inlet

System components		Pipe connections	
4P04	Circulation pump (pre-heating unit)	452	LT-water outlet
4P05	Stand-by pump (LT)	454	LT-water air vent from air cooler
4P09	Transfer pump	457	LT-water from stand-by pump

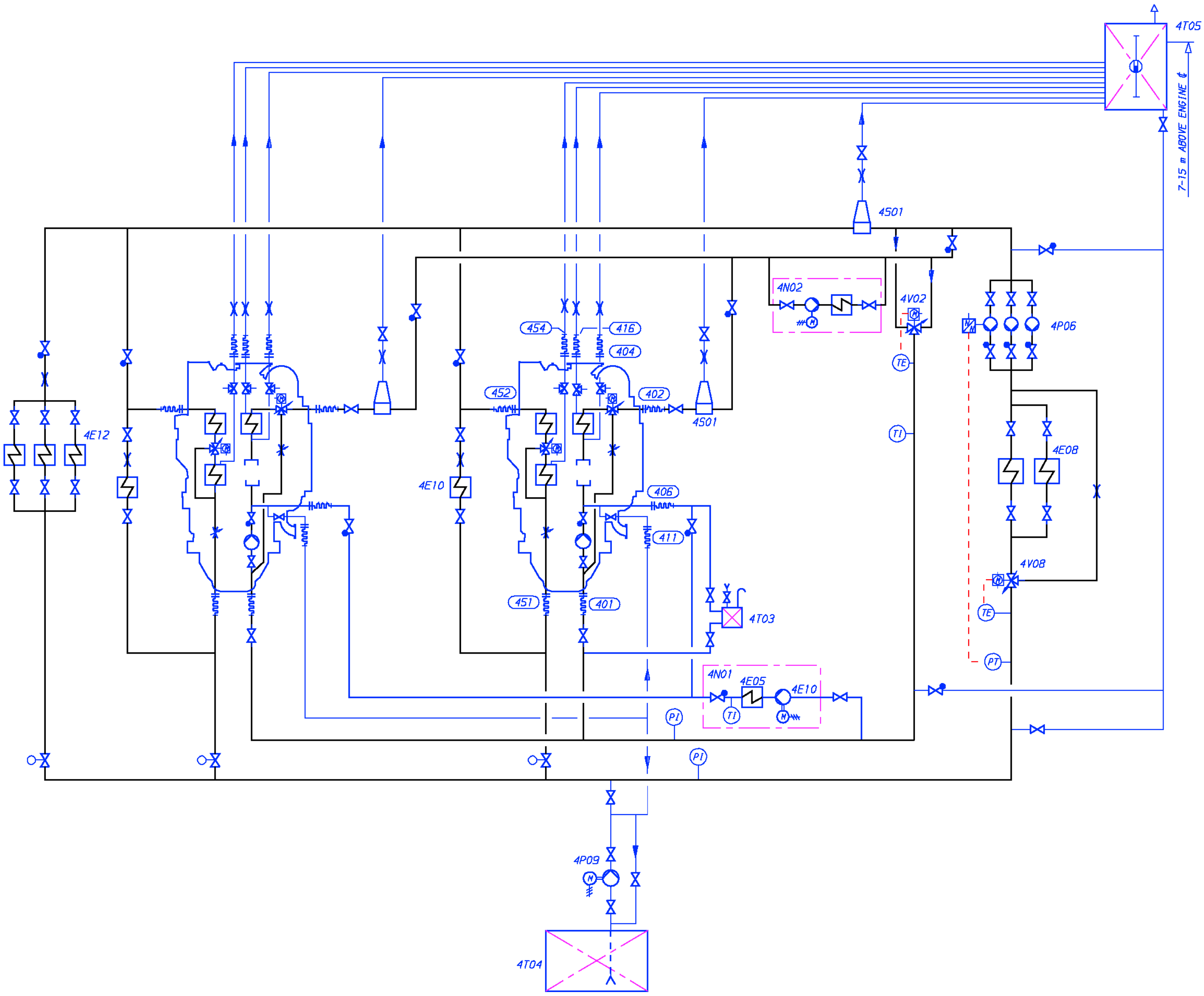
Figure 9.4 External cooling water system 2 x Wärtsilä L46F (DAAE022046a)



System components				Pipe connections	
4E05	Heater (pre-heating unit)	4T03	Additive dosing tank	401	HT-water inlet
4E08	Central cooler	4T04	Drain tank	402	HT-water outlet
4E12	Cooler (installation equipment)	4T05	Expansion tank	404	HT-water air vent
4N01	Pre-heating unit	4V02	Temperature control valve (heat recovery)	406	HT-water from preheater to HT-circuit
4N02	Evaporator unit	4V08	Temperature control valve (central cooler)	411	HT-water drain
4P04	Circulation pump (pre-heating unit)			416	HT-water air vent from air cooler

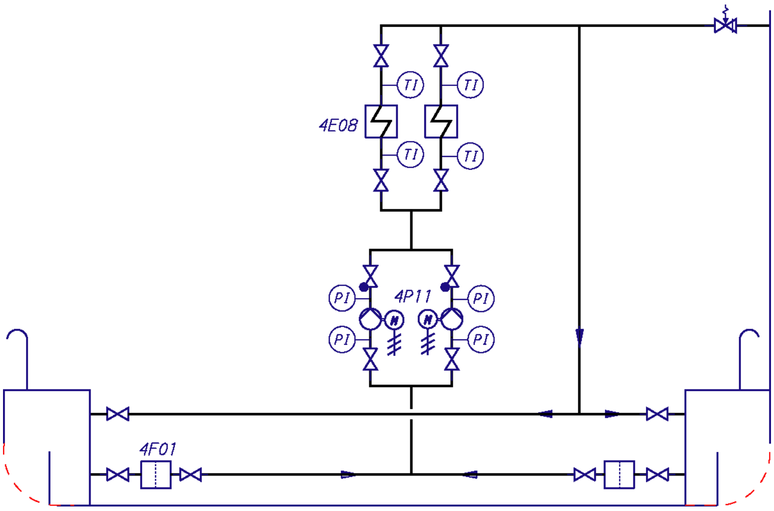
System components		Pipe connections	
4P06	Circulation pump	451	LT-water inlet
4P09	Transfer pump	452	LT-water outlet
4S01	Air venting	454	LT-water air vent from air cooler

Figure 9.5 External cooling water system 2 x Wärtsilä L46F (DAAE022047a)



System components				Pipe connections	
4E05	Heater (pre-heating unit)	4T03	Additive dosing tank	401	HT-water inlet
4E08	Central cooler	4T04	Drain tank	402	HT-water outlet
4E10	Cooler (reduction gear)	4T05	Expansion tank	404	HT-water air vent
4E12	Cooler (installation equipment)	4V02	Temperature control valve (heat recovery)	406	HT-water from preheater to HT-circuit
4N01	Pre-heating unit	4V08	Temperature control valve (central cooler)	411	HT-water drain
4N02	Evaporator unit				
4P04	Circulation pump (pre-heating unit)			416	HT-water air vent from air cooler
4P06	Circulation pump			451	LT-water inlet
4P09	Transfer pump			452	LT-water outlet
4S01	Air venting			454	LT-water air vent from air cooler

Figure 9.6 Sea water system DAAE0202523



System components

4E08	Central cooler
4F01	Suction strainer (sea water)
4P11	Circulation pump (sea water)

It is recommended to divide the engines into several circuits in multi-engine installations. One reason is of course redundancy, but it is also easier to tune the individual flows in a smaller system. Malfunction due to entrained gases, or loss of cooling water in case of large leaks can also be limited. In some installations it can be desirable to separate the HT circuit from the LT circuit with a heat exchanger.

The external system shall be designed so that flows, pressures and temperatures are close to the nominal values in *Technical data* and the cooling water is properly de-aerated.

Pipes with galvanized inner surfaces are not allowed in the fresh water cooling system. Some cooling water additives react with zinc, forming harmful sludge. Zinc also becomes nobler than iron at elevated temperatures, which causes severe corrosion of engine components.

Ships (with ice class) designed for cold sea-water should have provisions for recirculation back to the sea chest from the central cooler:

- For melting of ice and slush, to avoid clogging of the sea water strainer
- To enhance the temperature control of the LT water, by increasing the seawater temperature

9.3.1 Electrically driven HT and LT circulation pumps (4P03, 4P05, 4P14, 4P15)

Electrically driven pumps should be of centrifugal type. Required capacities and delivery pressures for stand-by pumps are stated in *Technical data*.

In installations without engine driven LT pumps, several engines can share a common LT circulating pump, also together with other equipment such as reduction gear, generator and compressors. When such an arrangement is preferred and the number of engines in operation varies, significant energy savings can be achieved with frequency control of the LT pumps.

Note
Some classification societies require that spare pumps are carried onboard even though the ship has multiple engines. Stand-by pumps can in such case be worth considering also for this type of application.

9.3.2 Sea water pump (4P11)

The sea water pumps are always separate from the engine and electrically driven.

The capacity of the pumps is determined by the type of coolers and the amount of heat to be dissipated.

Significant energy savings can be achieved in most installations with frequency control of the sea water pumps. Minimum flow velocity (fouling) and maximum sea water temperature (salt deposits) are however issues to consider.

9.3.3 Temperature control valve for central cooler (4V08)

The temperature control valve is installed after the central cooler and it controls the temperature of the LT water before the engine, by partly bypassing the cooler. The control valve can be either self-actuated or electrically actuated. Normally there is one temperature control valve per circuit.

The set-point of the control valve is 35 °C, or lower if required by other equipment connected to the same circuit.

9.3.4 Temperature control valve for heat recovery (4V02)

The temperature control valve after the heat recovery controls the maximum temperature of the water that is mixed with HT water from the engine outlet before the HT pump. The control valve can be either self-actuated or electrically actuated.

The set-point is usually somewhere close to 75 °C.

The arrangement shown in the example system diagrams also results in a smaller flow through the central cooler, compared to a system where the HT and LT circuits are connected in parallel to the cooler.

9.3.5 Coolers for other equipment and MDF coolers

The engine driven LT circulating pump can supply cooling water to one or two small coolers installed in parallel to the engine charge air and lubricating oil cooler, for example a MDF cooler or a generator cooler. Separate circulating pumps are required for larger flows.

Design guidelines for the MDF cooler are given in chapter *Fuel system*.

9.3.6 Fresh water central cooler (4E08)

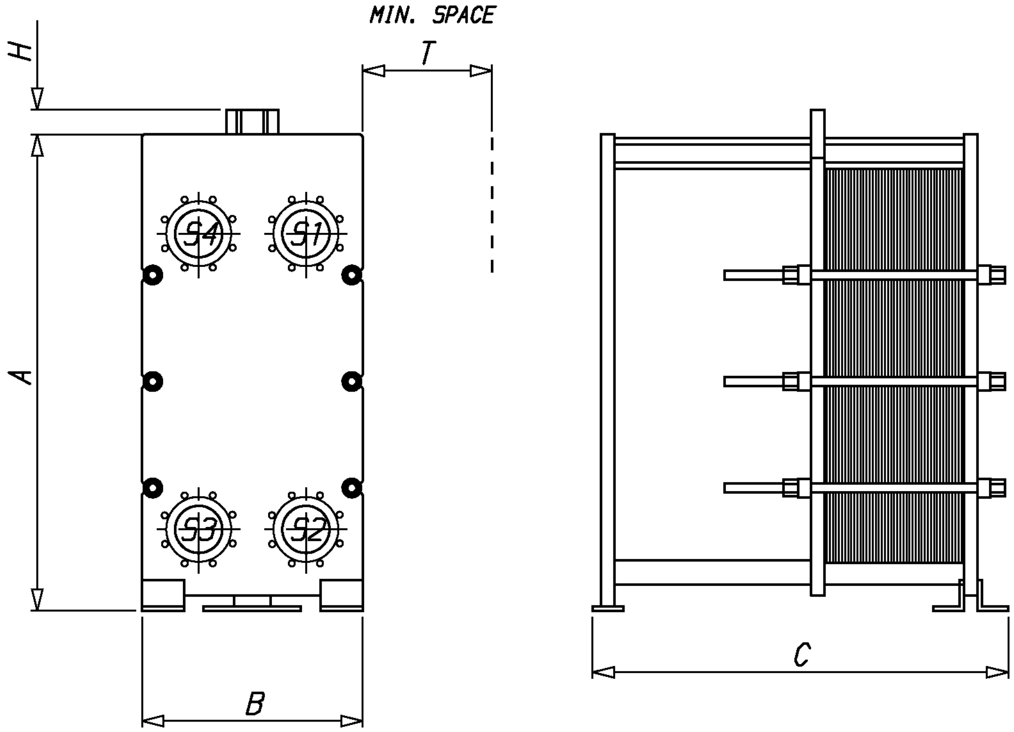
Plate type coolers are most common, but tube coolers can also be used. Several engines can share the same cooler.

If the system layout is according to one of the example diagrams, then the flow capacity of the cooler should be equal to the total capacity of the LT circulating pumps in the circuit. The flow may be higher for other system layouts and should be calculated case by case.

It can be necessary to compensate a high flow resistance in the circuit with a smaller pressure drop over the central cooler.

Design data:	
Fresh water flow	see chapter *Technical Data*
Heat to be dissipated	see chapter *Technical Data*
Pressure drop on fresh water side	max. 60 kPa (0.6 bar)
Sea-water flow	acc. to cooler manufacturer, normally 1.2 - 1.5 x the fresh water flow
Pressure drop on sea-water side, norm.	acc. to pump head, normally 80 - 140 kPa (0.8 - 1.4 bar)
Fresh water temperature after cooler	max. 38°C
Margin (heat rate, fouling)	15%

Figure 9.7 Central cooler main dimensions (4V47F0004). Example for guidance only



Number of cylinders	A [mm]	B [mm]	C [mm]	H [mm]	T [mm]	Weight [kg]
6	1910	720	1135	55	450	1380
7	1910	720	1135	55	450	1410
8	1910	720	1435	55	450	1450
9	1910	720	1435	55	450	1500

9.3.7 Waste heat recovery

The waste heat in the HT cooling water can be used for fresh water production, central heating, tank heating etc. The system should in such case be provided with a temperature control valve to avoid unnecessary cooling, as shown in the example diagrams. With this arrangement the HT water flow through the heat recovery can be increased.

The heat available from HT cooling water is affected by ambient conditions. It should also be taken into account that the recoverable heat is reduced by circulation to the expansion tank, radiation from piping and leakages in temperature control valves.

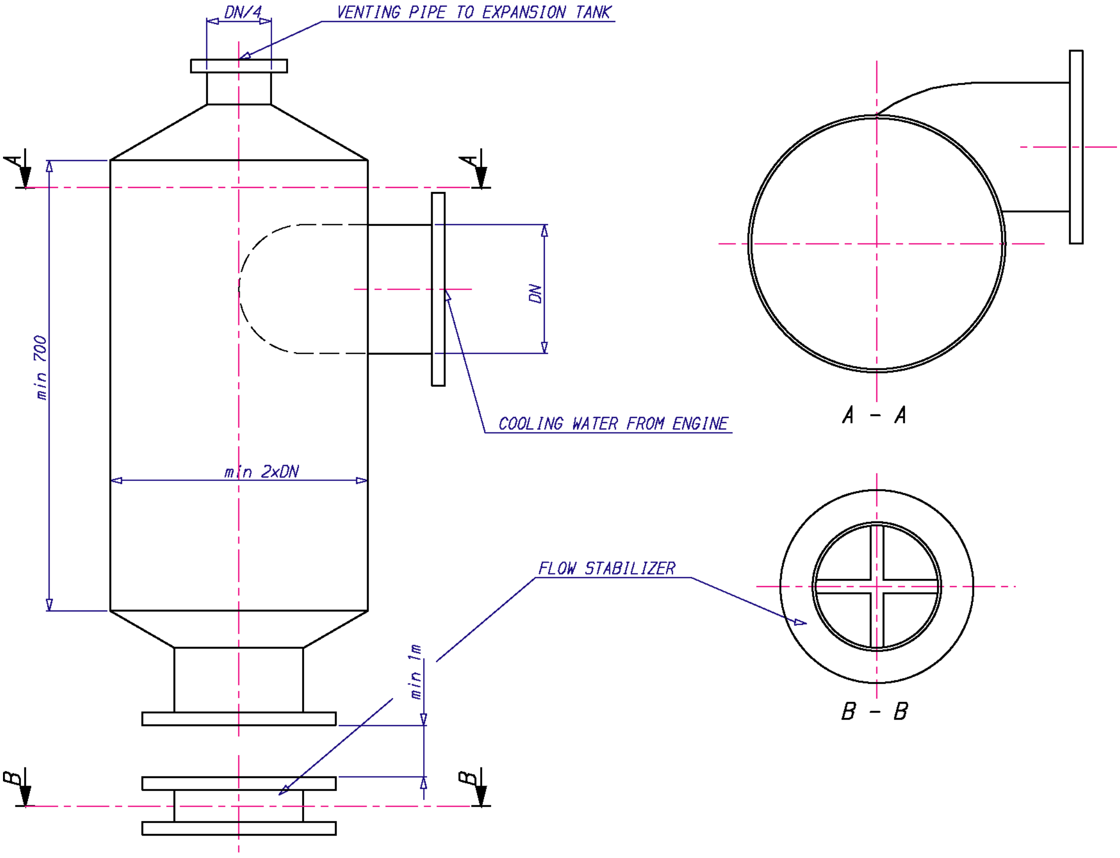
9.3.8 Air venting

Air may be entrained in the system after an overhaul, or a leak may continuously add air or gas into the system. The engine is equipped with vent pipes to evacuate air from the cooling water circuits. The vent pipes should be drawn separately to the expansion tank from each connection on the engine, except for the vent pipes from the charge air cooler on V-engines, which may be connected to the corresponding line on the opposite cylinder bank.

Venting pipes to the expansion tank are to be installed at all high points in the piping system, where air or gas can accumulate.

The vent pipes must be continuously rising.

Figure 9.8 Example of air venting device (3V76C4757)



9.3.9 Expansion tank (4T05)

The expansion tank compensates for thermal expansion of the coolant, serves for venting of the circuits and provides a sufficient static pressure for the circulating pumps.

Design data:

Pressure from the expansion tank at pump inlet	70 - 150 kPa (0.7...1.5 bar)
Volume	min. 10% of the total system volume

Note

The maximum pressure at the engine must not be exceeded in case an electrically driven pump is installed significantly higher than the engine.

Concerning the water volume in the engine, see chapter *Technical data*.

The expansion tank should be equipped with an inspection hatch, a level gauge, a low level alarm and necessary means for dosing of cooling water additives.

The vent pipes should enter the tank below the water level. The vent pipes must be drawn separately to the tank (see air venting) and the pipes should be provided with labels at the expansion tank.

The balance pipe down from the expansion tank must be dimensioned for a flow velocity not exceeding 1.0...1.5 m/s in order to ensure the required pressure at the pump inlet with engines running. The flow through the pipe depends on the number of vent pipes to the tank and the size of the orifices in the vent pipes. The table below can be used for guidance.

Table 9.1 Minimum diameter of balance pipe

Nominal pipe size	Max. flow velocity (m/s)	Max. number of vent pipes with ø 5 mm orifice
DN 40	1.2	6
DN 50	1.3	10

Nominal pipe size	Max. flow velocity (m/s)	Max. number of vent pipes with ø 5 mm orifice
DN 65	1.4	17
DN 80	1.5	28

9.3.10 Drain tank (4T04)

It is recommended to collect the cooling water with additives in a drain tank, when the system has to be drained for maintenance work. A pump should be provided so that the cooling water can be pumped back into the system and reused.

Concerning the water volume in the engine, see chapter *Technical data*. The water volume in the LT circuit of the engine is small.

9.3.11 Additive dosing tank (4T03)

It is also recommended to provide a separate additive dosing tank, especially when water treatment products are added in solid form. The design must be such that the major part of the water flow is circulating through the engine when treatment products are added.

The tank should be connected to the HT cooling water circuit as shown in the example system diagrams.

9.3.12 Preheating

The cooling water circulating through the cylinders must be preheated to at least 60 °C, preferably 70 °C. This is an absolute requirement for installations that are designed to operate on heavy fuel, but strongly recommended also for engines that operate exclusively on marine diesel fuel.

The energy required for preheating of the HT cooling water can be supplied by a separate source or by a running engine, often a combination of both. In all cases a separate circulating pump must be used. It is common to use the heat from running auxiliary engines for preheating of main engines. In installations with several main engines the capacity of the separate heat source can be dimensioned for preheating of two engines, provided that this is acceptable for the operation of the ship. If the cooling water circuits are separated from each other, the energy is transferred over a heat exchanger.

Heater (4E05)

The energy source of the heater can be electric power, steam or thermal oil.

It is recommended to heat the HT water to a temperature near the normal operating temperature. The heating power determines the required time to heat up the engine from cold condition.

The minimum required heating power is 12 kW/cyl, which makes it possible to warm up the engine from 20 °C to 60...70 °C in 10-15 hours. The required heating power for shorter heating time can be estimated with the formula below. About 6 kW/cyl is required to keep a hot engine warm.

Design data:	
Preheating temperature	min. 60°C
Heating power to keep hot engine warm	6 kW/cyl

Required heating power to heat up the engine, see formula below:

$$P = \frac{(T_1 - T_0)(m_{eng} \times 0.14 + V_{FW} \times 1.16)}{t} + k_{eng} \times n_{cyl}$$

where:

P = Preheater output [kW]

T_1 = Preheating temperature = 60...70 °C

T_0 = Ambient temperature [°C]

m_{eng} = Engine weight [ton]

V_{FW} = HT water volume [m^3]

t = Preheating time [h]

where:

k_{eng} = Engine specific coefficient = 3 kW

n_{cyl} = Number of cylinders

The formula above should not be used for P < 10 kW/cyl

Circulation pump for preheater (4P04)

Design data:	
Capacity	1.6 m^3/h per cylinder
Delivery pressure	80 kPa (0.8 bar)

Preheating unit (4N01)

A complete preheating unit can be supplied. The unit comprises:

- Electric or steam heaters
- Circulating pump
- Control cabinet for heaters and pump
- Set of thermometers
- Non-return valve
- Safety valve

Figure 9.9 Example of preheating unit, electric (4V47K0045)

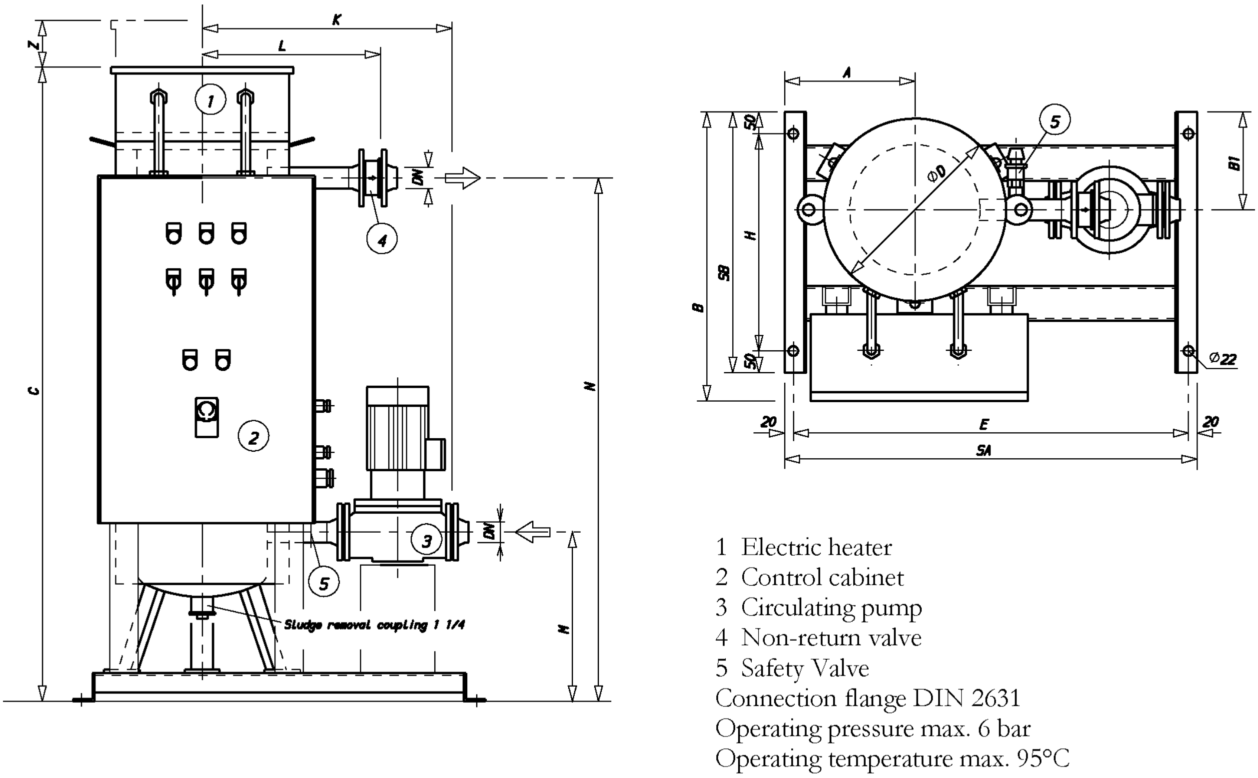
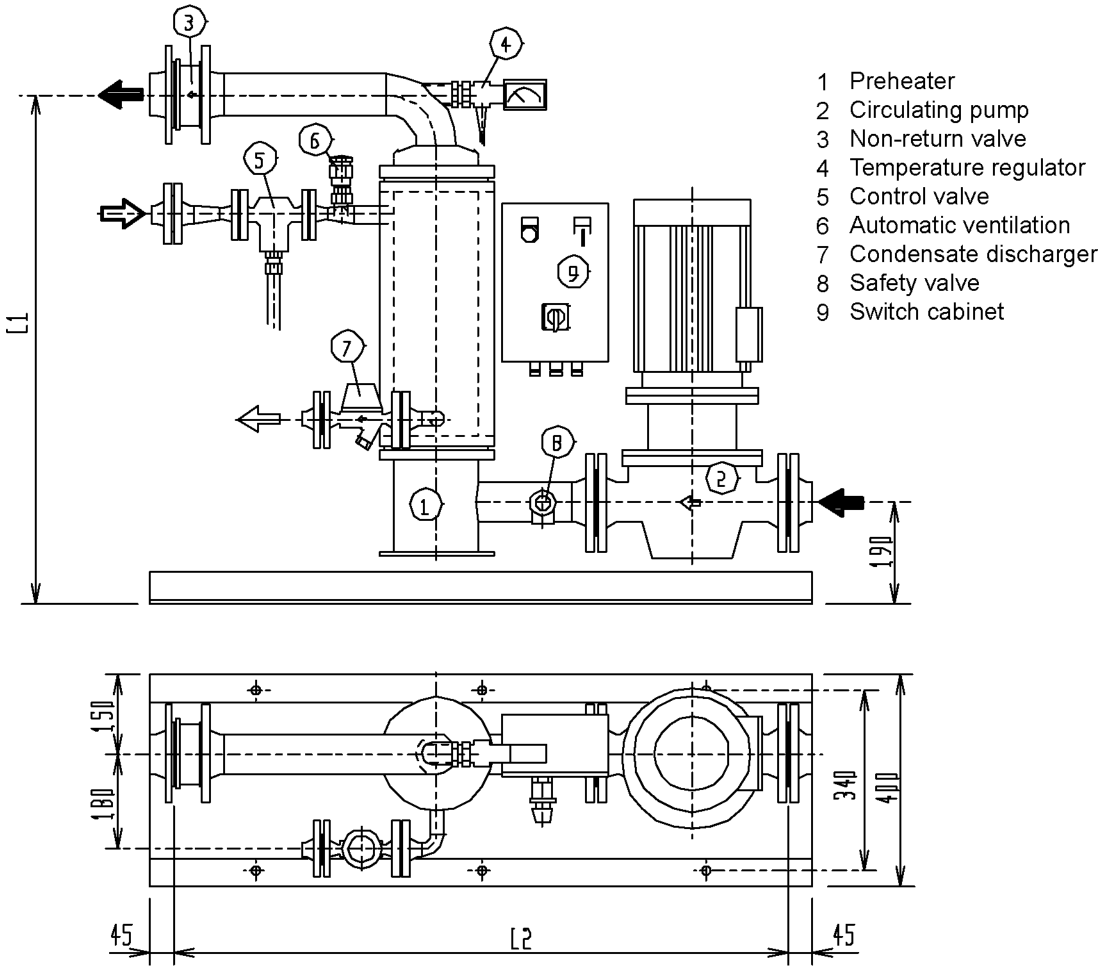


Table 9.2 Example of preheating unit

Capacity [kW]	B	C	SA	Z	Water content [kg]	Weight [kg]
72	665	1455	950	900	67	225
81	665	1455	950	900	67	225
108	715	1445	1000	900	91	260
135	715	1645	1000	1100	109	260
147	765	1640	1100	1100	143	315
169	765	1640	1100	1100	142	315
203	940	1710	1200	1100	190	375
214	940	1710	1200	1100	190	375
247	990	1715	1250	1100	230	400
270	990	1715	1250	1100	229	400

All dimensions are in mm

Figure 9.10 Example of preheating unit, steam



Type	kW	L1 [mm]	L2 [mm]	Dry weight [kg]
KVDS-72	72	960	1160	190
KVDS-96	96	960	1160	190
KVDS-108	108	960	1160	190
KVDS-135	135	960	1210	195
KVDS-150	150	960	1210	195
KVDS-170	170	1190	1210	200
KVDS-200	200	1190	1260	200
KVDS-240	240	1190	1260	205
KVDS-270	270	1430	1260	205

9.3.13 Throttles

Throttles (orifices) are to be installed in all by-pass lines to ensure balanced operating conditions for temperature control valves. Throttles must also be installed wherever it is necessary to balance the waterflow between alternate flow paths.

9.3.14 Thermometers and pressure gauges

Local thermometers should be installed wherever there is a temperature change, i.e. before and after heat exchangers etc.

Local pressure gauges should be installed on the suction and discharge side of each pump.

10. Combustion air system

10.1 Engine room ventilation

To maintain acceptable operating conditions for the engines and to ensure trouble free operation of all equipment, attention shall be paid to the engine room ventilation and the supply of combustion air.

The air intakes to the engine room must be located and designed so that water spray, rain water, dust and exhaust gases cannot enter the ventilation ducts and the engine room.

The dimensioning of blowers and extractors should ensure that an overpressure of about 50 Pa is maintained in the engine room in all running conditions.

For the minimum requirements concerning the engine room ventilation and more details, see applicable standards, such as ISO 8861.

The amount of air required for ventilation is calculated from the total heat emission Φ to evacuate. To determine Φ, all heat sources shall be considered, e.g.:

- Main and auxiliary diesel engines
- Exhaust gas piping
- Generators
- Electric appliances and lighting
- Boilers
- Steam and condensate piping
- Tanks

It is recommended to consider an outside air temperature of no less than 35°C and a temperature rise of 11°C for the ventilation air.

The amount of air required for ventilation is then calculated using the formula:

$$Q_V = \frac{\Phi}{\rho \times \Delta t \times c}$$

where:

Qv = amount of ventilation air [m³/s]

Φ = total heat emission to be evacuated [kW]

ρ = density of ventilation air 1.13 kg/m³

Δt = temperature rise in the engine room [°C]

c = specific heat capacity of the ventilation air 1.01 kJ/kgK

The heat emitted by the engine is listed in chapter *Technical data*.

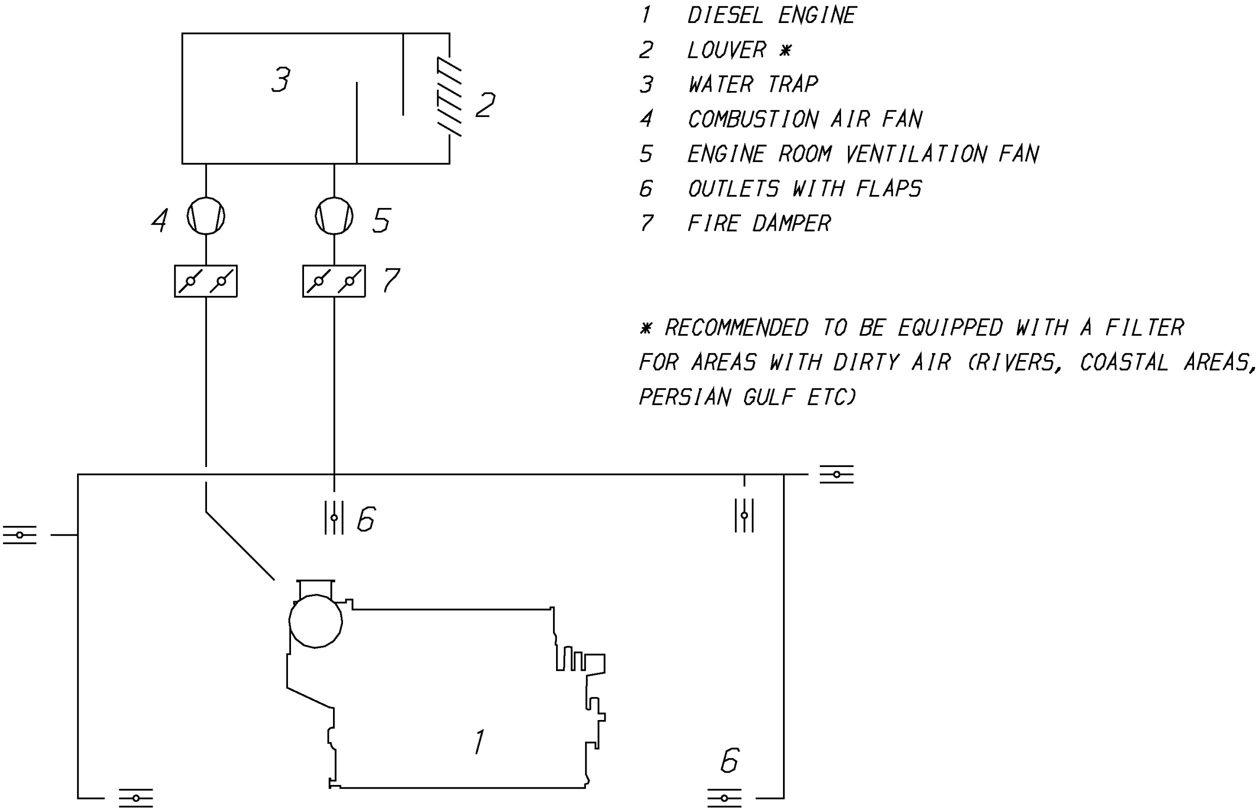
The engine room ventilation air has to be provided by separate ventilation fans. These fans should preferably have two-speed electric motors (or variable speed). The ventilation can then be reduced according to outside air temperature and heat generation in the engine room, for example during overhaul of the main engine when it is not preheated (and therefore not heating the room).

The ventilation air is to be equally distributed in the engine room considering air flows from points of delivery towards the exits. This is usually done so that the funnel serves as exit for most of the air. To avoid stagnant air, extractors can be used.

It is good practice to provide areas with significant heat sources, such as separator rooms with their own air supply and extractors.

Under-cooling of the engine room should be avoided during all conditions (service conditions, slow steaming and in port). Cold draft in the engine room should also be avoided, especially in areas of frequent maintenance activities. For very cold conditions a pre-heater in the system should be considered. Suitable media could be thermal oil or water/glycol to avoid the risk for freezing. If steam is specified as heating medium for the ship, the pre-heater should be in a secondary circuit.

Figure 10.1 Engine room ventilation (4V69E8169b)



10.2 Combustion air system design

Usually, the combustion air is taken from the engine room through a filter on the turbocharger. This reduces the risk for too low temperatures and contamination of the combustion air. It is important that the combustion air is free from sea water, dust, fumes, etc.

As far as possible the air temperature at turbocharger inlet should be kept between 5 and 35°C. Temporarily max. 45°C is allowed. For the required amount of combustion air, see chapter *Technical data*.

The combustion air shall be supplied by separate combustion air fans, with a capacity slightly higher than the maximum air consumption. The fans should preferably have two-speed electric motors (or variable speed) for enhanced flexibility. In addition to manual control, the fan speed can be controlled by engine load.

In multi-engine installations each main engine should preferably have its own combustion air fan. Thus the air flow can be adapted to the number of engines in operation.

The combustion air should be delivered through a dedicated duct close to the turbocharger, directed towards the turbocharger air intake. The outlet of the duct should be equipped with a flap for controlling the direction and amount of air. Also other combustion air consumers, for example other engines, gas turbines and boilers shall be served by dedicated combustion air ducts.

If necessary, the combustion air duct can be connected directly to the turbocharger with a flexible connection piece. With this arrangement an external filter must be installed in the duct to protect the turbocharger and prevent fouling of the charge air cooler. The permissible total pressure drop in the duct is max. 1.5 kPa. The duct should be provided with a step-less change-over flap to take the air from the engine room or from outside depending on engine load and air temperature.

For very cold conditions heating of the supply air must be arranged. The combustion air fan is stopped during start of the engine and the necessary combustion air is drawn from the engine room. After start either the ventilation air supply, or the combustion air supply, or both in combination must be able to maintain the minimum required combustion air temperature. The air supply from the combustion air fan is to be directed away from the engine, when the intake air is cold, so that the air is allowed to heat up in the engine room.

10.2.1 Condensation in charge air coolers

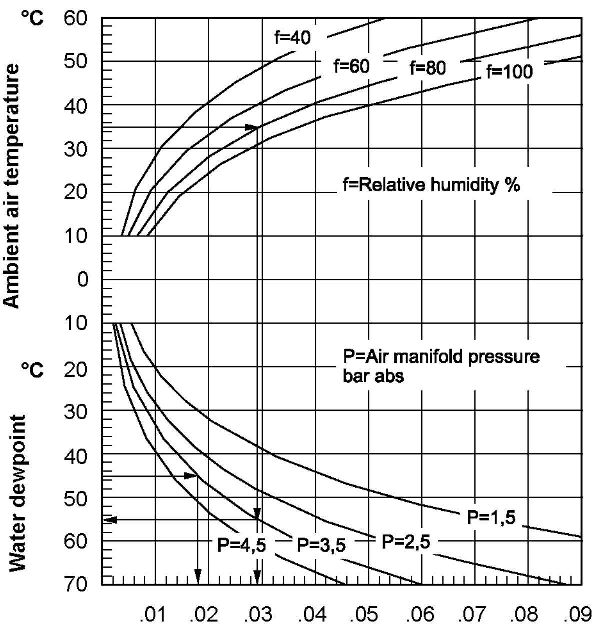
Air humidity may condense in the charge air cooler, especially in tropical conditions. The engine equipped with a small drain pipe from the charge air cooler for condensed water.

The amount of condensed water can be estimated with the diagram below.

Example, according to the diagram:

At an ambient air temperature of 35°C and a relative humidity of 80%, the content of water in the air is 0.029 kg water/ kg dry air. If the air manifold pressure (receiver pressure) under these conditions is 2.5 bar (= 3.5 bar absolute), the dew point will be 55°C. If the air temperature in the air manifold is only 45°C, the air can only contain 0.018 kg/kg. The difference, 0.011 kg/kg (0.029 - 0.018) will appear as condensed water.

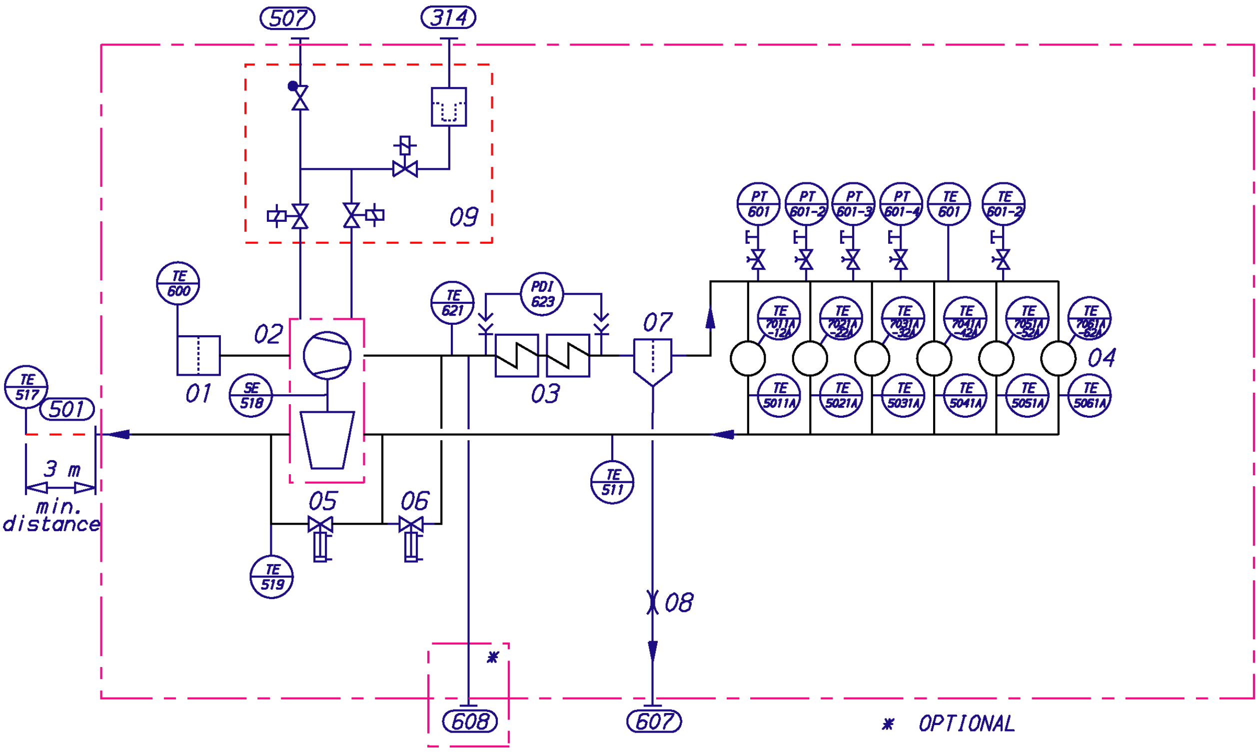
Figure 10.2 Condensation in charge air coolers



11. Exhaust gas system

11.1 Internal exhaust gas system

Figure 11.1 Charge air and exhaust gas system (DAAE017293)



System components	
01	Air filter
02	Turbocharger
03	Charge air cooler
04	Cylinders
05	Exhaust wastegate valve
06	Air by-pass valve
07	Water separator
08	Restrictor
09	Turbocharger cleaning valves

Abbreviations:

CAC = Charge air cooler
WG = Wastegate
BP = By-pass

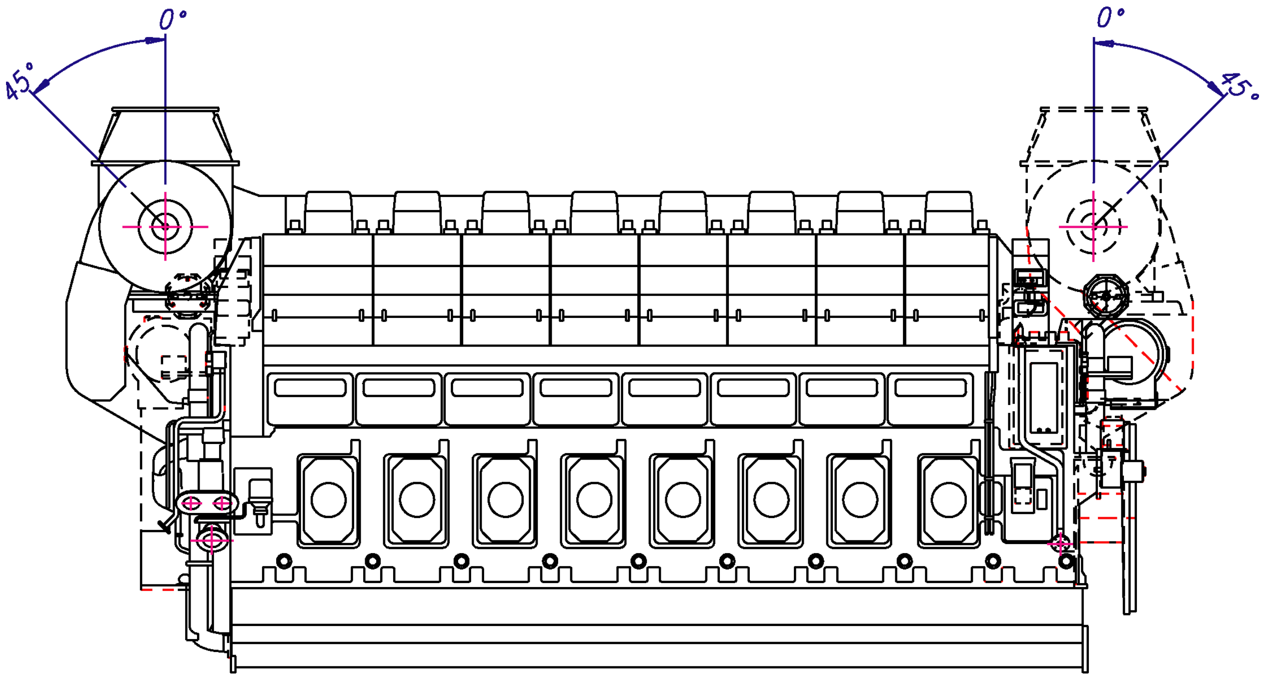
Sensors and indicators	
TE50x1A..	Exhaust gas temperature after each cylinder
TE70x1A..	Cylinder liner temperature, sensor 1
TE70x2A..	Cylinder liner temperature, sensor 2
TE511	Exhaust gas temperature before turbine
TE517	Exhaust gas temperature after turbine
TE519	Exhaust gas temperature after wastegate
TE601	Charge air temperature after CAC
TE601-2	Charge air temperature after CAC (for cooling water control)
TE621	Charge air temperature before CAC
SE518	Turbocharger speed
PT601	Charge air pressure after CAC
PT601-2	Charge air pressure, if external speed control
PT601-3	Charge air pressure, if UNIC C1 (for WG, BP control)
PT601-4	Charge air pressure (for local indication)
PDI623	Pressure difference over CAC (portable instrument)
	(x = cylinder number)

Pipe connections		Size	Standard
314	Air supply to compressor and turbine cleaning device	G3/4	DIN ISO 228
501	Exhaust gas outlet	6L46F: DN600 7-9L46F: DN800	ISO 7005-1

Pipe connections		Size	Standard
507	Cleaning water to turbine and compressor	G2	DIN ISO 228
607	Condensate after air cooler	OD35	
608	Cleaning water to charge air cooler	OD10	

11.2 Exhaust gas outlet

Figure 11.2 Exhaust pipe connection

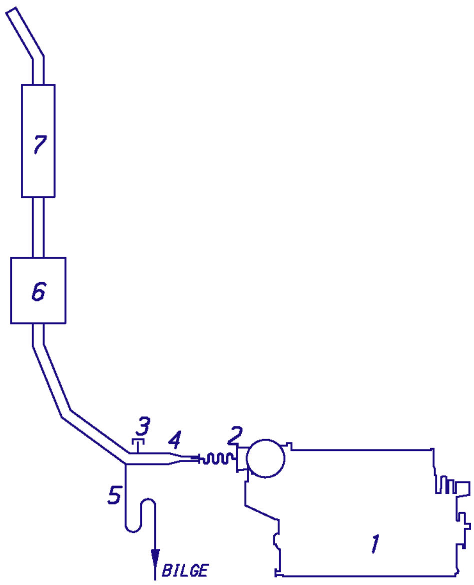


11.3 External exhaust gas system

Each engine should have its own exhaust pipe into open air. Backpressure, thermal expansion and supporting are some of the decisive design factors.

Flexible bellows must be installed directly on the turbocharger outlet, to compensate for thermal expansion and prevent damages to the turbocharger due to vibrations.

Figure 11.3 External exhaust gas system



1. Diesel engine
2. Flexible bellows
3. Connection for measurement of back pressure
4. Transition piece
5. Drain with water trap, continuously open
6. Exhaust gas boiler
7. Silencer

11.3.1 Piping

The piping should be as short and straight as possible. Pipe bends and expansions should be smooth to minimise the backpressure. The diameter of the exhaust pipe should be increased directly after the bellows on the turbocharger. Pipe bends should be made with the largest possible bending radius; the bending radius should not be smaller than 1.5 x D.

The recommended flow velocity in the pipe is 35…40 m/s at full output. If there are many resistance factors in the piping, or the pipe is very long, then the flow velocity needs to be lower. The exhaust gas mass flow given in chapter *Technical data* can be translated to velocity using the formula:

$$v = \frac{4 \times m}{1.3 \times \left(\frac{273}{273 + t} \right) \times \pi \times D^2}$$

Where:

v = gas velocity [m/s]

m = exhaust gas mass flow [kg/s]

t = exhaust gas temperature [°C]

D = exhaust gas pipe diameter [m]

Each exhaust pipe should be provided with a connection for measurement of the backpressure.

The exhaust gas pipe should be provided with water separating pockets and drain.

The exhaust pipe must be insulated all the way from the turbocharger and the insulation is to be protected by a covering plate or similar to keep the insulation intact. Closest to the turbocharger the insulation should consist of a hook on padding to facilitate maintenance. It is especially important to prevent that insulation is detached by the strong airflow to the turbocharger.

11.3.2 Supporting

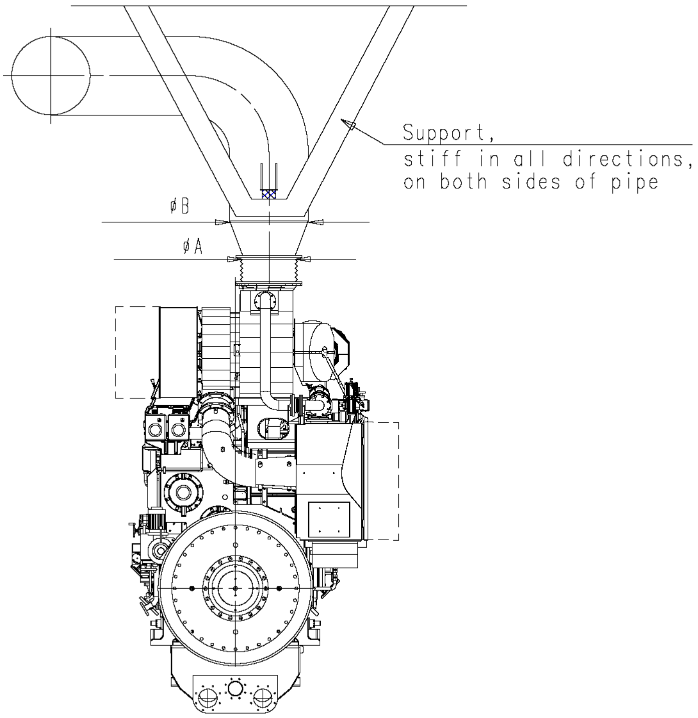
It is very important that the exhaust pipe is properly fixed to a support that is rigid in all directions directly after the bellows on the turbocharger. There should be a fixing point on both sides of the pipe at the support. The bellows on the turbocharger may not be used to absorb thermal expansion from the exhaust pipe. The first fixing point must direct the thermal expansion away from the engine. The following support must prevent the pipe from pivoting around the first fixing point.

Absolutely rigid mounting between the pipe and the support is recommended at the first fixing point after the turbocharger. Resilient mounts can be accepted for resiliently mounted engines with long bellows, provided that the mounts are self-captive; maximum deflection at total failure being less than 2 mm radial and 4 mm axial with regards to the bellows. The natural frequencies of the mounting should be on a safe distance from the running speed, the firing frequency of the engine and the blade passing frequency of the propeller. The resilient mounts can be rubber mounts of conical type, or high damping stainless steel wire pads. Adequate thermal insulation must be provided to protect rubber mounts from high temperatures. When using resilient mounting, the alignment of the exhaust bellows must be checked on a regular basis and corrected when necessary.

After the first fixing point resilient mounts are recommended. The mounting supports should be positioned at stiffened locations within the ship’s structure, e.g. deck levels, frame webs or specially constructed supports.

The supporting must allow thermal expansion and ship’s structural deflections.

Figure 11.4 First pipe support after the turbocharger (DAAE048775a)



11.3.3 Back pressure

The maximum permissible exhaust gas back pressure is 3 kPa at full load. The back pressure in the system must be calculated by the shipyard based on the actual piping design and the resistance of the components in the exhaust system. The exhaust gas mass flow and temperature given in chapter *Technical data* may be used for the calculation.

The back pressure must also be measured during the sea trial.

11.3.4 Exhaust gas bellows (5H01, 5H03)

Bellows must be used in the exhaust gas piping where thermal expansion or ship's structural deflections have to be segregated. The flexible bellows mounted directly on the turbocharger outlet serves to minimise the external forces on the turbocharger and thus prevent excessive vibrations and possible damage. All exhaust gas bellows must be of an approved type.

11.3.5 Selective Catalytic Reduction (11N03)

The exhaust gas piping must be straight at least 3...5 meters in front of the SCR unit. If both an exhaust gas boiler and a SCR unit will be installed, then the exhaust gas boiler shall be installed after the SCR. Arrangements must be made to ensure that water cannot spill down into the SCR, when the exhaust boiler is cleaned with water.

11.3.6 Exhaust gas silencer (5R02)

Yard/designer should take into account that unfavourable layout of the exhaust system (length of straight parts in the exhaust system) might cause amplification of the exhaust noise between engine outlet and the silencer. Hence the attenuation of the silencer does not give any absolute guarantee for the noise level after the silencer.

When included in the scope of supply, the standard silencer is of the absorption type, equipped with a spark arrester. It is also provided with a soot collector and a condense drain, but it comes without mounting brackets and insulation. The silencer can be mounted either horizontally or vertically.

The noise attenuation of the standard silencer is either 25 or 35 dB(A). This attenuation is valid up to a flow velocity of max. 40 m/s.

11.3.7 Exhaust gas boiler

If exhaust gas boilers are installed, each engine should have a separate exhaust gas boiler. Alternatively, a common boiler with separate gas sections for each engine is acceptable.

For dimensioning the boiler, the exhaust gas quantities and temperatures given in chapter *Technical data* may be used.

12. Turbocharger cleaning

Regular water cleaning of the turbine and the compressor reduces the formation of deposits and extends the time between overhauls. Fresh water is injected into the turbocharger during operation. Additives, solvents or salt water must not be used and the cleaning instructions in the operation manual must be carefully followed.

Wärtsilä 46F engines are delivered with an automatic cleaning system, which comprises a valve unit mounted in the engine room close to the turbocharger and a common control unit for up to six engines. Cleaning is started from the control panel on the control unit and the cleaning sequence is then controlled automatically. A flow meter and a pressure control valve are supplied for adjustment of the water flow.

The water supply line must be dimensioned so that the required pressure can be maintained at the specified flow. If it is necessary to install the valve unit at a distance from the engine, stainless steel pipes must be used between the valve unit and the engine. The valve unit should not be mounted more than 5 m from the engine. The water pipes between the valve unit and the turbocharger are constantly purged with charge air from the engine when the engine is operating above 25% load. External air supply is needed below 25% load.

Water supply:

Fresh water

Pressure	0.4...0.8 MPa (4...8 bar)
Max. temperature	40 °C
Flow	22...34 l/min

Washing time ~10 minutes per engine.

Air supply:

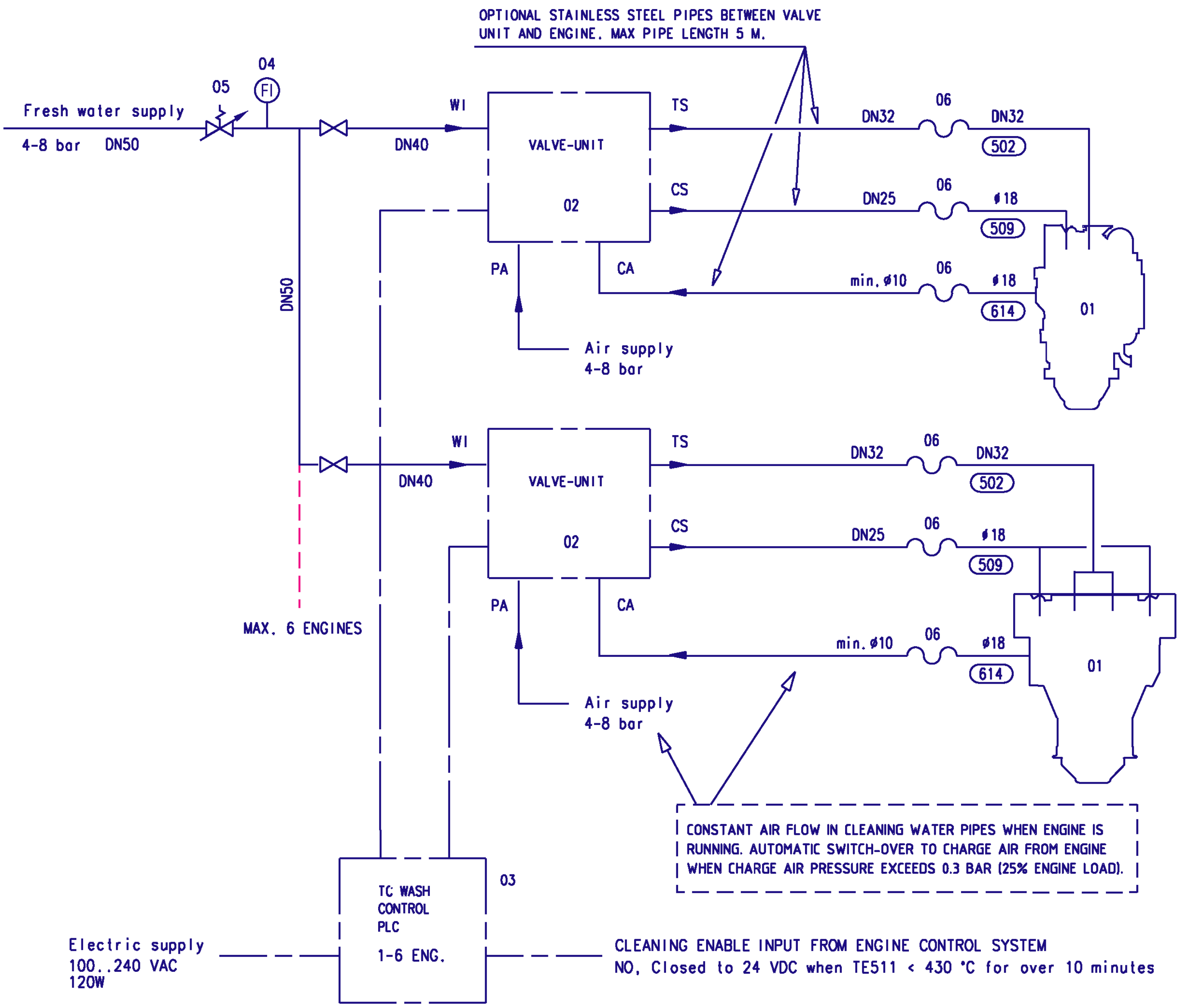
Pressure	0.4...0.8 MPa (4...8 bar)
Max. temperature	55 °C
Flow	0.3...0.5 kg/min

Air consumption only below 25% engine load.

Electric supply:

100...240 VAC / 120 W

Figure 12.1 Turbocharger cleaning system (DAAE066685).



System components			
01	Diesel engine	04	Flow meter
02	Valve unit	05	Pressure control valve
03	Control unit	06	Flexible hose *

**) Flexible hose length 1.3 m*

Pipe connections on engine		Size
502	Cleaning water to turbine	DN32 ISO 7005-1 PN40
509	Cleaning water to compressor	OD18 DIN 2353
614	Charge air outlet	OD18 DIN 2353

Pipe connections on valve unit		Size
WI	Water inlet	DN40 ISO 7005-1 PN40
TS	Cleaning water to turbine	DN32 ISO 7005-1 PN40
CS	Cleaning water to compressor	DN25 ISO 7005-1 PN40
CA	Charge air	G3/8" ISO 228
PA	Compressed air	G3/8" ISO 228

Figure 12.2 Valve unit

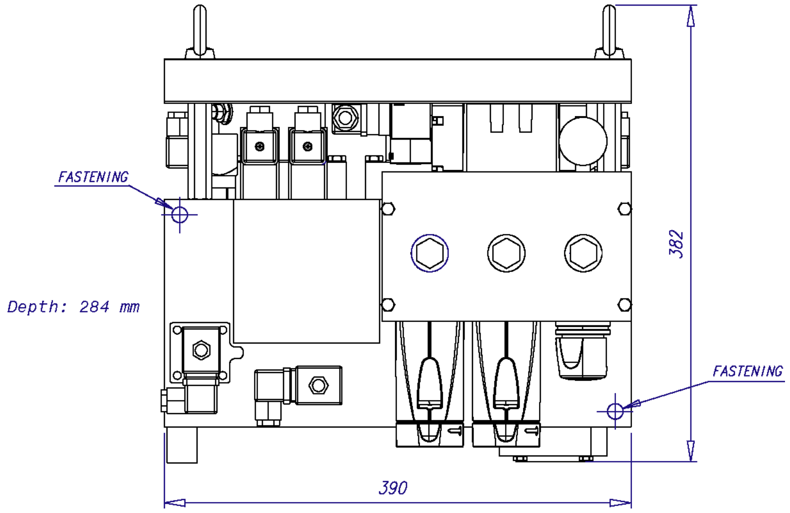
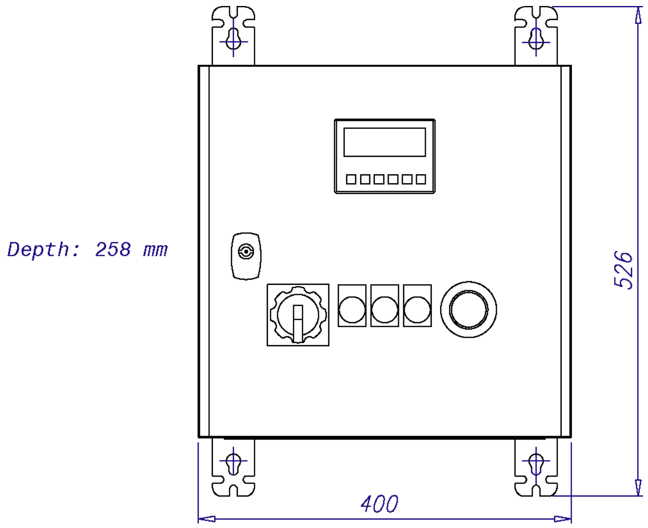


Figure 12.3 Control unit



13. Exhaust emissions

13.1 General

Exhaust emissions from the diesel engine mainly consist of nitrogen, oxygen and combustion products like carbon dioxide (CO_2), water vapour and minor quantities of carbon monoxide (CO), sulphur oxides (SO_x), nitrogen oxides (NO_x), partially reacted and non-combusted hydrocarbons (HC) and particulate matter (PM).

There are different emission control methods depending on the aimed pollutant. These are mainly divided in two categories; primary methods that are applied on the engine itself and secondary methods that are applied on the exhaust gas stream.

13.2 Diesel engine exhaust components

The nitrogen and oxygen in the exhaust gas are the main components of the intake air which don't take part in the combustion process.

CO_2 and water are the main combustion products. Secondary combustion products are carbon monoxide, hydrocarbons, nitrogen oxides, sulphur oxides, soot and particulate matters.

In a diesel engine the emission of carbon monoxide and hydrocarbons are low compared to other internal combustion engines, thanks to the high air/fuel ratio in the combustion process. The air excess allows an almost complete combustion of the HC and oxidation of the CO to CO_2, hence their quantity in the exhaust gas stream are very low.

13.2.1 Nitrogen oxides (NO_x)

The combustion process gives secondary products as Nitrogen oxides. At high temperature the nitrogen, usually inert, react with oxygen to form Nitric oxide (NO) and Nitrogen dioxide (NO_2), which are usually grouped together as NO_x emissions. Their amount is strictly related to the combustion temperature.

NO can also be formed through oxidation of the nitrogen in fuel and through chemical reactions with fuel radicals. NO in the exhaust gas flow is in a high temperature and high oxygen concentration environment, hence oxidizes rapidly to NO_2. The amount of NO_2 emissions is approximately 5 % of total NOx emissions.

13.2.2 Sulphur Oxides (SO_x)

Sulphur oxides (SO_x) are direct result of the sulphur content of the fuel oil. During the combustion process the fuel bound sulphur is rapidly oxidized to sulphur dioxide (SO_2). A small fraction of SO_2 may be further oxidized to sulphur trioxide (SO_3).

13.2.3 Particulate Matter (PM)

The particulate fraction of the exhaust emissions represents a complex mixture of inorganic and organic substances mainly comprising soot (elemental carbon), fuel oil ash (together with sulphates and associated water), nitrates, carbonates and a variety of non or partially combusted hydrocarbon components of the fuel and lubricating oil.

13.2.4 Smoke

Although smoke is usually the visible indication of particulates in the exhaust, the correlations between particulate emissions and smoke is not fixed. The lighter and more volatile hydrocarbons will not be visible nor will the particulates emitted from a well maintained and operated diesel engine.

Smoke can be black, blue, white, yellow or brown in appearance. Black smoke is mainly comprised of carbon particulates (soot). Blue smoke indicates the presence of the products of the incomplete combustion of the fuel or lubricating oil. White smoke is usually condensed water vapour. Yellow smoke is caused by NO_x emissions. When the exhaust gas is cooled significantly prior to discharge to the atmosphere, the condensed NO_2 component can have a brown appearance.

13.3 Marine exhaust emissions legislation

13.3.1 International Maritime Organization (IMO)

The increasing concern over the air pollution has resulted in the introduction of exhaust emission controls to the marine industry. To avoid the growth of uncoordinated regulations, the IMO (International Maritime Organization) has developed the Annex VI of MARPOL 73/78, which represents the first set of regulations on the marine exhaust emissions.

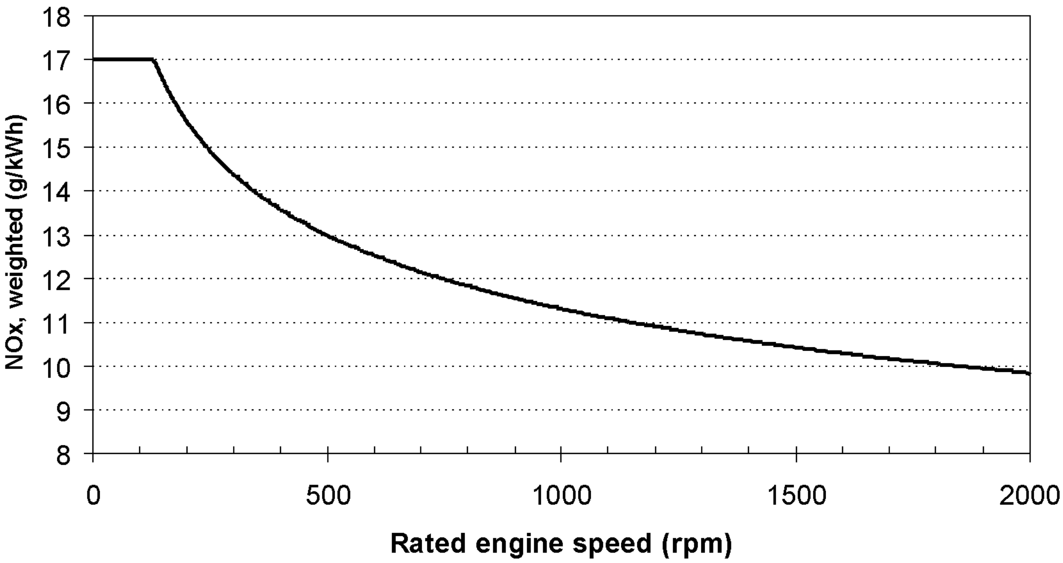
MARPOL Annex VI

MARPOL 73/78 Annex VI includes regulations for example on such emissions as nitrogen oxides, sulphur oxides, volatile organic compounds and ozone depleting substances. The Annex VI entered into force on the 19th of May 2005. The most important regulation of the MARPOL Annex VI is the control of NO_x emissions.

The IMO NO_x limit is defined as follows:

NOx [g/kWh] = 17 when rpm < 130
= 45 x $rpm^{-0.2}$ when 130 < rpm < 2000
= 9.8 when rpm > 2000

Figure 13.1 IMO NO_x emission limit



The NO_x controls apply to diesel engines over 130 kW installed on ships built (defined as date of keel laying or similar stage of construction) on or after January 1, 2000 along with engines which have undergone a major conversion on or after January 1, 2000.

The Wärtsilä engines comply with the NO_x levels set by the IMO in the MARPOL Annex VI.

EIAPP Certificate

An EIAPP (Engine International Air Pollution Prevention) certificate will be issued for each engine showing that the engine complies with the NO_x regulations set by the IMO.

When testing the engine for NO_x emissions, the reference fuel is Marine Diesel Fuel (distillate) and the test is performed according to ISO 8178 test cycles. Subsequently, the NO_x value has to be calculated using different weighting factors for different loads that have been corrected to ISO 8178 conditions. The most commonly used ISO 8178 test cycles are presented in the following table.

Table 13.1 ISO 8178 test cycles.

E2: Diesel electric propulsion or controllable pitch propeller	Speed (%)	100	100	100	100
	Power (%)	100	75	50	25
	Weighting factor	0.2	0.5	0.15	0.15

For EIAPP certification, the “engine family” or the “engine group” concepts may be applied. This has been done for the Wärtsilä 46F diesel engine. The engine families are represented by their parent engines and the certification emission testing is only necessary for these parent engines. Further engines can be certified by checking documents, components, settings etc., which have to show correspondence with those of the parent engine.

All non-standard engines, for instance over-rated engines, non-standard-speed engines etc. have to be certified individually, i.e. “engine family” or “engine group” concepts do not apply.

According to the IMO regulations, a Technical File shall be made 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 injection nozzle, injection pump, camshaft, cylinder head, piston, connecting rod, charge air cooler and turbocharger. The allowable setting values and parameters for running the engine are also specified in the Technical File.

The marked components can later, on-board the ship, be identified 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.

Sulphur Emission Control Area (SECA)

MARPOL Annex VI sets a general global limit on sulphur content in fuels of 4.5% in weight. Annex VI also contains provisions allowing for special SOx Emission Control Areas (SECA) to be established with more stringent controls on sulphur emissions. In SECA areas, the sulphur content of fuel oil used onboard ships must not exceed 1.5% in weight. Alternatively, an exhaust gas cleaning system should be applied to reduce the total emission of sulphur oxides from ships, including both auxiliary and main propulsion engines, to 6.0 g/kWh or less calculated as the total weight of sulphur dioxide emission. At the moment Baltic Sea and North Sea are included in SECA.

13.3.2 Other Legislations

There are also other local legislations in force in particular regions.

13.4 Methods to reduce exhaust emissions

All standard Wärtsilä engines meet the NOx emission level set by the IMO (International Maritime Organisation) and most of the local emission levels without any modifications. Wärtsilä has also developed solutions to significantly reduce NOx emissions when this is required.

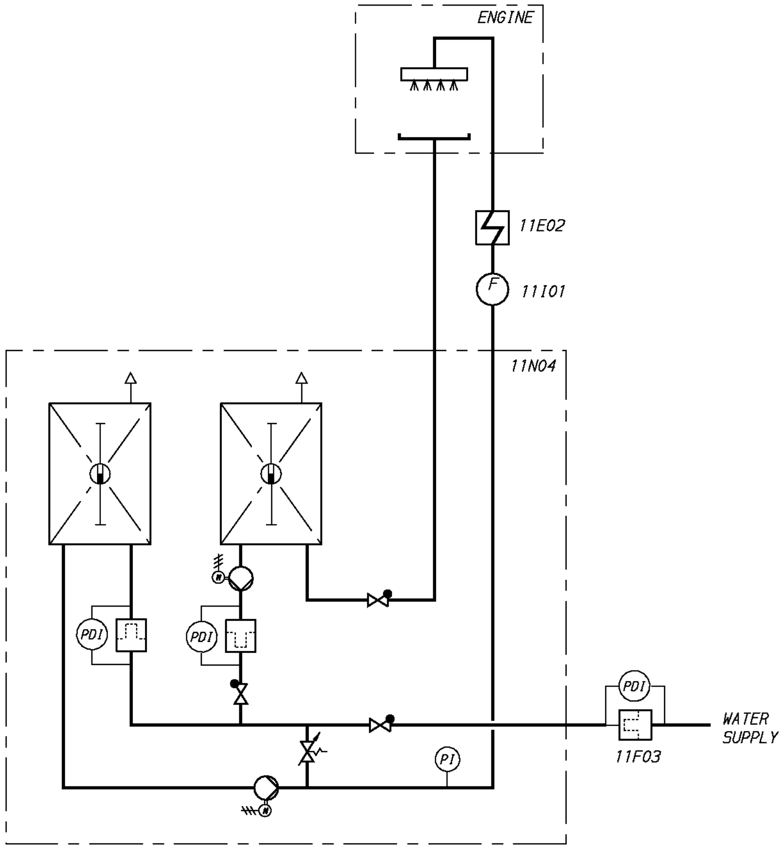
Diesel engine exhaust emissions can be reduced either with primary or secondary methods. The primary methods limit the formation of specific emissions during the combustion process. The secondary methods reduce emission components after formation as they pass through the exhaust gas system.

13.4.1 Humidification of charge air (Wetpac H)

Wetpac H technology allows a NO_x emissions reduction up to 40%. It is based on water injection after the turbocharger. The water mist decreases the maximum temperatures in the cylinders, thus reducing NO_x. Wetpac H is suitable for fuels with sulphur contents less than 1.5%.

The Wetpac H system includes a water treatment system, a pump unit, a spraywater heater (only for small engines with single stage charge air cooler), a control unit outside the engine and group(s) of spraying nozzles with solenoid valves built on the charge air duct. The pump unit should be placed somewhere close to the engine.

Figure 13.2 External scheme Wetpac H (DAAE039819)



Main components

11N04	Humidification pump unit
11E02	Heater
11F03	Pre-filter
11I01	Flowmeter

The system is designed and built so that the amount of water injected can be adjusted and the Wetpac H system can also be shut off if necessary. In case of failure the system will automatically go in off-mode.

The amount of water needed varies with the load and with the NO_x level the operator wants to achieve. Typically the water amount needed is 1.5...2 times the engine fuel oil consumption for full NO_x reduction. The water used for Wetpac H has to be of very good quality, produced by evaporators or 2-stage reverse osmosis, see table *13.2 Water quality requirements*.

Please note that when Wetpac H is in operation the heat balance of the engine will change, always ask for project specific information.

Water used for Wetpac H has to fulfill the following requirements:

Table 13.2 Water quality requirements

Property	Unit	Maximum value
PH		6...8
Hardness	°dH	0.4
Chlorides as Cl	mg/l	5
Suspended solids	mg/l	5
Temperature before pump unit	°C	40

In order to achieve a safe operation of the Wetpac H system and the engine, water produced with a fresh water generator / distiller or a 2-stage reverse osmosis unit has to be used. The water must not be contaminated by oil, grease, surfactants or similar impurities. These kinds of impurities may cause blocking of the filters or other malfunctions in the Wetpac H system.

Table 13.3 Water consumption

Engine type	Water consumption [l/h]
W 6L46F	2300
W 7L46F	2700
W 8L46F	3100
W 9L46F	3500

The water consumption is calculated at max NO_x reduction and 85% load of the engine.

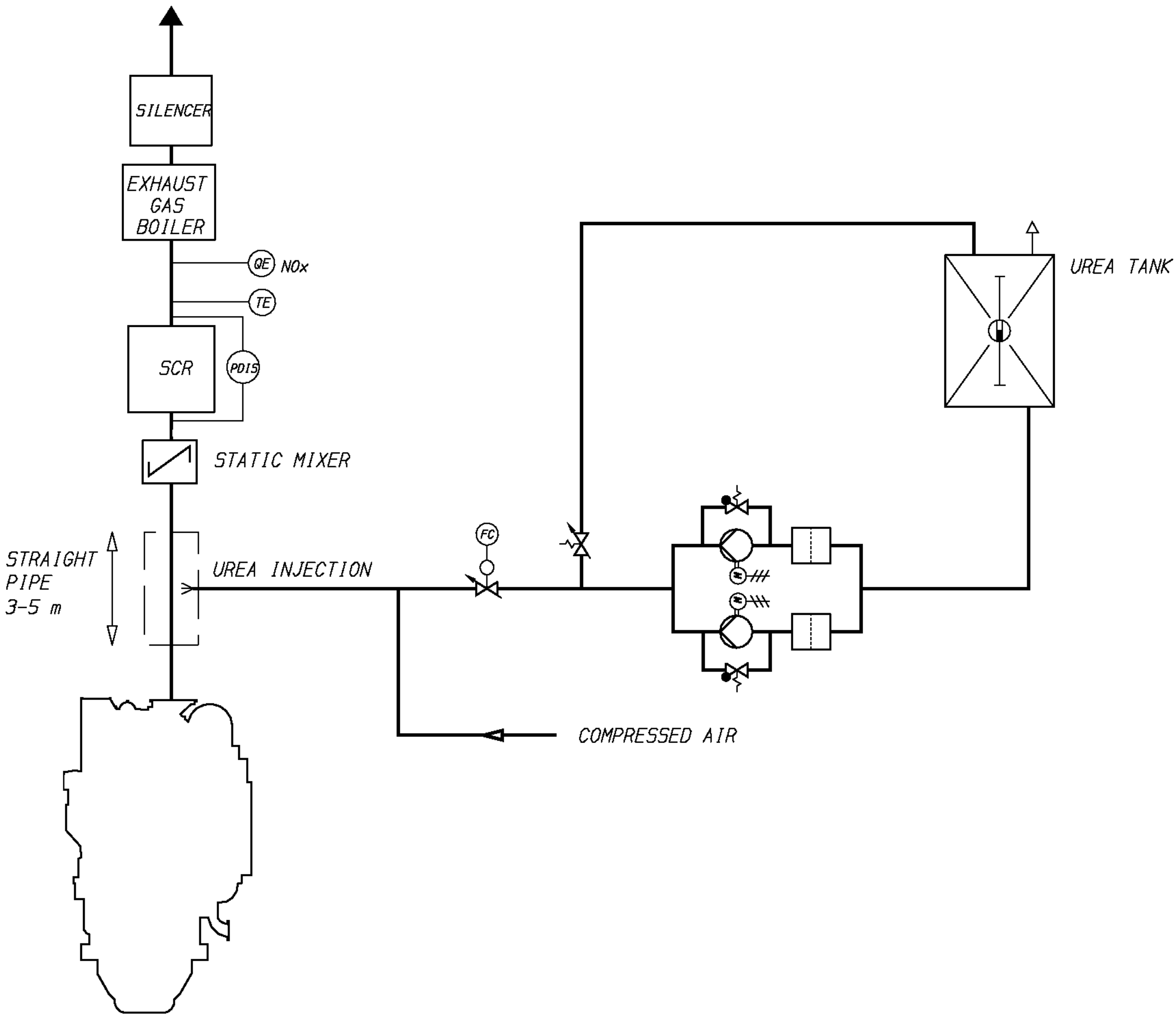
13.4.2 Selective Catalytic Reduction (SCR)

Selective Catalytic Reduction (SCR) is the only way to reach a NO_x reduction level of 85-95%. The disadvantages of the SCR are the large size and the relatively high installation and operation costs.

A reducing agent, aqueous solution of urea (40 wt-%), is injected into the exhaust gas directly after the turbocharger. Urea decays rapidly to ammonia (NH_3) and carbon dioxide. The mixture is passed through the catalyst where NO_x is converted to harmless nitrogen and water.

A typical SCR system comprises a urea solution storage tank, a urea solution pumping system, a reducing agent injection system and the catalyst housing with catalyst elements. In the next figure a typical SCR system is shown.

Figure 13.3 Typical P&ID for SCR system



The catalyst elements are of honeycomb type and are typically of a ceramic structure with the active catalytic material spread over the catalyst surface. The catalyst elements are arranged in layers and a soot blowing system should provided before each layer in order to avoid catalyst clogging.

The injection of urea is controlled by feedback from a NO_x measuring device after the catalyst. The rate of NO_x reduction depends on the amount of urea added, which can be expressed as NH_3/NO_x ratio. The increase of the catalyst volume can also increase the reduction rate.

When operating on HFO, the exhaust gas temperature before the SCR must be at least 330°C, depending on the sulphur content of the fuel. When operating on MDF, the exhaust gas temperature can be lower. If an exhaust gas boiler is specified, it should be installed after the SCR.

The lifetime of the catalyst is mainly dependent on the fuel oil quality and also to some extent on the lubricating oil quality. The lifetime of a catalyst is typically 3-5 years for liquid fuels and slightly longer if the engine is operating on gas. The total catalyst volume is usually divided into three layers of catalyst, and thus one layer at time can be replaced, and remaining activity in the older layers can be utilised.

Urea consumption and replacement of catalyst layers are generating the main running costs of the catalyst. The urea consumption is about 15 g/kWh of 40 wt-% urea. The urea solution can be prepared mixing urea granulates with water or the urea can be purchased as a 40 wt-% solution. The urea tank should be big enough for the ship to achieve the required autonomy.

14. Automation system

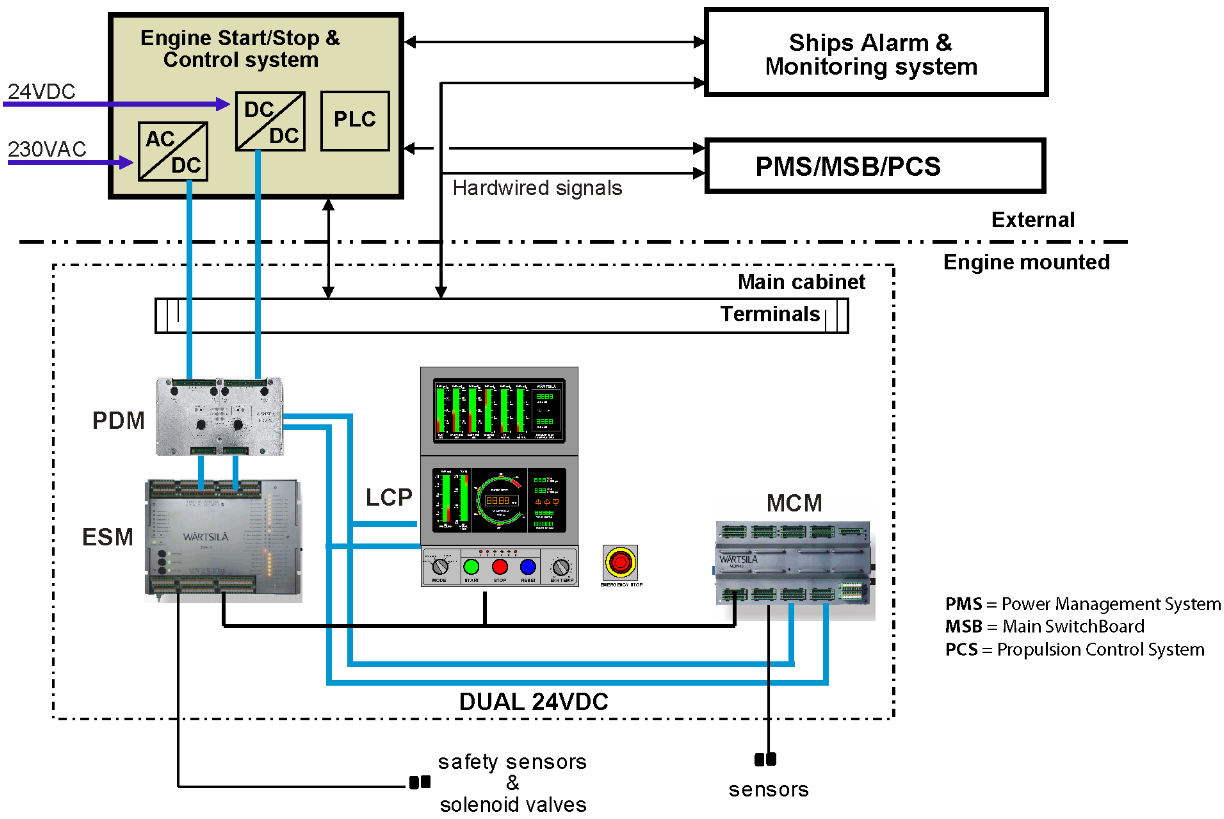
Wärtsilä Unified Controls – UNIC is a modular embedded automation system, which is available in three different versions. The basic functionality is the same in all versions, but the functionality can be easily expanded to cover different applications. UNIC C1 and UNIC C2 are applicable for engines with conventional fuel injection, whereas UNIC C3 additionally includes fuel injection control for engines with common rail fuel injection.

UNIC C1 has a completely hardwired signal interface with external systems, whereas UNIC C2 and C3 have hardwired interface for control functions and a bus communication interface for alarm and monitoring.

14.1 UNIC C1

The equipment on the engine included in UNIC C1 handles critical safety functions, some basic signal conversion and power distribution on the engine. The engine is equipped with push buttons for local operation and local display of the most important operating parameters. Speed control can also be integrated in the system on the engine. All terminals for signals to/from external systems are located in the main cabinet on the engine.

Figure 14.1 Architecture of UNIC C1



Equipment in the main cabinet on the engine:

MCM Main Control Module is used for speed/load control.

ESM Engine Safety Module handles fundamental engine safety, for example shutdown due to overspeed, low lubricating oil pressure, or oil mist in crankcase. The safety module is the interface to the shutdown devices on the engine for all other control equipment.

LCP Local Control Panel is equipped with push buttons and switches for local engine control, as well as a graphical panel with indication of the most important operating parameters.

PDM Power Distribution Module handles fusing, power distribution, earth fault monitoring and EMC filtration in the system. It provides two fully redundant 24 VDC supplies to all modules, sensors and control devices.

Equipment locally on the engine

- Sensors
- Solenoids
- Actuators

The above equipment is prewired to the main cabinet on the engine. The ingress protection class is IP54.

External equipment

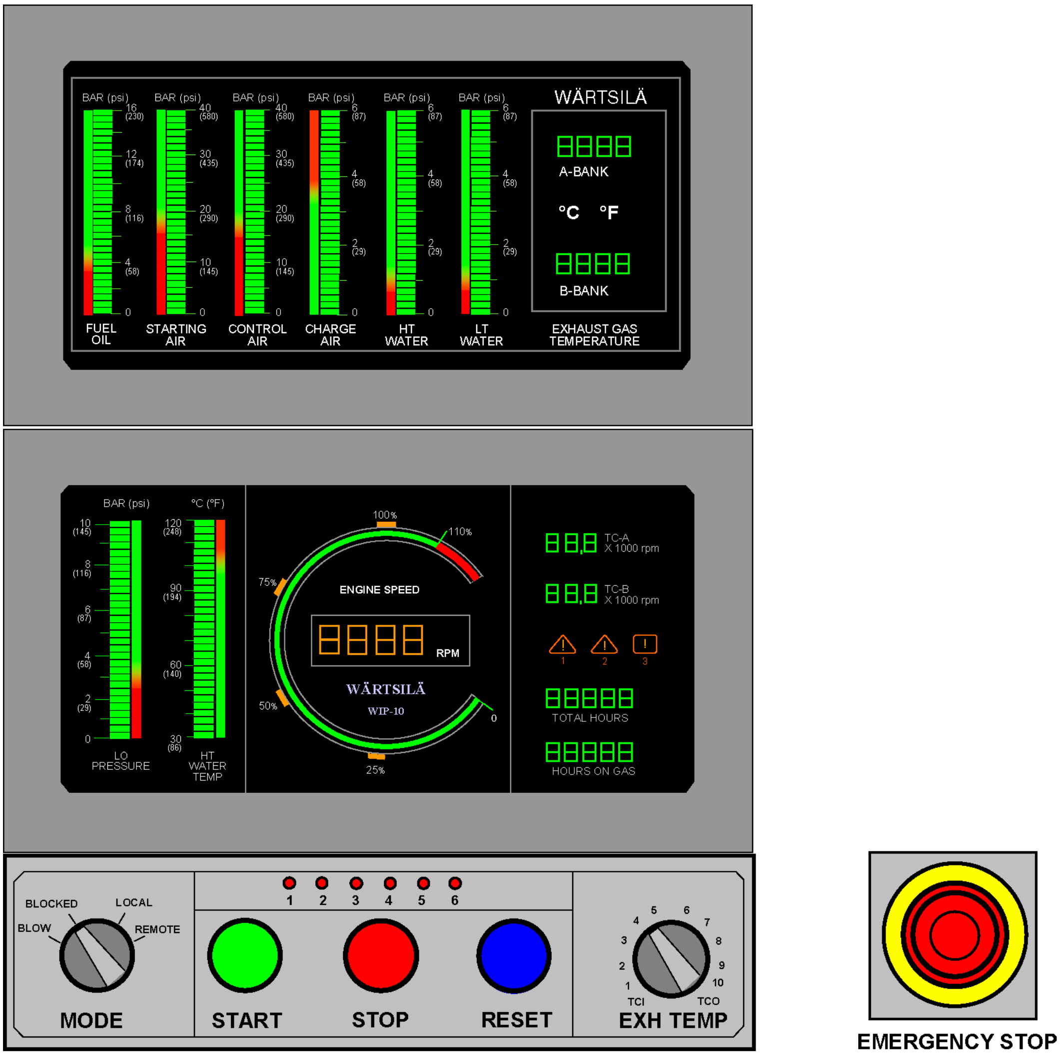
Engine start/stop & control system

The equipment listed below is mounted in a steel sheet cabinet for bulkhead mounting, protection class IP44.

- Programmable logic controller for startblockings, slowturning, wastegate control etc.
- Two redundant power supply converters/isolators
- Fuses and terminals
- Display unit

14.1.1 Local control panel (LCP)

Figure 14.2 Local control panel



Operational functions available at the LCP:

- Local start
- Local stop
- Local emergency stop
- Local shutdown reset
- Exhaust gas temperature selector switch
- Local mode selector switch with positions: blow, blocked, local and remote.
  - Local: Engine start and stop can be done only at the local control panel.
  - Remote: Engine can be started and stopped only remotely.
  - Blow: In this position it is possible to perform a “blow” (an engine rotation check with indicator valves open and disabled fuel injection) by the start button.
  - Blocked: Normal start of the engine is inhibited.

Parameters indicated at the LCP

- Engine speed
- Turbocharger speed
- Running hours
- Fuel oil pressure
- Lubricating oil pressure
- Starting air pressure
- Control air pressure
- Charge air pressure
- LT cooling water pressure
- HT cooling water pressure
- HT cooling water temperature
- Exhaust gas temperature after each cylinder, before and after the turbocharger

14.1.2 Engine safety system

The engine safety system is based on hardwired logic with redundant design for safety-critical functions. The engine safety module handles fundamental safety functions, for example overspeed protection. It is also the interface to the shutdown devices on the engine for all other parts of the control system.

Main features:

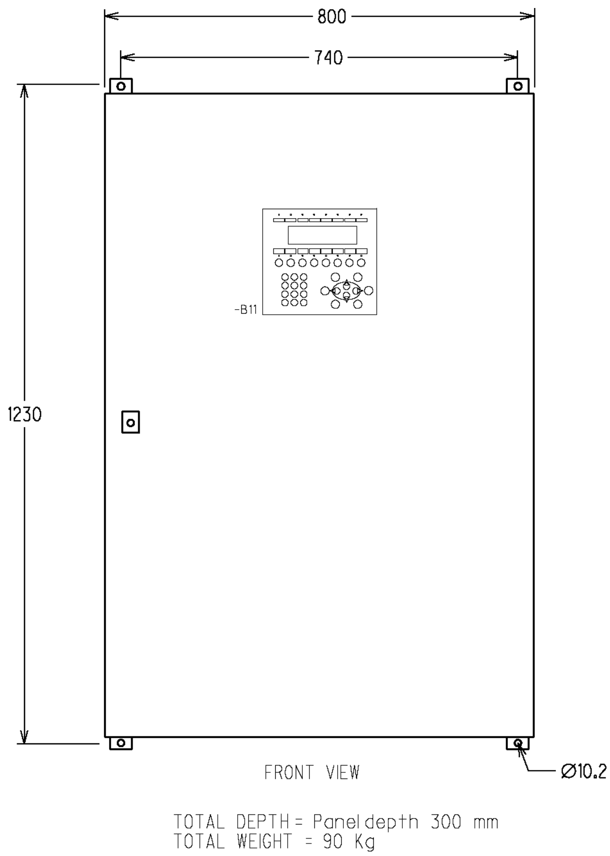
- Redundant design for power supply, speed inputs and shutdown solenoid control
- Fault detection on sensors, solenoids and wires
- Led indication of status and detected faults
- Digital status outputs
- Shutdown latching and reset
- Shutdown pre-warning
- Shutdown override (configuration depending on application)
- Analogue outputs for engine speed and turbocharger speed
- Adjustable speed switches

14.1.3 Engine start/stop & control system

The main features of the engine start/stop & control system are:

- Steel sheet cabinet for bulkhead mounting, protection class IP44
- Programmable logic controller for the main functions:
  - Startblocking
  - Slowturning and start sequence
  - Control of LT- and HT thermostatic valves, charge air bypass and exhaust gas wastegate
  - Control of pre-lubricating pump, cooling water pre-heater pump and standby pumps (when applicable) through external motor starters
- Display unit in the cabinet door showing the status of startblocking signals, shutdown reasons and control function parameters. Interface for adjustment of control parameters.
- Conversion to 24 VDC, isolation from other DC systems onboard, distribution of 2 x 24 VDC internally in the cabinet and to the engine mounted equipment, as well as bumpless switching between power supplies. At least one of the two incoming supplies must be connected to a UPS.
- Distribution of 230 VAC for timing rack-, HT-, LT thermostatic valve actuators
- Power supply from ship's system:
  - Supply 1: 230 VAC / abt. 1600 W
  - Supply 2: 24 VDC / abt. 200 W

Figure 14.3 Front layout of the cabinet



14.1.4 Cabling and system overview

The following figure and table show typical system- and cable interface overview for the engine in mechanical propulsion and generating set applications.

Figure 14.4 UNIC C1 overview

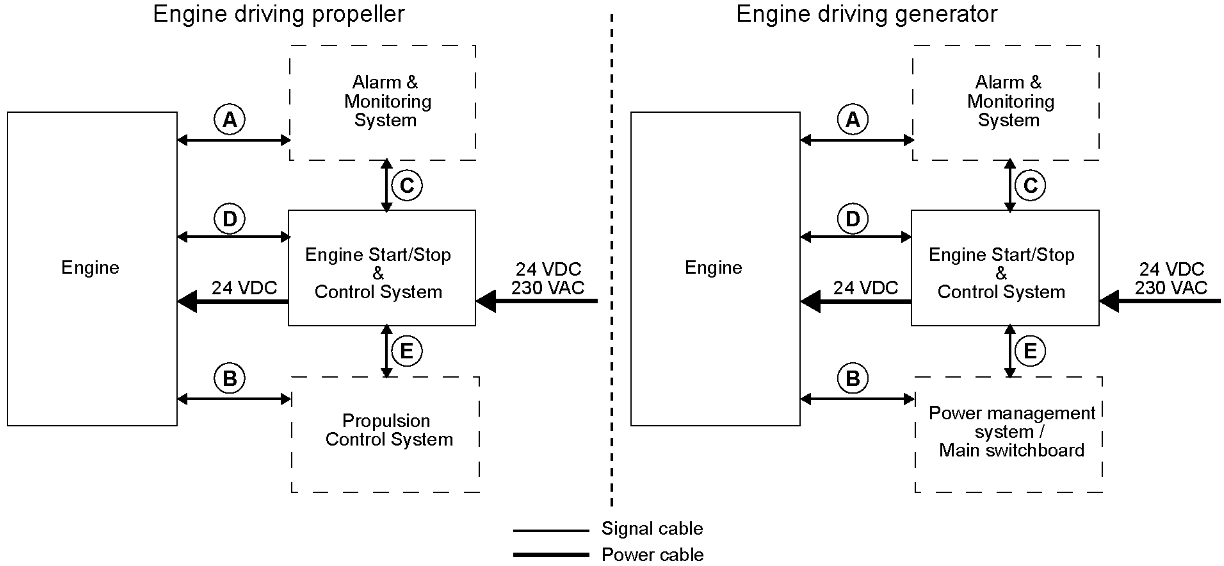


Table 14.1 Typical amount of cables for UNIC C1

Cable	From <=> To	Cable types (typical)
A	Engine <=> alarm & monitoring system	17 x 2 x 0.75 mm² 16 x 2 x 0.75 mm² 14 x 2 x 0.75 mm² 11 x 2 x 0.75 mm² 10 x 2 x 0.75 mm² 7 x 2 x 0.75 mm² 14 x 0.75 mm²
B	Engine <=> propulsion control system Engine <=> power management system / main switchboard	1 x 2 x 0.75 mm² 1 x 2 x 0.75 mm² 10 x 0.75 mm² 4 x 0.75 mm²
C	Engine start/stop & control system <=> alarm & monitoring system	4 x 2 x 0.75 mm² 15 x 0.75 mm²
D	Engine <=> engine start/stop & control system	4 x 2.5 mm² (power supply) 6 x 1.5 mm² 3 x 1.5 mm² 3 x 1.5 mm² 4 x 2 x 0.75 mm² 4 x 2 x 0.75 mm² 3 x 2 x 0.75 mm² 1 x 2 x 0.75 mm² 28 x 0.75 mm² 11 x 0.75 mm² 8 x 0.75 mm² 4 x 0.75 mm² 4 x 0.75 mm²
E	Engine start/stop & control system <=> propulsion control system Engine start/stop & control system <=> power management system / main switchboard	1 x 2 x 0.75 mm² 14 x 0.75 mm² 2 x 0.75 mm²

NOTE! Cable types and grouping of signals in different cables will differ depending on installation and cylinder configuration.

Power supply requirements are specified in section *Engine start/stop and control system*.

Figure 14.5 Signal overview (Main engine)

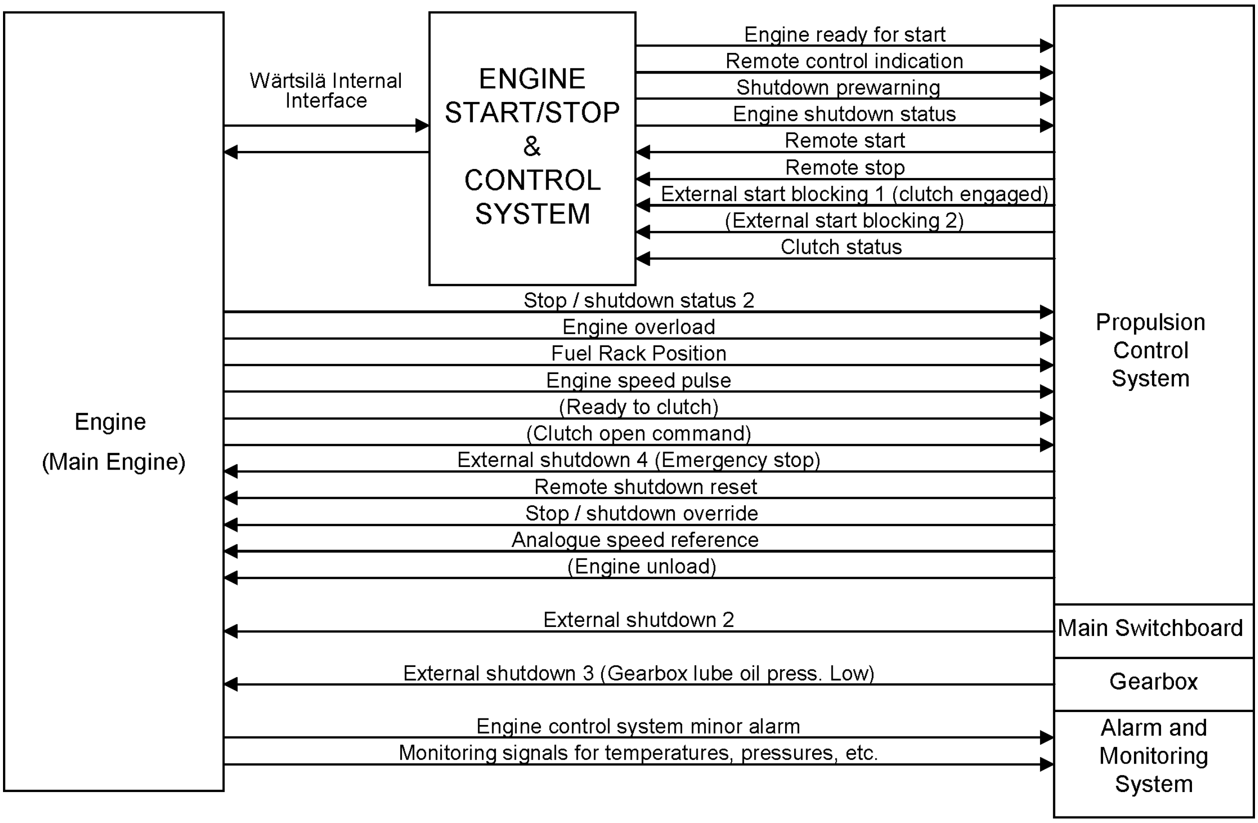
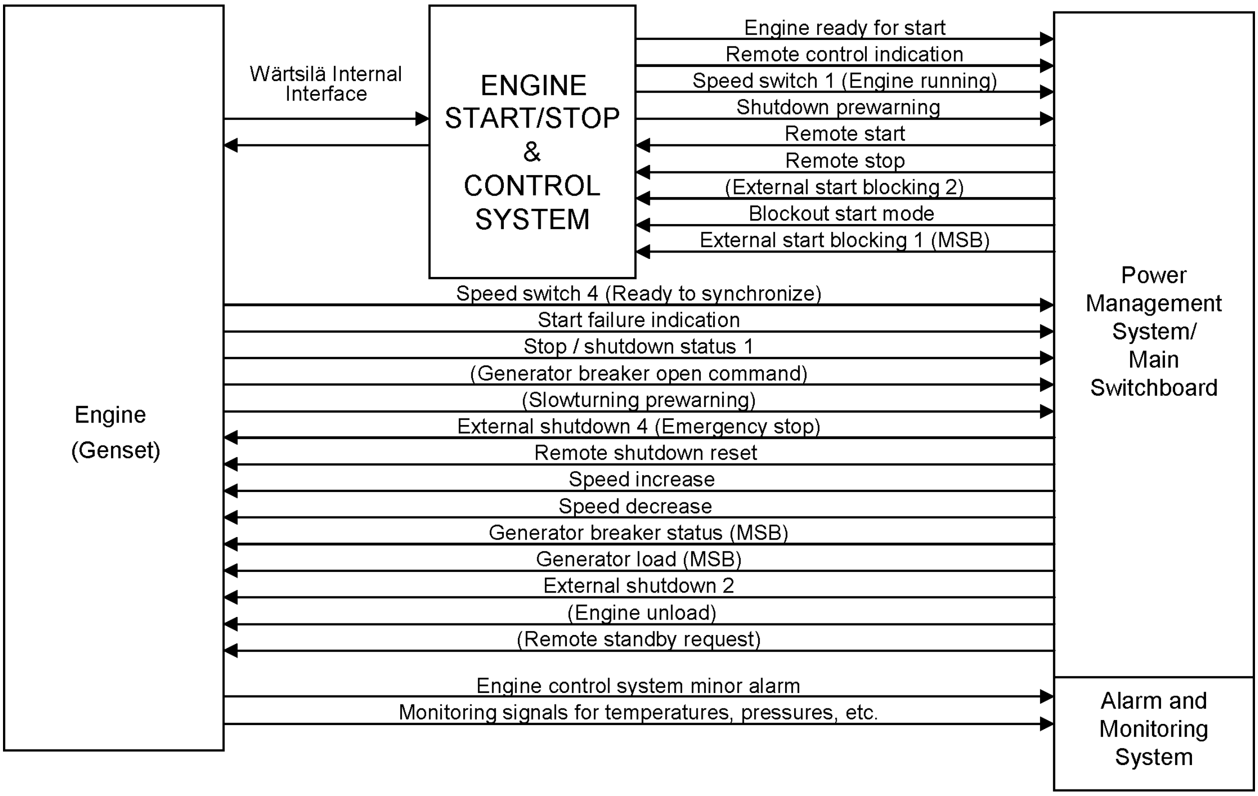


Figure 14.6 Signal overview (Generating set)



14.2 UNIC C2

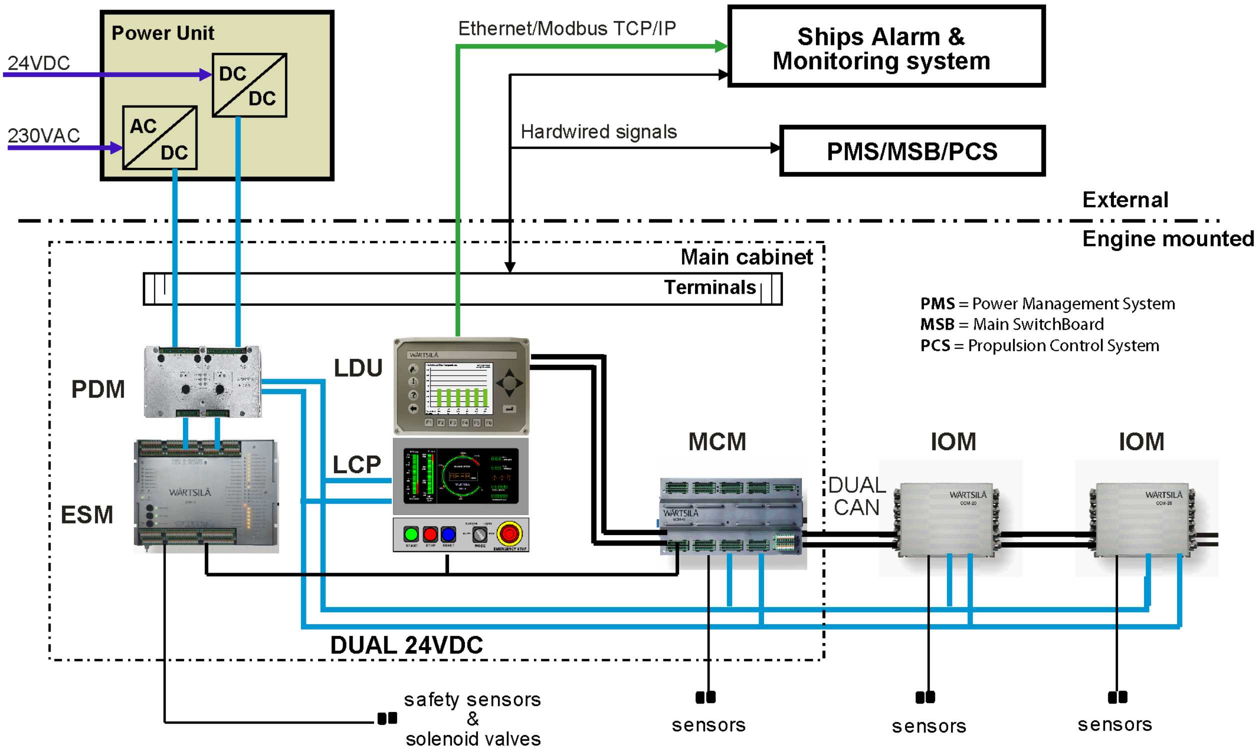
UNIC C2 is a fully embedded and distributed engine management system, which handles all control functions on the engine; for example start sequencing, start blocking, speed control, load sharing, normal stops and safety shutdowns.

The distributed modules communicate over a CAN-bus. CAN is a communication bus specifically developed for compact local networks, where high speed data transfer and safety are of utmost importance.

The CAN-bus and the power supply to each module are both physically doubled on the engine for full redundancy.

Control signals to/from external systems are hardwired to the terminals in the main cabinet on the engine. Process data for alarm and monitoring are communicated over an Modbus TCP connection to external systems.

Figure 14.7 Architecture of UNIC C2



Equipment in the main cabinet on the engine:

MCM Main Control Module handles all strategic control functions, for example start sequencing, start blocking and speed/load control. The module also supervises the fuel injection control on common rail engines.

ESM Engine Safety Module handles fundamental engine safety, for example shutdown due to overspeed or low lubricating oil pressure. The safety module is the interface to the shutdown devices on the engine for all other control equipment.

LCP Local Control Panel is equipped with push buttons and switches for local engine control, as well as indication of running hours and safety-critical operating parameters.

LDU Local Display Unit offers a set of menus for retrieval and graphical display of operating data, calculated data and event history. The module also handles communication with external systems over Modbus TCP.

PDM Power Distribution Module handles fusing, power distribution, earth fault monitoring and EMC filtration in the system. It provides two fully redundant 24 VDC supplies to all modules, sensors and control devices.

Equipment locally on the engine:

IOM Input/Output Module handles measurements and limited control functions in a specific area on the engine.

Sensors

Solenoids

Actuators

The above equipment is prewired on the engine. The ingress protection class is IP54.

External equipment

Power unit

Two redundant power supply converters/isolators are installed in a steel sheet cabinet for bulkhead mounting, protection class IP44.

14.2.1 Local control panel and local display unit

Operational functions available at the LCP:

- Local start
- Local stop
- Local emergency stop
- Local shutdown reset
- Local mode selector switch with positions blow, blocked, local and remote

  Positions:

  - Local: Engine start and stop can be done only at the local control panel
  - Remote: Engine can be started and stopped only remotely
  - Blow: In this position it is possible to perform a “blow” (an engine rotation check with indicator valves open and disabled fuel injection) by the start button
  - Blocked: Normal start of the engine is not possible

The LCP has back-up indication of the following parameters:

- Engine speed
- Turbocharger speed
- Running hours
- Lubricating oil pressure
- HT cooling water temperature

The local display unit has a set of menus for retrieval and graphical display of operating data, calculated data and event history.

Figure 14.8 Local control panel and local display unit

14.2.2 Engine safety system

The engine safety system is based on hardwired logic with redundant design for safety-critical functions. The engine safety module handles fundamental safety functions, for example overspeed protection. It is also the interface to the shutdown devices on the engine for all other parts of the control system.

Main features:

- Redundant design for power supply, speed inputs and stop solenoid control
- Fault detection on sensors, solenoids and wires
- Led indication of status and detected faults
- Digital status outputs
- Shutdown latching and reset
- Shutdown pre-warning
- Shutdown override (configuration depending on application)
- Analogue outputs for engine speed and turbocharger speed
- Adjustable speed switches

14.2.3 Power unit

A power unit is delivered with each engine for separate installation. The power unit supplies DC power to the electrical system on the engine and provides isolation from other DC systems onboard. The cabinet is designed for bulkhead mounting, protection degree IP44, max. ambient temperature 50 °C.

The power unit contains redundant power converters, each converter dimensioned for 100% load. At least one of the two incoming supplies must be connected to a UPS. The power unit supplies the equipment on the engine with 2 x 24 VDC.

Power supply from ship's system:

- Supply 1: 230 VAC / abt. 150 W
- Supply 2: 24 VDC / abt. 150 W.

14.2.4 Cabling and system overview

Figure 14.9 UNIC C2 overview

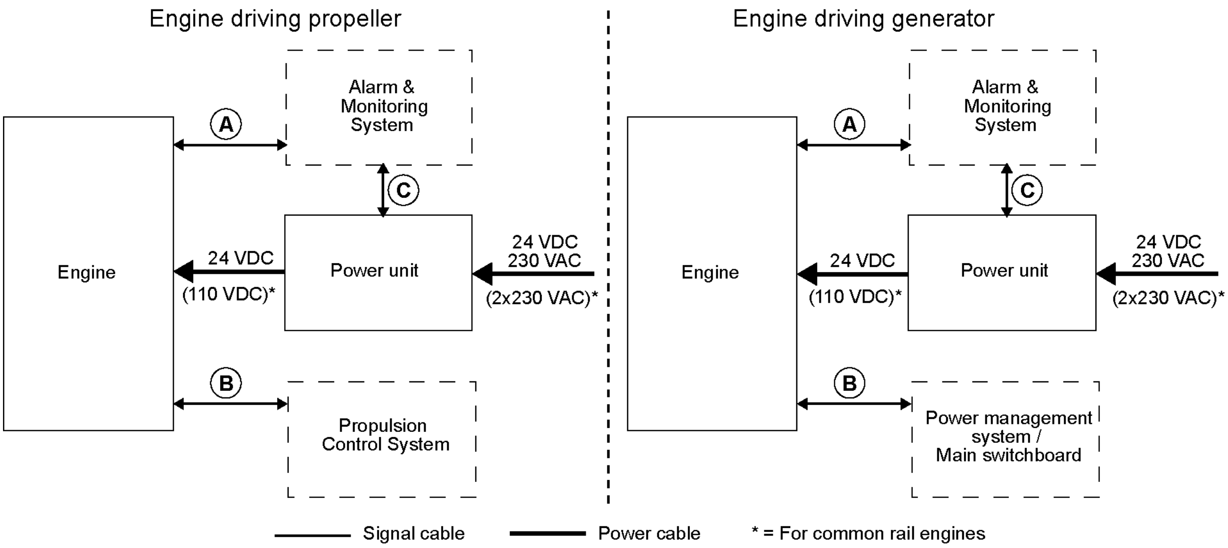


Table 14.2 Typical amount of cables for UNIC C2

Cable	From <=> To	Cable types (typical)
A	Engine <=> alarm & monitoring system	3 x 2 x 0.75 mm^2 4 x 2 x 0.5 mm^2 (Ethernet)
B	Engine <=> propulsion control system Engine <=> power management system / main switchboard	1 x 2 x 0.75 mm^2 16 x 0.75 mm^2 14 x 0.75 mm^2 8 x 0.75 mm^2
C	Power unit <=> alarm & monitoring system	2 x 0.75 mm^2
D	Engine <=> power unit	2 x 1.5 mm^2 (power supply) 2 x 1.5 mm^2 (power supply) 2 x 1.5 mm^2 (power supply) (CR) 2 x 1.5 mm^2 (power supply) (CR)

NOTE! Cable types and grouping of signals in different cables will differ depending on installation and cylinder configuration.

Power supply requirements are specified in section *Power unit*.

Figure 14.10 Signal overview (Main engine)

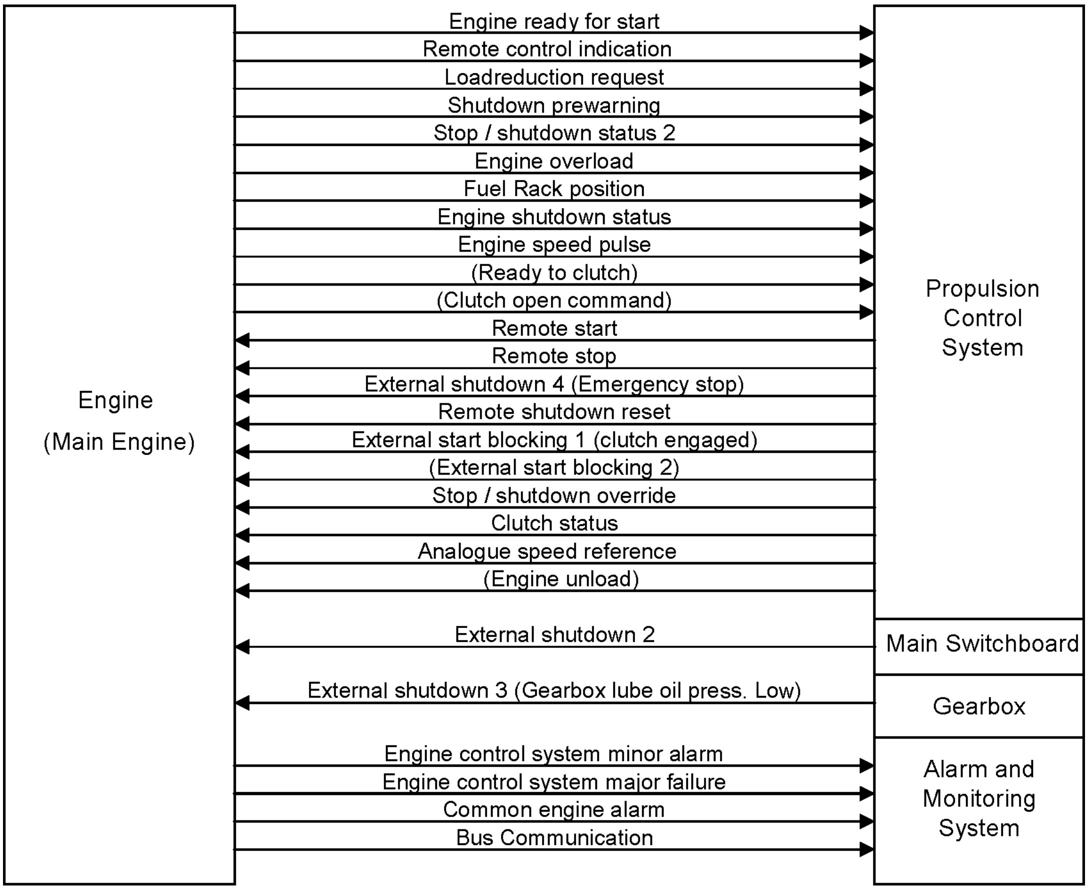
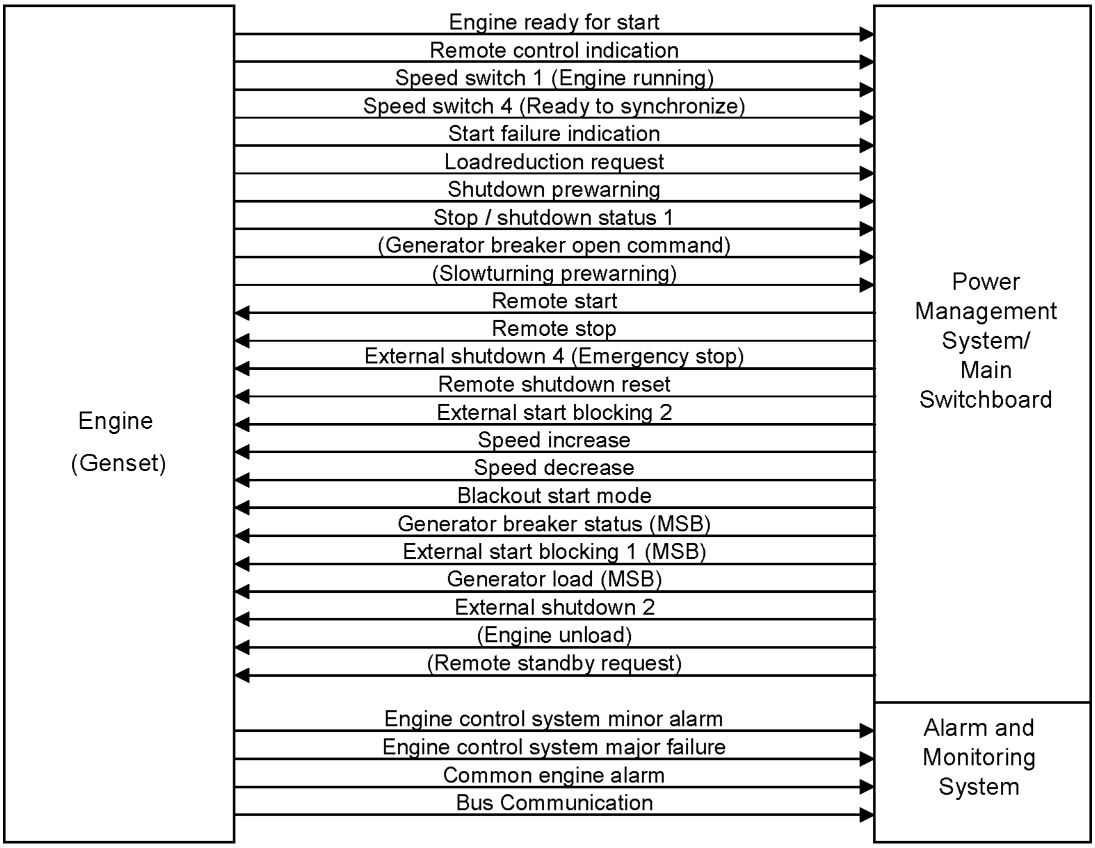


Figure 14.11 Signal overview (Generating set)



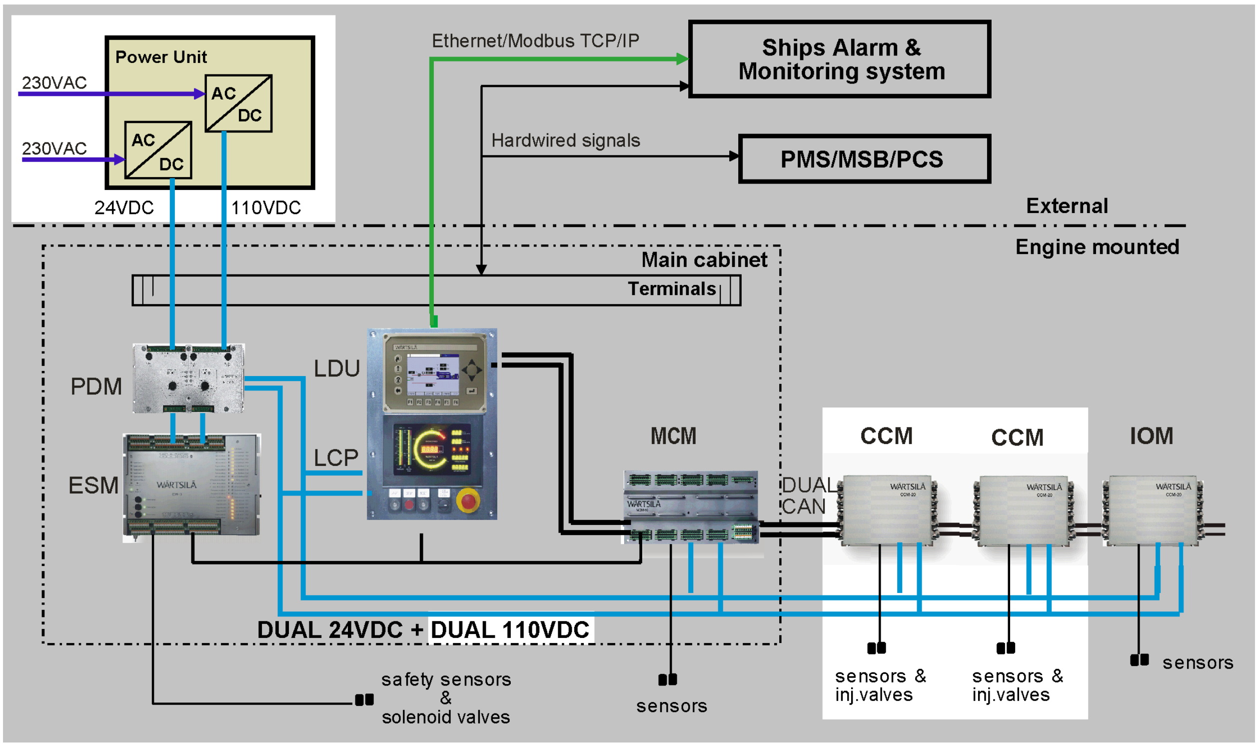
14.3 UNIC C3

The basic functionality is the same as in UNIC C2, but UNIC C3 additionally includes fuel injection control for engines with common rail fuel injection.

Differences compared to UNIC C2:

- Power supply from ship's system 2 x 230 VAC, each 600 W (no 24 VDC required).
- The power unit also supplies 2 x 110 VDC for the fuel injectors.
- Cylinder Control Modules (CCM) for fuel injection control.

Figure 14.12 Architecture of UNIC C3



14.4 Functions

14.4.1 Start

The engine is started by injecting compressed air directly into the cylinders. The solenoid controlling the master starting valve can be energized either locally with the start button, or from a remote control station. In an emergency situation it is also possible to operate the valve manually.

Injection of starting air is blocked both pneumatically and electrically when the turning gear is engaged. Fuel injection is blocked when the stop lever is in stop position (conventional fuel injection).

The starting air system is equipped with a slow turning valve, which rotates the engine slowly without fuel injection for a few turns before start. Slow turning is not performed if the engine has been running max. 30 minutes earlier, or if slow turning is automatically performed every 30 minutes. Stand-by diesel generators should have automatic slow turning.

Startblockings and slow turning are handled by the programmable logic in the external cabinet with UNIC C1, and by the system on the engine (main control module) with UNIC C2 and C3.

Startblockings

Starting is inhibited by the following functions:

- Turning gear engaged
- Stop lever in stop position

- Pre-lubricating pressure low
- Local engine selector switch in blocked position
- Stop or shutdown active
- External start blocking 1 (e.g. reduction gear oil pressure)
- External start blocking 2 (e.g. clutch position)
- Engine running

For restarting of a diesel generator in a blackout situation, start blocking due to low pre-lubricating oil pressure can be suppressed for 30 min.

14.4.2 Stop and shutdown

Normal stop is initiated either locally with the stop button, or from a remote control station. The control devices on the engine are held in stop position for a preset time until the engine has come to a complete stop. Thereafter the system automatically returns to “ready for start” state, provided that no start block functions are active, i.e. there is no need for manually resetting a normal stop.

Manual emergency shutdown is activated with the local emergency stop button, or with a remote emergency stop located in the engine control room for example.

The engine safety module handles safety shutdowns. Safety shutdowns can be initiated either independently by the safety module, or executed by the safety module upon a shutdown request from some other part of the automation system.

Typical shutdown functions are:

- Lubricating oil pressure low
- Overspeed
- Oil mist in crankcase
- Lubricating oil pressure low in reduction gear

Depending on the application it can be possible for the operator to override a shutdown. It is never possible to override a shutdown due to overspeed or an emergency stop.

Before restart the reason for the shutdown must be thoroughly investigated and rectified.

14.4.3 Speed control

Main engines (mechanical propulsion)

The electronic speed control is integrated in the engine automation system. For single main engines with conventional fuel injection a fuel rack actuator with a mechanical-hydraulic backup governor is specified. Mechanical back-up can also be specified for twin screw vessels with one engine per propellershaft.

Mechanical back-up is not an option in installations with two engines connected to the same reduction gear.

The remote speed setting from the propulsion control is an analogue 4-20 mA signal. It is also possible to select an operating mode in which the speed reference of the electronic speed control can be adjusted with increase/decrease signals.

The electronic speed control handles load sharing between parallel engines, fuel limiters, and various other control functions (e.g. ready to open/close clutch, speed filtering). Overload protection and control of the load increase rate must however be included in the propulsion control as described in the chapter *Operating ranges*.

Diesel generators

The electronic speed control is integrated in the engine automation system. Engine driven hydraulic fuel rack actuators are used on engines with conventional fuel injection.

The load sharing can be based on traditional speed droop, or handled independently by the speed control units without speed droop. The later load sharing principle is commonly referred to as isochronous load sharing. With isochronous load sharing there is no need for load balancing, frequency adjustment, or generator loading/unloading control in the external control system.

In a speed droop system each individual speed control unit decreases its internal speed reference when it senses increased load on the generator. Decreased network frequency with higher system load causes all generators to take on a proportional share of the increased total load. Engines with the same speed droop and speed reference will share load equally. Loading and unloading of a generator is accomplished by adjusting the speed reference of the individual speed control unit. The speed droop is normally 4%, which means that the difference in frequency between zero load and maximum load is 4%.

In isochronous mode the speed reference remains constant regardless of load level. Both isochronous load sharing and traditional speed droop are standard features in the speed control and either mode can be easily selected. If the ship has several switchboard sections with tie breakers between the different sections, then the status of each tie breaker is required for control of the load sharing in isochronous mode.

14.5 Alarm and monitoring signals

The number of sensors and signals may vary depending on the application. The actual configuration of signals and the alarm levels are found in the project specific documentation supplied for all contracted projects.

The table below lists typical sensors and signals for ship's alarm and monitoring system. The signal type is indicated for UNIC C1, which has a completely hardwired signal interface. UNIC C2 and C3 transmit information over a Modbus communication link to the ship's alarm and monitoring system.

Table 14.3 Typical sensors and signals

Code	Description	I/O type	Signal type	Range
PT101	Fuel oil pressure, engine inlet	AI	4-20 mA	0-16 bar
TE101	Fuel oil temp., engine inlet	AI	PT100	0-160 °C
LS103A	Fuel oil leakage, injection pipe (A-bank)	DI	Pot. free	on/off
LS103B 1)	Fuel oil leakage, injection pipe (B-bank)	DI	Pot. free	on/off
LS106A	fuel oil leakage, clean fuel, free end (A-bank)	DI	Pot. free	on/off
LS106B 1)	fuel oil leakage, clean fuel, free end (B-bank)	DI	Pot. free	on/off
LS108A	Fuel oil leakage, dirty fuel (A-bank)	DI	Pot. free	on/off
LS108B 1)	Fuel oil leakage, dirty fuel (B-bank)	DI	Pot. free	on/off
PT201	Lub. oil pressure, engine inlet	AI	4-20 mA	0-10 bar
TE201	Lub. oil temp., engine inlet	AI	PT100	0-160 °C
TE231	Lub. oil temp, LOC inlet	AI	PT100	0-160 °C
PDT243	Lube oil filter pressure difference	AI	4-20 mA	0-2 bar
PT271	Lube oil pressure, TC A inlet	AI	4-20 mA	0-10 bar
TE272	Lube oil temp., TC A outlet	AI	PT100	0-160 °C
PT281 1)	Lube oil pressure, TC B inlet	AI	4-20 mA	0-10 bar
TE282 1)	Lube oil temp., TC B outlet	AI	PT100	0-160 °C
PT301	Starting air pressure	AI	4-20 mA	0-40 bar
PT311	Control air pressure	AI	4-20 mA	0-40 bar
PT312	Instrument air pressure	AI	4-20 mA	0-10 bar
PT401	HT water pressure, jacket inlet	AI	4-20 mA	0-6 bar
TE401	HT water temp., jacket inlet	AI	PT100	0-160 °C
TE402	HT water temp., jacket outlet, A-bank	AI	PT100	0-160 °C
TEZ402	HT water temp., jacket outlet, A-bank	AI	PT100	0-160 °C
TE403 1)	HT water temp., jacket outlet, B-bank	AI	PT100	0-160 °C
TEZ403 1)	HT water temp., jacket outlet, B-bank	AI	PT100	0-160 °C
TE432	HT water temp., HT CAC outlet	AI	PT100	0-160 °C
PT471	LT water pressure, CAC inlet	AI	4-20 mA	0-6 bar
TE471	LT water temp., LT CAC inlet	AI	PT100	0-160 °C
TE472	LT water temp., CAC outlet	AI	PT100	0-160 °C
TE482	LT water temp., LOC outlet	AI	PT100	0-160 °C

Code	Description	I/O type	Signal type	Range
TE5011A ... TE5091A	Exhaust gas temp., cylinder A1 outlet ... Exhaust gas temp., cylinder A9 outlet	AI	4-20 mA	0-750 °C
TE5011B 1) ... TE5091B	Exhaust gas temp., cylinder B1 outlet ... Exhaust gas temp., cylinder B9 outlet	AI	4-20 mA	0-750 °C
TE511	Exhaust gas temp., TC A inlet	AI	4-20 mA	0-750 °C
TE521 1)	Exhaust gas temp., TC B inlet	AI	4-20 mA	0-750 °C
TE517	Exhaust gas temp., TC A outlet	AI	4-20 mA	0-750 °C
TE527 1)	Exhaust gas temp., TC B outlet	AI	4-20 mA	0-750 °C
TE600	Air temp. TC inlet	AI	PT100	0-160 °C
PT601	Charge air pressure, CAC outlet	AI	4-20 mA	0-6 bar
TE601	Charge air temp. engine inlet	AI	PT100	0-160 °C
TE621	Charge air temp. CAC inlet A bank	AI	4-20 mA	0-750 °C
TE631 1)	Charge air temp. CAC inlet B bank	AI	4-20 mA	0-750 °C
TE700 ... TE710	Main bearing 0 temp ... Main bearing 10 temp	AI	4-20 mA	0-250 °C
TE7016 ... TE7076	Big end bearing 1 temp ... Big end bearing 8 temp	AI	4-20 mA	0-160 °C
TE7011A ... TE7092B	Cylinder liner temp, 2 sensors/cylinder	AI	4-20 mA	0-250 °C
PT700	Crankcase pressure	AI	4-20 mA	0-10 mbar
NS700	Oil mist detector failure	DI	Pot. free	on/off
QS700	Oil mist in crankcase, alarm	DI	Pot. free	on/off
IS1741	Alarm, overspeed shutdown	DI	Pot. free	on/off
IS2011	Alarm, lub oil press. low shutdown	DI	Pot. free	on/off
IS7311	Alarm, red.gear lo press low shutdown	DI	Pot. free	on/off
IS7338	Alarm, oil mist in crankcase shutdown	DI	Pot. free	on/off
IS7339	Alarm, big end bearing temp. high shutdown	DI	Pot. free	on/off
IS7305	Emergency stop	DI	Pot. free	on/off
NS881	Engine control system minor alarm	DI	Pot. free	on/off
IS7306	Alarm, shutdown override	DI	Pot. free	on/off
SI196	Engine speed	AI	4-20 mA	0-750 rpm
SI518	Turbocharger A speed	AI	4-20 mA	0-25000 rpm
SI528 1)	Turbocharger B speed	AI	4-20 mA	0-25000 rpm
IS875	Start failure	DI	Pot. free	on/off
	Power supply failure	DI	Pot. free	on/off

Note 1 V-engines only

14.6 Electrical consumers

14.6.1 Motor starters and operation of electrically driven pumps

Separators, preheaters, compressors and fuel feed units are normally supplied as pre-assembled units with the necessary motor starters included. The engine turning device and various electrically driven pumps require separate motor starters. Motor starters for electrically driven pumps are to be dimensioned according to the selected pump and electric motor.

Motor starters are not part of the control system supplied with the engine, but available as optional delivery items.

Engine turning device (9N15)

The crankshaft can be slowly rotated with the turning device for maintenance purposes. The motor starter must be designed for reversible control of the motor. The electric motor ratings are listed in the table below.

Table 14.4 Electric motor ratings for engine turning device

Engine	Voltage [V]	Frequency [Hz]	Power [kW]	Current [A]
6L46F, 7L46F, 8L46F	3 x 400/440	50/60	2.2/2.6	5
9L46F	3 x 400/440	50/60	5.5/6.4	12

Pre-lubricating oil pump (2P02)

The pre-lubricating oil pump must always be running when the engine is stopped. The pump shall start when the engine stops, and stop when the engine starts. The engine control system handles start/stop of the pump automatically via a motor starter.

It is recommended to arrange a back-up power supply from an emergency power source. Diesel generators serving as the main source of electrical power must be able to resume their operation in a black out situation by means of stored energy. Depending on system design and classification regulations, it may be permissible to use the emergency generator.

Stand-by pump, lubricating oil (if installed) (2P04)

The engine control system starts the pump automatically via a motor starter, if the lubricating oil pressure drops below a preset level when the engine is running. There is a dedicated sensor on the engine for this purpose.

The pump must not be running when the engine is stopped, nor may it be used for pre-lubricating purposes. Neither should it be operated in parallel with the main pump, when the main pump is in order.

Stand-by pump, HT cooling water (if installed) (4P03)

The engine control system starts the pump automatically via a motor starter, if the cooling water pressure drops below a preset level when the engine is running. There is a dedicated sensor on the engine for this purpose.

Stand-by pump, LT cooling water (if installed) (4P05)

The engine control system starts the pump automatically via a motor starter, if the cooling water pressure drops below a preset level when the engine is running. There is a dedicated sensor on the engine for this purpose.

Circulating pump for preheater (4P04)

If the main cooling water pump (HT) is engine driven, the preheater pump shall start when the engine stops (to ensure water circulation through the hot engine) and stop when the engine starts. The engine control system handles start/stop of the pump automatically via a motor starter.

Sea water pumps (4P11)

The pumps can be stopped when all engines are stopped, provided that cooling is not required for other equipment in the same circuit.

Lubricating oil separator (2N01)

Continuously in operation.

Feeder/booster unit (1N01)

Continuously in operation.

14.7 System requirements and guidelines for diesel-electric propulsion

Typical features to be incorporated in the propulsion control and power management systems in a diesel-electric ship:

1. The load increase program must limit the load increase rate during ship acceleration and load transfer between generators according to the curves in chapter *2.2 Loading Capacity*.

- Continuously active limit: “normal max. loading in operating condition”.
- During the first 6 minutes after starting an engine: “preheated engine”

If the control system has only one load increase ramp, then the ramp for a preheated engine is to be used.

The load increase rate of a recently connected generator is the sum of the load transfer performed by the power management system and the load increase performed by the propulsion control, if the load sharing is based on speed droop. In a system with isochronous load sharing the loading rate of a recently connected generator is not affected by changes in the total system load (as long as the generators already sharing load equally are not loaded over 100%).

2. Rapid loading according to the “emergency” curve in chapter *2.2 Loading Capacity* may only be possible by activating an emergency function, which generates visual and audible alarms in the control room and on the bridge.

3. The propulsion control should be able to control the propulsion power according to the load increase rate at the diesel generators. Controlled load increase with different number of generators connected and in different operating conditions is difficult to achieve with only time ramps for the propeller speed.

4. The load reduction rate should also be limited in normal operation. Crash stop can be recognised by for example a large lever movement from ahead to astern.

5. Some propulsion systems can generate power back into the network. The diesel generator can absorb max. 5% reverse power.

6. The power management system performs loading and unloading of generators in a speed droop system, and it usually also corrects the system frequency to compensate for the droop offset, by adjusting the speed setting of the individual speed control units. The speed reference is adjusted by sending an increase/decrease pulse of a certain length to the speed control unit. The power management should determine the length of the increase/decrease pulse based on the size of the desired correction and then wait for 30 seconds or more before performing a new correction, in particular when performing small corrections.

The relation between duration of increase/decrease signal and change in speed reference is usually 0.1 Hz per second. The actual speed and/or load will change at a slower rate.

7. The full output of the generator is in principle available as soon as the generator is connected to the network, but only if there is no power limitation controlling the power demand. In practice the control system should monitor the generator load and reduce the system load, if the generator load exceeds 100%.

In speed droop mode all generators take an equal share of increased system load, regardless of any difference in initial load. If the generators already sharing load equally are loaded beyond their max. capacity, the recently connected generator will continue to pick up load according to the speed droop curve. Also in isochronous load sharing mode a generator still on the loading ramp will start to pick up load, if the generators in even load sharing have reached their max. capacity.

8. The system should monitor the network frequency and reduce the load, if the network frequency tends to drop excessively. To safely handle tripping of a breaker more direct action can be required, depending on the operating condition and the load step on the engine(s).

15. Foundation

Engines can be either rigidly mounted on chocks, or resiliently mounted on steel spring elements. If resilient mounting is considered, Wärtsilä must be informed about existing excitations such as propeller blade passing frequency. Dynamic forces caused by the engine are listed in the chapter *Vibration and noise*.

15.1 Steel structure design

The system oil tank should not extend under the reduction gear or generator, if the oil tank is located beneath the engine foundation. Neither should the tank extend under the support bearing, in case there is a PTO arrangement in the free end. The oil tank must also be symmetrically located in transverse direction under the engine.

The foundation and the double bottom should be as stiff as possible in all directions to absorb the dynamic forces caused by the engine, reduction gear and thrust bearing.

The foundation should be dimensioned and designed so that harmful deformations are avoided.

The foundation of the driven equipment should be integrated with the engine foundation.

15.2 Engine mounting

The mounting arrangement is similar for diesel electric installations and conventional propulsion.

15.2.1 Rigid mounting

Engines can be rigidly mounted to the foundation either on steel chocks or resin chocks.

The holding down bolts are through-bolts with a lock nut at the lower end and a hydraulically tightened nut at the upper end. The tool included in the standard set of engine tools is used for hydraulic tightening of the holding down bolts. Bolts number two and three from the flywheel end on each side of the engine are to be Ø46 H7/n6 fitted bolts. The rest of the holding down bolts are clearance bolts.

A distance sleeve should be used together with the fitted bolts. The distance sleeve must be mounted between the seating top plate and the lower nut in order to provide a sufficient guiding length for the fitted bolt in the seating top plate. The guiding length in the seating top plate should be at least equal to the bolt diameter.

The design of the holding down bolts appear from the foundation drawing. It is recommended that the bolts are made from a high-strength steel, e.g. 42CrMo4 or similar. A high strength material makes it possible to use a higher bolt tension, which results in a larger bolt elongation (strain). A large bolt elongation improves the safety against loosening of the nuts.

To avoid a gradual reduction of tightening tension due to unevenness in threads, the threads should be machined to a finer tolerance than normal threads. The bolt thread must fulfil tolerance 6g and the nut thread must fulfil tolerance 6H. In order to avoid bending stress in the bolts and to ensure proper fastening, the contact face of the nut underneath the seating top plate should be counterbored.

Lateral supports must be installed for all engines. One pair of supports should be located at the free end and one pair (at least) near the middle of the engine. The lateral supports are to be welded to the seating top plate before fitting the chocks. The wedges in the supports are to be installed without clearance, when the engine has reached normal operating temperature. The wedges are then to be secured in position with welds. An acceptable contact surface must be obtained on the wedges of the supports.

Resin chocks

The recommended dimensions of the resin chocks are 600 x 180 mm. The total surface pressure on the resin must not exceed the maximum value, which is determined by the type of resin and the requirements of the classification society.

It is recommended to select a resin type that is approved by the relevant classification society for a total surface pressure of 5 N/mm^2. (A typical conservative value is P_{tot} 3.5 N/mm^2).

During normal conditions, the support face of the engine feet has a maximum temperature of about 75°C, which should be considered when selecting the type of resin.

The bolts must be made as tensile bolts with a reduced shank diameter to ensure a sufficient elongation since the bolt force is limited by the permissible surface pressure on the resin. For a given bolt diameter the permissible bolt tension is limited either by the strength of the bolt material (max. stress 80% of the yield strength), or by the maximum permissible surface pressure on the resin.

Locking of the upper nuts is required when the total surface pressure on the resin chocks is below 4 MPa with the recommended chock dimensions. The lower nuts should always be locked regardless of the bolt tension.

Steel chocks

The top plates of the engine girders are normally inclined outwards with regard to the centre line of the engine. The inclination of the supporting surface should be 1/100. The seating top plate should be designed so that the wedge-type steel chocks can easily be fitted into their positions. The wedge-type chocks also have an inclination of 1/100 to match the inclination of the seating. If the top plate of the engine girder is fully horizontal, a chock is welded to each point of support. The chocks should be welded around the periphery as well as through holes drilled for this purpose at regular intervals to avoid possible relative movement in the surface layer. The welded chocks are then face-milled to an inclination of 1/100. The surfaces of the welded chocks should be large enough to fully cover the wedge-type chocks.

The supporting surface of the seating top plate should be machined so that a bearing surface of at least 75% is obtained. The chock should be fitted so that they are approximately equally inserted under the engine on both sides.

The chocks should always cover two bolts, except the chock closest to the flywheel, which accommodates only one bolt. Steel is preferred, but cast iron chocks are also accepted.

Holes are to be drilled and reamed to the correct tolerance for the fitted bolts after the coupling alignment has been checked and the chocks have been lightly knocked into position.

Steel chocks with adjustable height

As an alternative to resin chocks or conventional steel chocks it is also permitted to install the engine on adjustable steel chocks. The chock height is adjustable between 45 mm and 65 mm for the approved type of chock. There must be a chock of adequate size at the position of each holding down bolt.

15.2.2 Resilient mounting

In order to reduce vibrations and structure borne noise, engines can be resiliently mounted on steel spring elements. The transmission of forces emitted by the engine is 10-20% when using resilient mounting. Typical structure borne noise levels can be found in chapter 17.

The resilient elements consist of an upper steel plate fastened directly to the engine, vertical steel springs, and a lower steel plate fastened to the foundation. Resin chocks are cast under the lower steel plate after final alignment adjustments and drilling of the holes for the fastening screws. The steel spring elements are compressed to the calculated height under load and locked in position on delivery. Compression screws and distance pieces between the two steel plates are used for this purpose.

Rubber elements are used in the transverse and longitudinal buffers. Steel chocks must be used under the horizontal buffers.

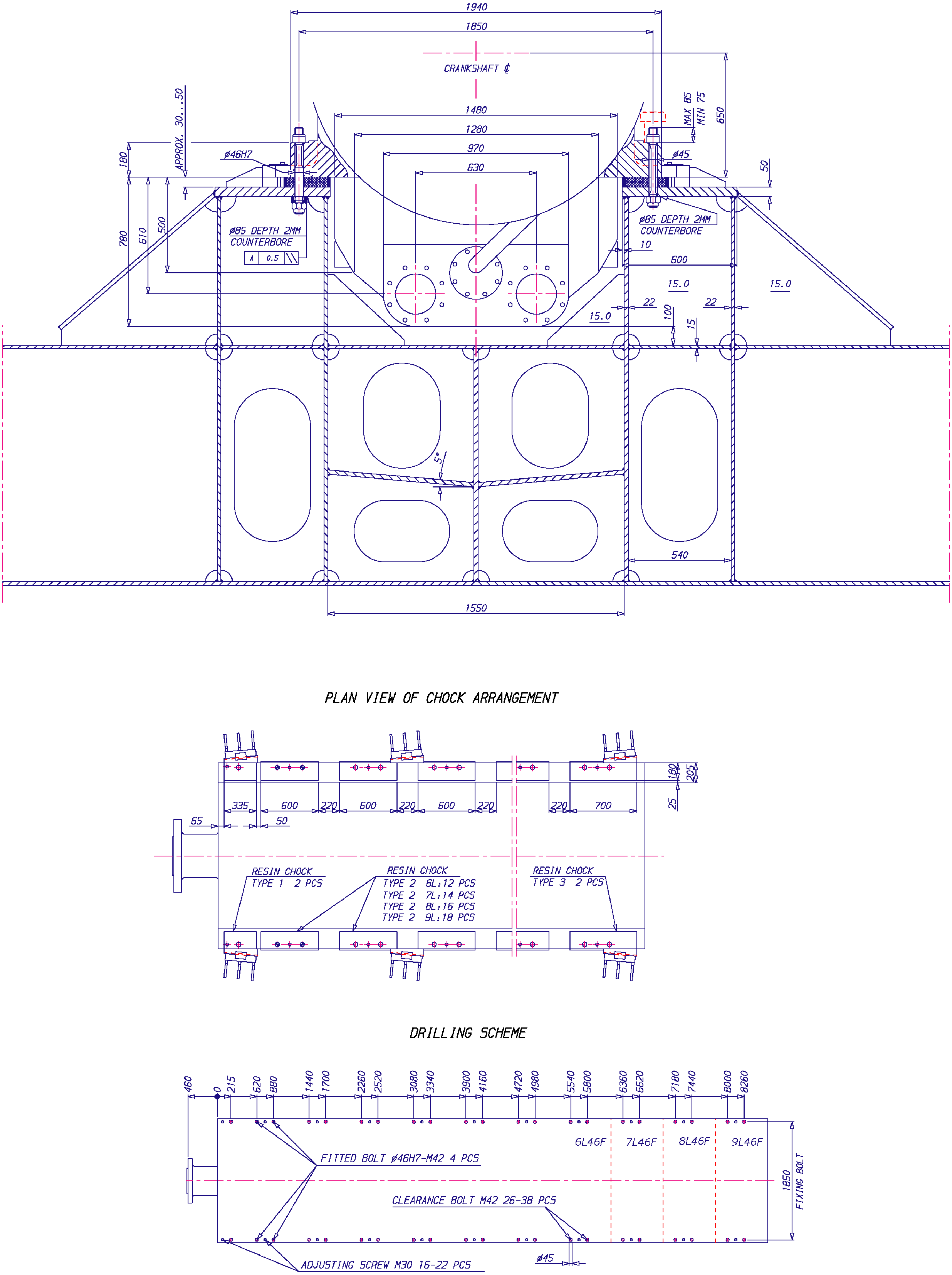
The speed range is limited to 450-600 rpm for resiliently mounted 8L46F engines. For other cylinder configurations a speed range of 400-600 rpm is generally available.

Flexible pipe connections

When the engine is resiliently mounted, all connections must be flexible and no grating nor ladders may be fixed to the engine. Especially the connection to the turbocharger must be arranged so that the above mentioned displacements can be absorbed, without large forces on the turbocharger.

Proper fixing of pipes next to flexible pipe connections is not less important for resiliently mounted engines. See the chapter *Piping design, treatment and installation* for more detailed information.

Figure 15.1 Seating and fastening, installation on resin chocks (DAAE012078)



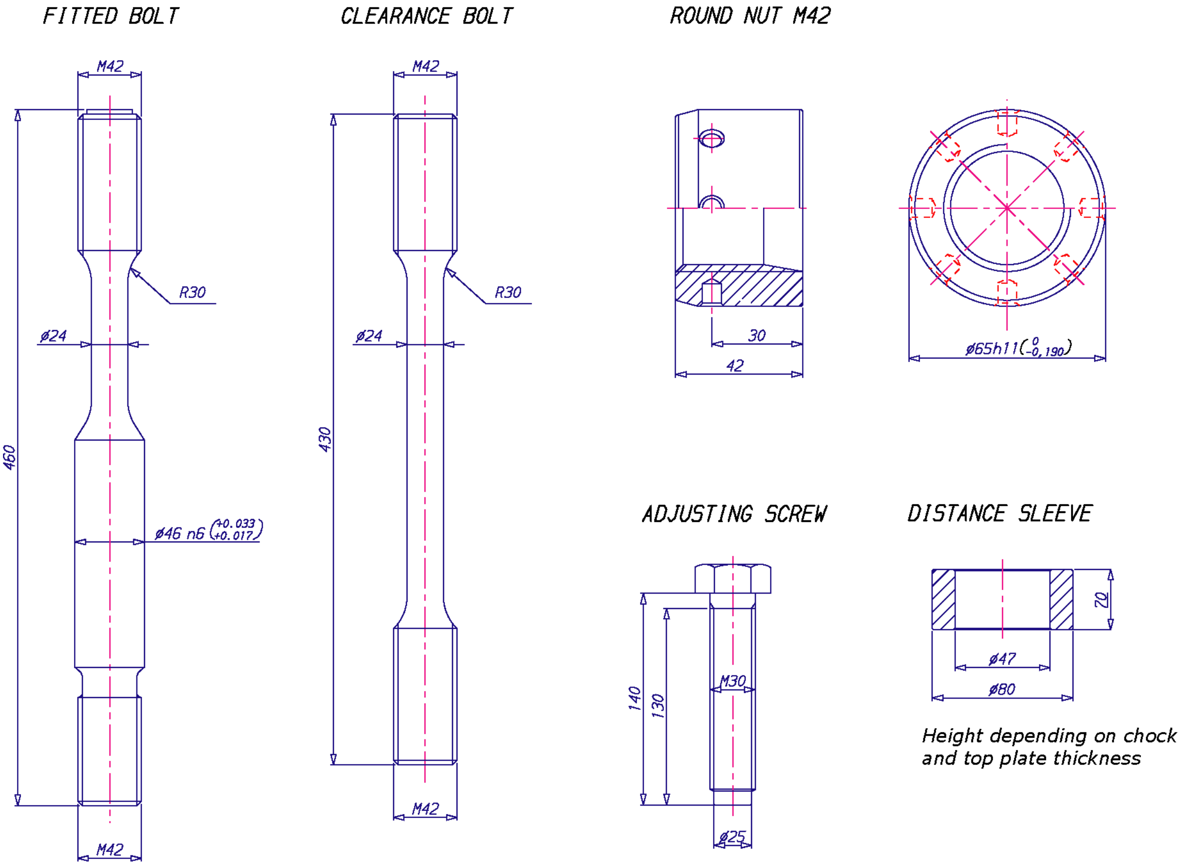
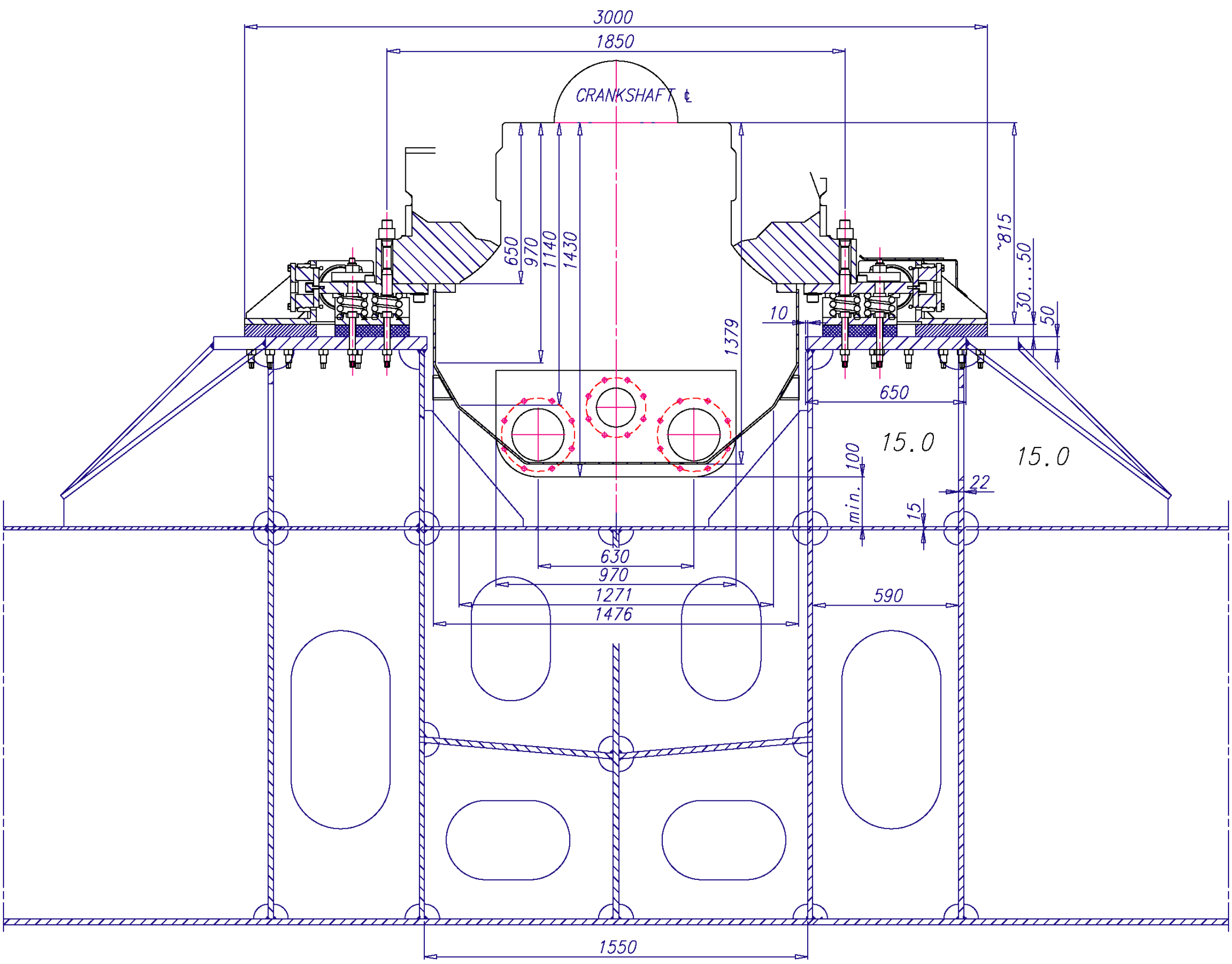


Figure 15.2 Transverse section of resilient mounting (DAAE029031)



16. Vibration and noise

Resiliently mounted engines comply with the requirements of the following standards regarding vibration level on the engine:

6L engines	ISO 10816-6 Class 4
other cylinder configurations	ISO 10816-6 Class 5

16.1 External forces and couples

Some cylinder configurations produce dynamic forces and couples. These are listed in the tables below.

The ship designer should avoid natural frequencies of decks, bulkheads and superstructures close to the excitation frequencies. The double bottom should be stiff enough to avoid resonances especially with the rolling frequencies.

Figure 16.1 Coordinate system

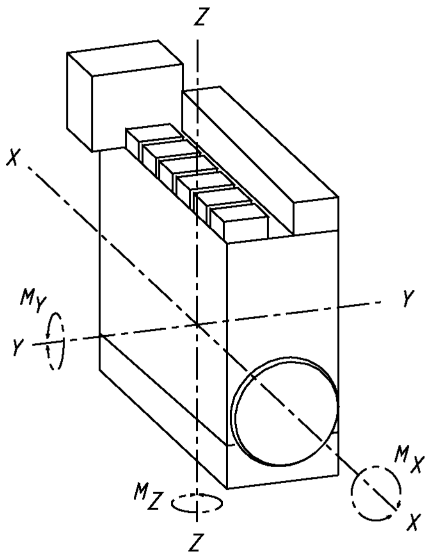


Table 16.1 External forces

Engine	Speed [rpm]	Frequency [Hz]	F_Y [kN]	F_Z [kN]	Frequency [Hz]	F_Y [kN]	F_Z [kN]	Frequency [Hz]	F_Y [kN]	F_Z [kN]
8L46F	600	10	–	–	20	–	–	40	–	12.3

– forces are zero or insignificant

Table 16.2 External couples

Engine	Speed [rpm]	Frequency [Hz]	M_Y [kNm]	M_Z [kNm]	Frequency [Hz]	M_Y [kNm]	M_Z [kNm]	Frequency [Hz]	M_Y [kNm]	M_Z [kNm]
7L46F	600	10	0	0	20	104.2	0	40	12.4	–
9L46F	600	10	0	0	20	56.7	0	40	20.6	–

– couples are zero or insignificant

16.2 Torque variations

Table 16.3 Torque variation at full load

Engine	Speed [rpm]	Frequency [Hz]	M_X [kNm]	Frequency [Hz]	M_X [kNm]	Frequency [Hz]	M_X [kNm]
6L46F	600	30	81.0	60	64.2	90	13.7
7L46F	600	35	231.4	70	44.4	105	7.5
8L46F	600	40	195.1	80	30.5	120	4.1
9L46F	600	45	189.5	90	20.5	135	2.2

16.3 Mass moments of inertia

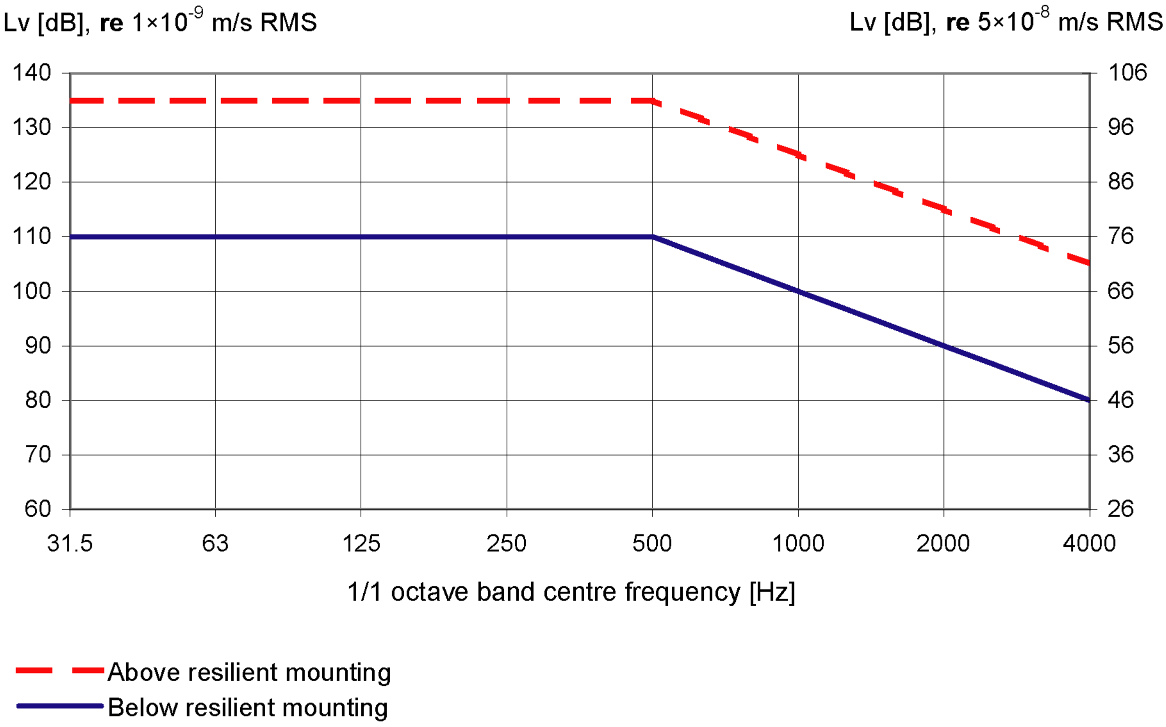
These typical inertia values include the flexible coupling part connected to the flywheel and the torsional vibration damper, if needed.

Table 16.4 Polar mass moments of inertia

Engine	Inertia [kgm²]
6L46F	3620
7L46F	2920
8L46F	4160
9L46F	4110

16.4 Structure borne noise

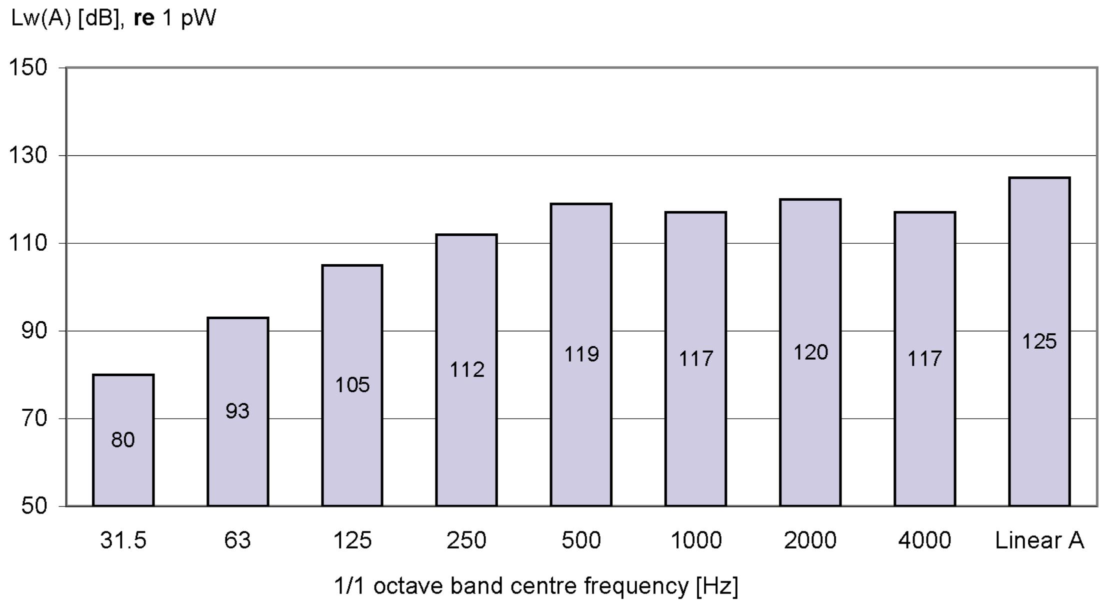
Figure 16.2 Typical structure borne noise levels



16.5 Air borne noise

The airborne noise from the engine is measured as a sound power level according to ISO 3746-1979. The results are presented with A-weighting in octave bands, reference level 1 pW. The values are applicable with an intake air filter on the turbocharger.

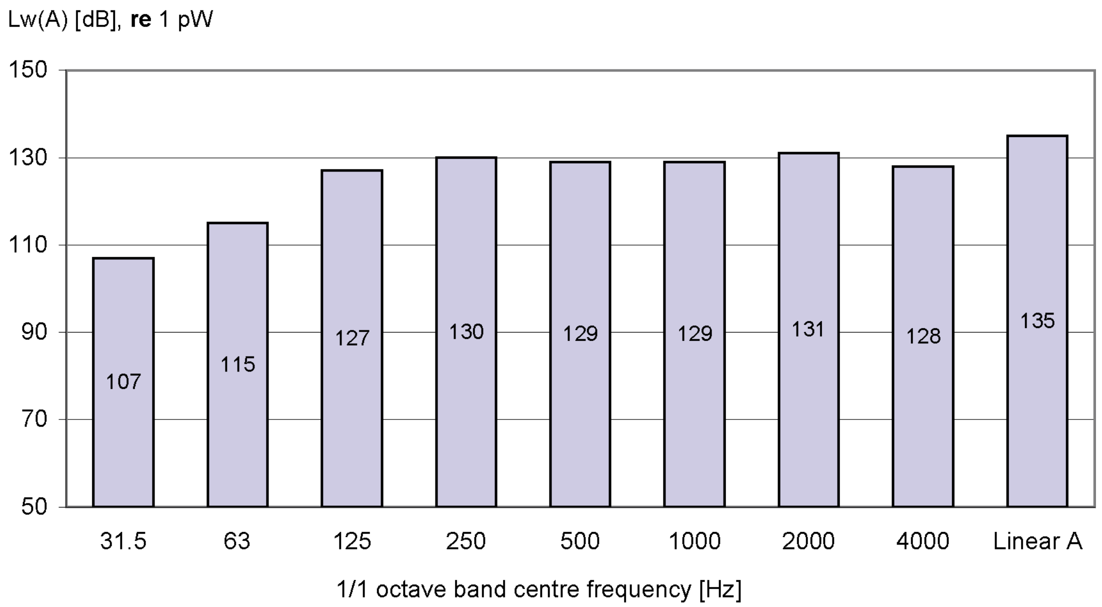
Figure 16.3 Sound power levels of engine noise



16.6 Exhaust noise

The exhaust noise is measured as a sound power level according to ISO 9614-2. The results are presented with A-weighting in octave bands, reference level 1 pW.

Figure 16.4 Sound power levels of exhaust noise



17. Power transmission

17.1 Flexible coupling

The engine is connected to the reduction gear or generator with a flexible coupling. The type of flexible coupling is determined separately for each installation based on the torsional vibration calculations.

17.2 Clutch

Hydraulically operated multi-plate clutches in the reduction gear are recommended.

A clutch is not absolutely required in single main engine installations, provided that the friction torque of the shaft line does not exceed the torque capacity of the turning gear, or there is a tooth coupling so that the engine can be separated from the propeller shaft. A combined flexible coupling and clutch mounted on the flywheel is usually possible without intermediate bearings, because the engine is equipped with an additional bearing at the flywheel end.

Clutches are required when two or more engines are connected to the same reduction gear.

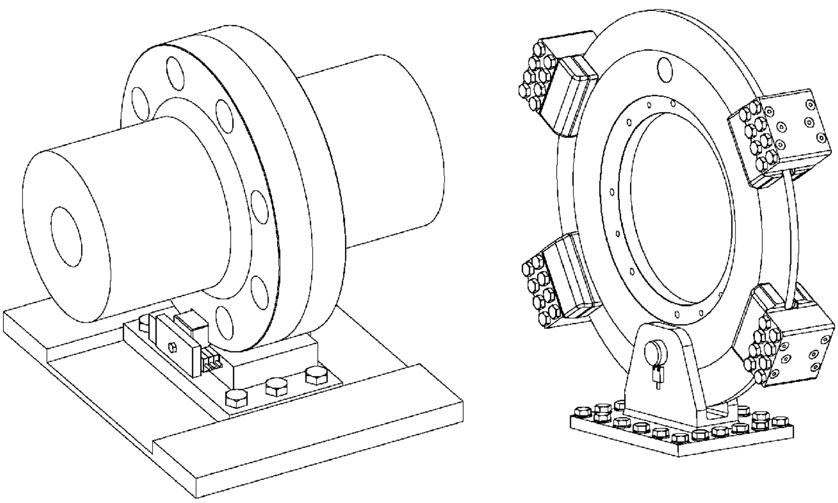
To permit maintenance of a stopped engine, either clutches or tooth couplings are required in twin screw vessels, if the vessel can operate with only one propeller.

17.3 Shaft locking device

Twin screw vessels are to be equipped with shaft locking devices to prevent propeller windmilling, if the vessel can operate with only one propeller. Locking devices should be installed as safety equipment for maintenance operations also when the ship can operate with one propeller trailing (requires continuous lubrication of gear and shaft).

The shaft locking device can be either a disc brake with calipers, or a bracket and key arrangement.

Figure 17.1 Shaft locking device and brake disc with calipers



17.4 Power-take-off from the free end

Full output is available also from the free end of the engine. The weight of the coupling determines whether a support bearing is needed, and for this reason each installation must be evaluated separately. Such a support bearing is possible only with rigidly mounted engines. The permissible coupling weight can be increased if the engine is configured without built-on pumps.

17.5 Input data for torsional vibration calculations

A torsional vibration calculation is made for each installation. For this purpose exact data of all components included in the shaft system are required. See list below.

Installation

- Classification
- Ice class
- Operating modes

Reduction gear

A mass elastic diagram showing:

- All clutching possibilities
- Sense of rotation of all shafts
- Dimensions of all shafts
- Mass moment of inertia of all rotating parts including shafts and flanges
- Torsional stiffness of shafts between rotating masses
- Material of shafts including tensile strength and modulus of rigidity
- Gear ratios
- Drawing number of the diagram

Propeller and shafting

A mass-elastic diagram or propeller shaft drawing showing:

- Mass moment of inertia of all rotating parts including the rotating part of the OD-box, SKF couplings and rotating parts of the bearings
- Mass moment of inertia of the propeller at full/zero pitch in water
- Torsional stiffness or dimensions of the shaft
- Material of the shaft including tensile strength and modulus of rigidity
- Drawing number of the diagram or drawing

Main generator or shaft generator

A mass-elastic diagram or an generator shaft drawing showing:

- Generator output, speed and sense of rotation
- Mass moment of inertia of all rotating parts or a total inertia value of the rotor, including the shaft
- Torsional stiffness or dimensions of the shaft
- Material of the shaft including tensile strength and modulus of rigidity
- Drawing number of the diagram or drawing

Flexible coupling/clutch

If a certain make of flexible coupling has to be used, the following data of it must be informed:

- Mass moment of inertia of all parts of the coupling
- Number of flexible elements
- Linear, progressive or degressive torsional stiffness per element
- Dynamic magnification or relative damping
- Nominal torque, permissible vibratory torque and permissible power loss
- Drawing of the coupling showing make, type and drawing number

Operational data

- Operational profile (load distribution over time)

- Clutch-in speed
- Power distribution between the different users
- Power speed curve of the load

17.6 Turning gear

The engine is equipped with an electrically driven turning gear, which is capable of turning the propeller shaft line in most installations. The need for a separate turning gear with higher torque capacity should be considered for example in the cases listed below:

- Installations with a stern tube with a high friction torque
- Installations with a heavy ice-classed shaft line
- Installations with several engines connected to the same shaft line
- If the shaft line and a heavy generator are to be turned at the same time.

Table 17.1 Turning gear torque

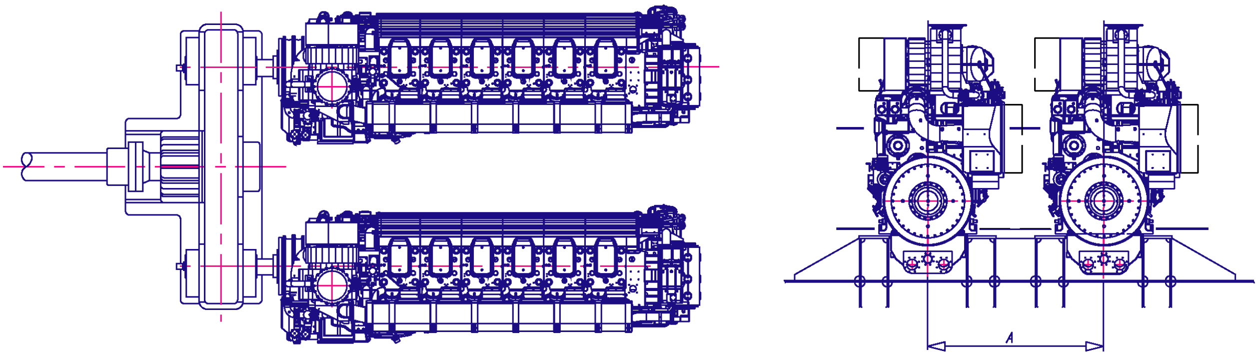
Cylinder number	Type of turning gear	Max. torque at crankshaft [kNm]	Torque needed to turn the engine [kNm]	Additional torque available [kNm]
6L	LKV 145	18	12	6
7L	LKV 145	18	13	5
8L	LKV 145	18	15	3
9L	LKV 250	75	17	58

18. Engine room layout

18.1 Crankshaft distances

18.1.1 Twin engines

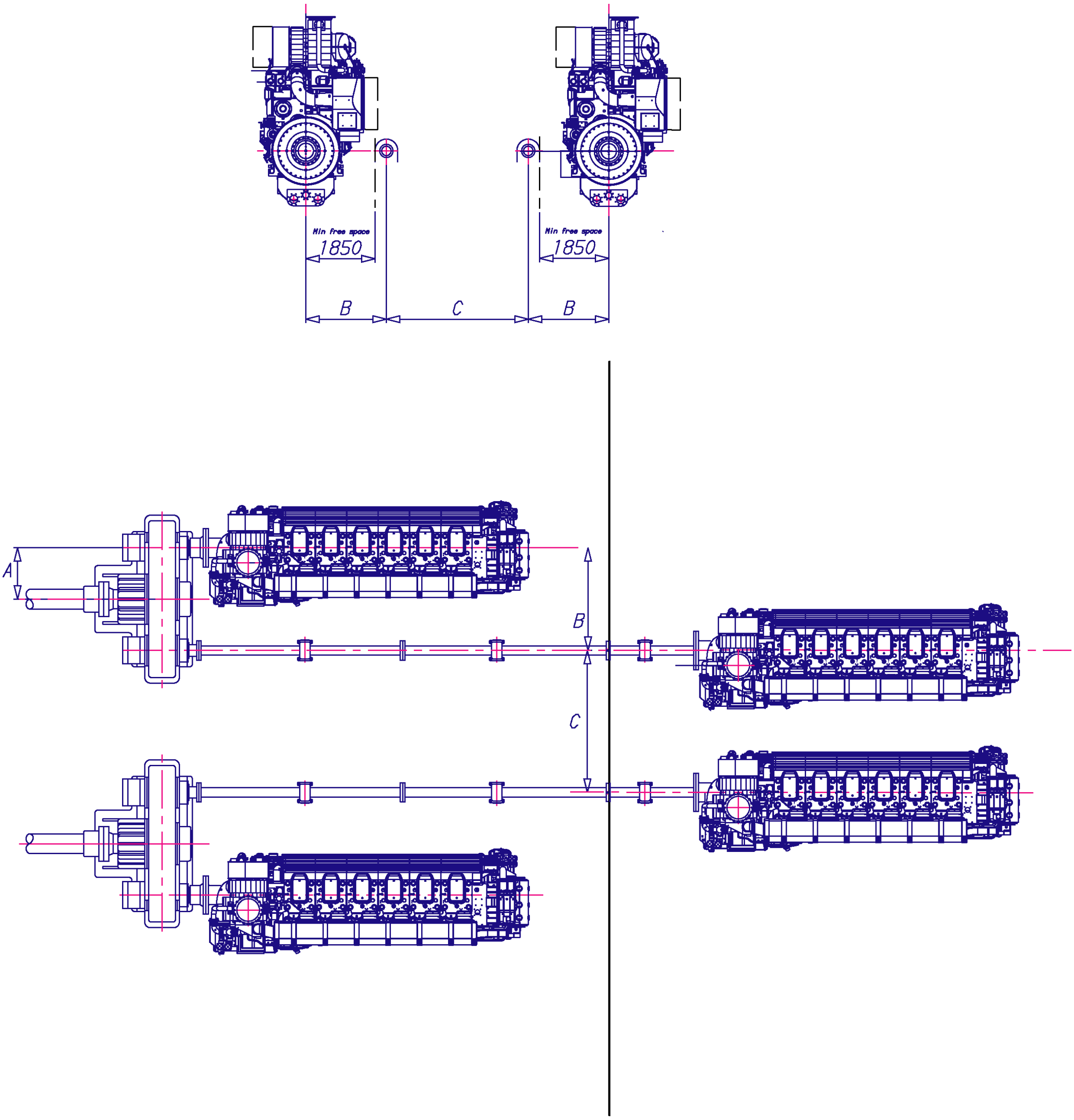
Figure 18.1 Minimum crankshaft distance (DAAE044913)



Engine type	A [mm]
6L46F	3400
7-9L46F	3700

18.1.2 Four-engine installations

Figure 18.2 Main engine arrangement, four engines (DAAE045069)

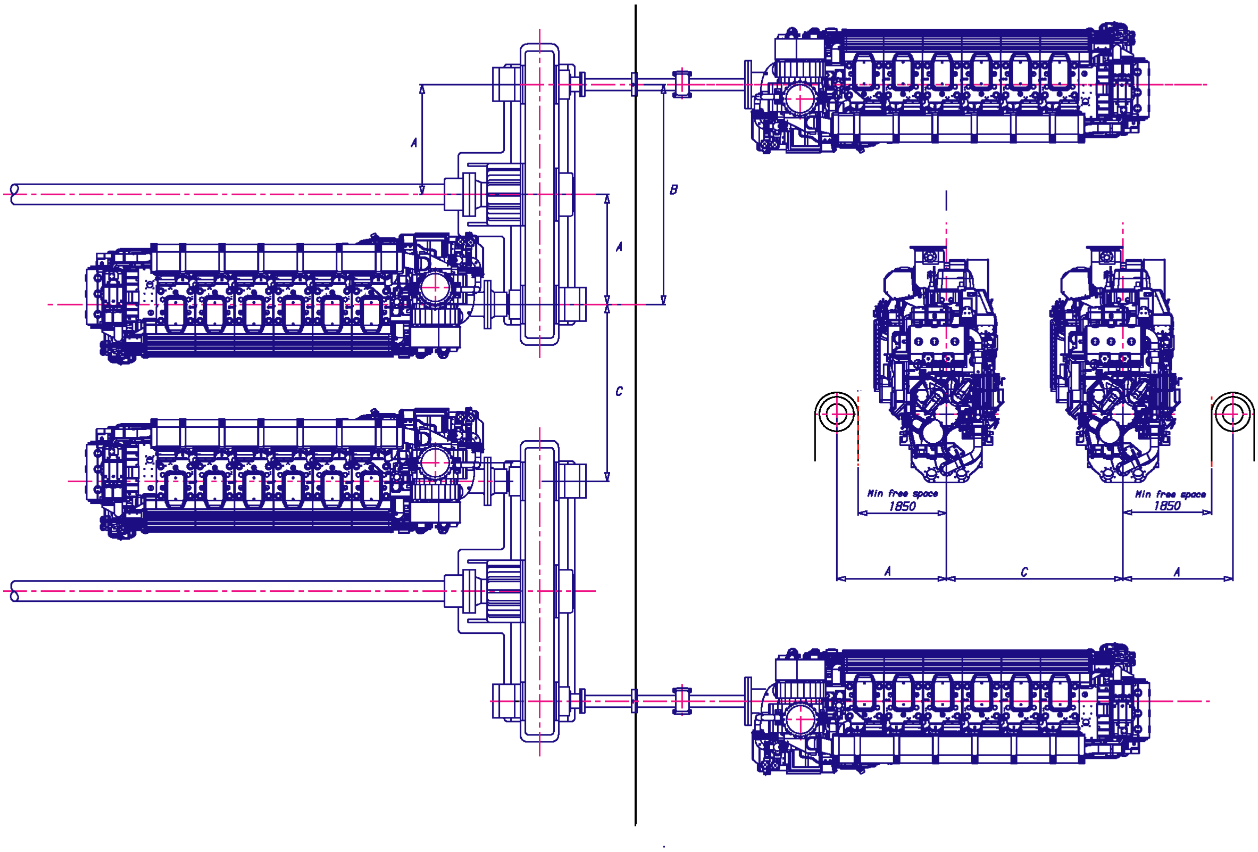


Engine type	A [mm]	B [mm]	C [mm]
6L46F	1050	2100	3400
7-9L46F	1050	2100	3700

Intermediate shaft diameter to be determined case by case.

Dismantling of big end bearing requires 1500 mm on one side and 2300 mm on the other side. Direction may be freely chosen.

Figure 18.3 Main engine arrangement, four engines (DAAE045142)



Engine type	A [mm]	B [mm]	C [mm]
6L46F	2300	4600	3400
7-9L46F	2300	4600	3700

Propeller shaft diameter to be determined case by case.

Dismantling of big end bearing requires 1500 mm on one side and 2300 mm on the other side. Direction may be freely chosen.

18.2 Space requirements for maintenance

18.2.1 Working space around the engine

Under work

18.2.2 Engine room height and lifting equipment

The required engine room height is determined by the transportation routes for engine parts. If there is sufficient space in transverse and longitudinal direction, there is no need to transport engine parts over the rocker arm covers or over the exhaust pipe and in such case the necessary height is minimized.

Separate lifting arrangements are usually required for overhaul of the turbocharger since the crane travel is limited by the exhaust pipe. A chain block on a rail located over the turbocharger axis is recommended.

Table 18.1 Capacity of crane and other lifting arrangements

Engine components	2.0 ton
Complete turbocharger, 6L46F	2.2 ton
Complete turbocharger, 7-9L46F	3.9 ton

Hook height and lifting position

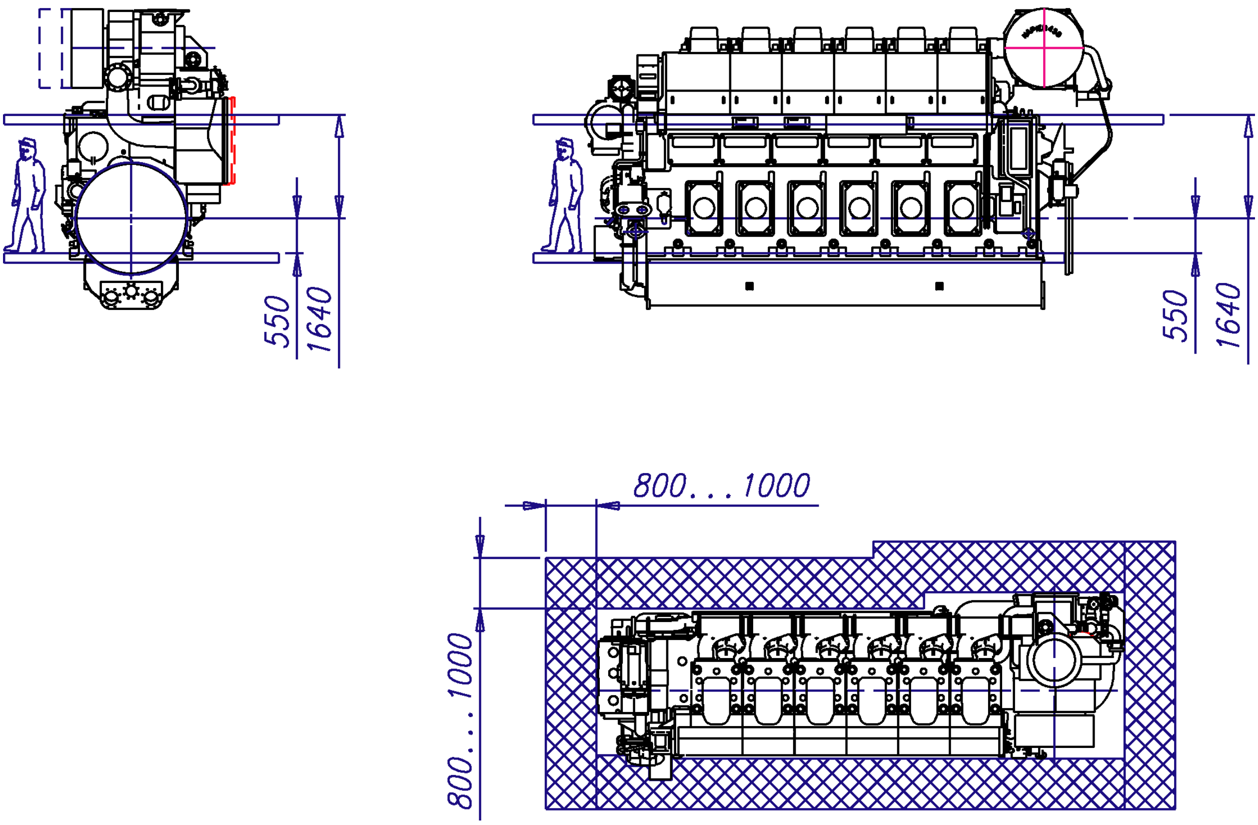
Under work

Bridge crane

Under work

18.2.3 Platforms

Figure 18.4 Maintenance platforms (DAAE007096)



18.3 Handling of spare parts and tools

Transportation arrangements from engine room to workshop and storage locations must be provided for heavy engine components, for example by means of several chain blocks on rails, or by suitable routes for trolleys.

The engine room maintenance hatch must be large enough to allow transportation of all main components to/from the engine room.

It is recommended to store heavy engine components on a slightly elevated and adaptable surface, e.g. wooden pallets. All engine spare parts should be protected from corrosion and excessive vibration.

18.4 Required deck area for service work

During engine overhaul a free deck area is required for cleaning and storing dismantled components. The size of the service area depends on the overhaul strategy , e.g. one cylinder at time or the whole engine at time. The service area should be a plain steel deck dimensioned to carry the weight of engine parts.

Table 18.2 Required deck area for overhaul work

Piston - connecting rod assembly	2.5 m x 3 m
Cylinder head	2 m x 2 m

Required service area for overhauling both cylinder head and piston-connecting rod assembly (not at the same time) is approximately 8…10 m^2.

For overhaul of more than one cylinder at a time, an additional area of about 4 m^2 per cylinder is required. This area is used for temporary storing of dismantled parts.

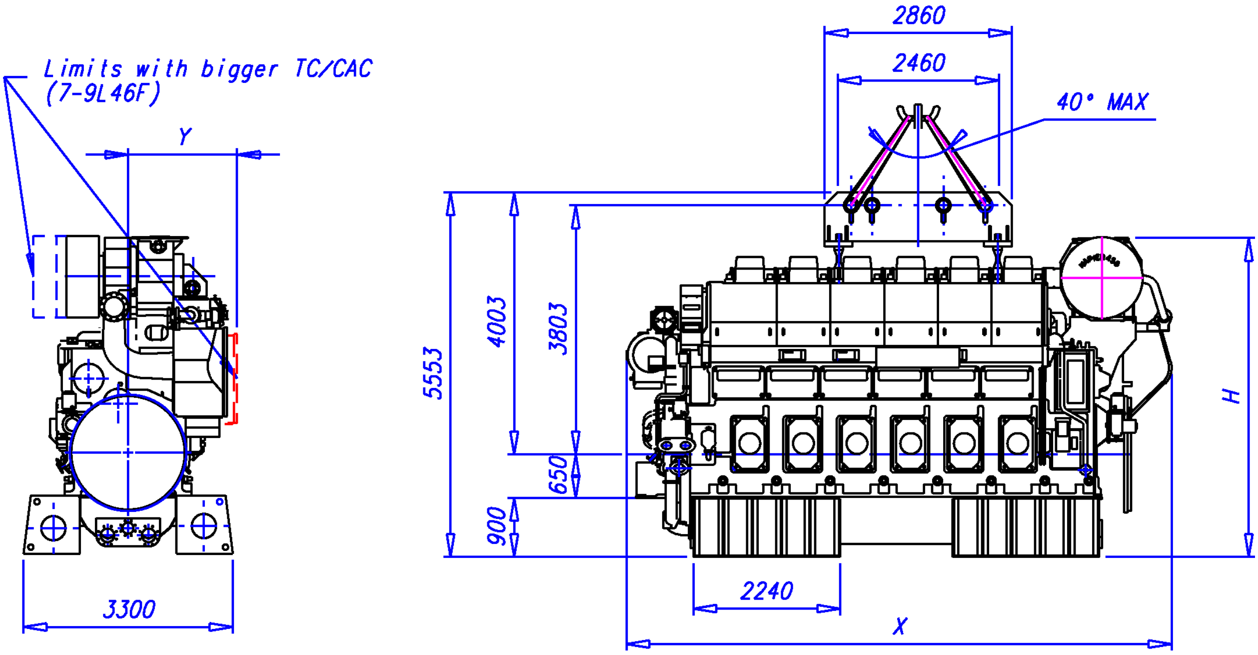
Table 18.3 Example of recommended service area for overhaul

	8L46F
Service area for overhaul work of one cylinder	10 m^2
Storage area for dismantled parts (8L46F, 7 cylinders)	28 m^2
Total service area required	38 m^2

19. Transport dimensions and weights

19.1 Lifting of engines

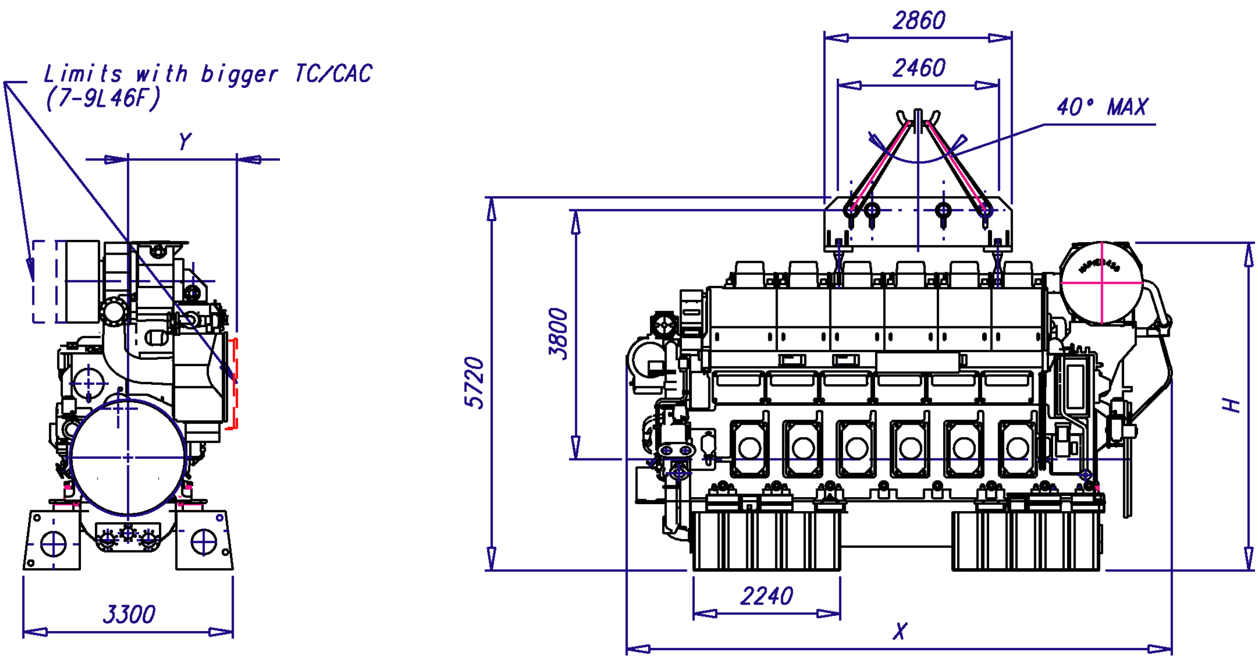
Figure 19.1 Lifting of rigidly mounted engines (DAAE016050a)



Engine type	X [mm]	Y [mm]	H [mm]	Weights without flywheel [ton]			
				Engine	Lifting device	Transport cradle	Total weight
6L46F	8330 1) 8350 2)	1520 1520	5050 5050	97 97	3.3 3.3	6.4 6.4	106.7 106.7
7L46F	9380 1) 9430 2)	1720 1720	5350 5350	113 113	3.3 3.3	6.4 6.4	122.7 122.7
8L46F	10200 1) 10250 2)	1720 1720	5350 5350	124 124	3.3 3.3	6.4 6.4	133.7 133.7
9L46F	11020 1) 11070 2)	1720 1720	5350 5350	140 140	3.3 3.3	9.6 9.6	152.9 152.9

1) Turbocharger at free end
2) Turbocharger at flywheel end

Figure 19.2 Lifting of resiliently mounted engines (DAAE038985)

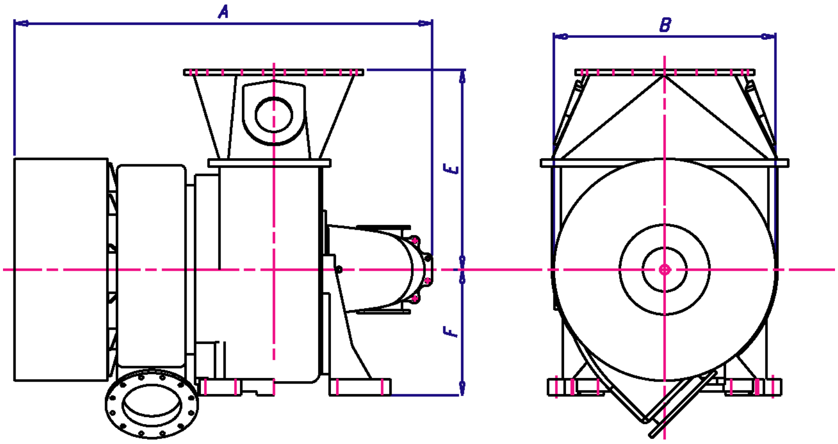


Engine type	X [mm]	Y [mm]	H [mm]	Weights without flywheel [ton]				
				Engine	Lifting device	Transport cradle	Res. mounting	Total weight
6L46F	8330 1) 8350 2)	1520 1520	5220 5220	97 97	3.3 3.3	6.4 6.4	3.2 3.2	109.9 109.9
7L46F	9380 1) 9430 2)	1720 1720	5520 5520	113 113	3.3 3.3	6.4 6.4	3.3 3.3	126.0 126.0
8L46F	10200 1) 10250 2)	1720 1720	5520 5520	124 124	3.3 3.3	6.4 6.4	3.4 3.4	137.1 137.1
9L46F	11020 1) 11070 2)	1720 1720	5520 5520	140 140	3.3 3.3	9.6 9.6	3.5 3.5	156.4 156.4

1) Turbocharger at free end
2) Turbocharger at flywheel end

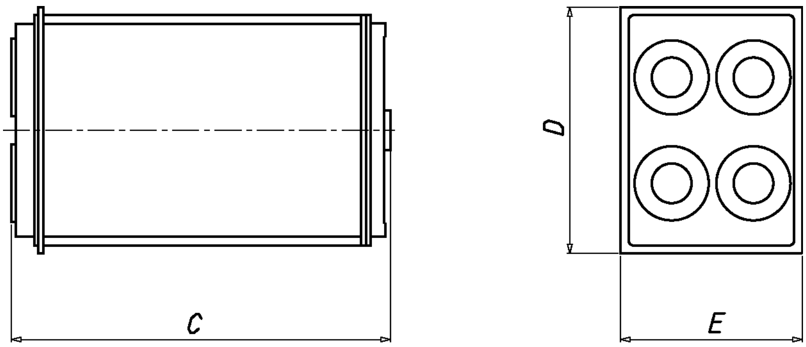
19.2 Engine components

Figure 19.3 Turbocharger



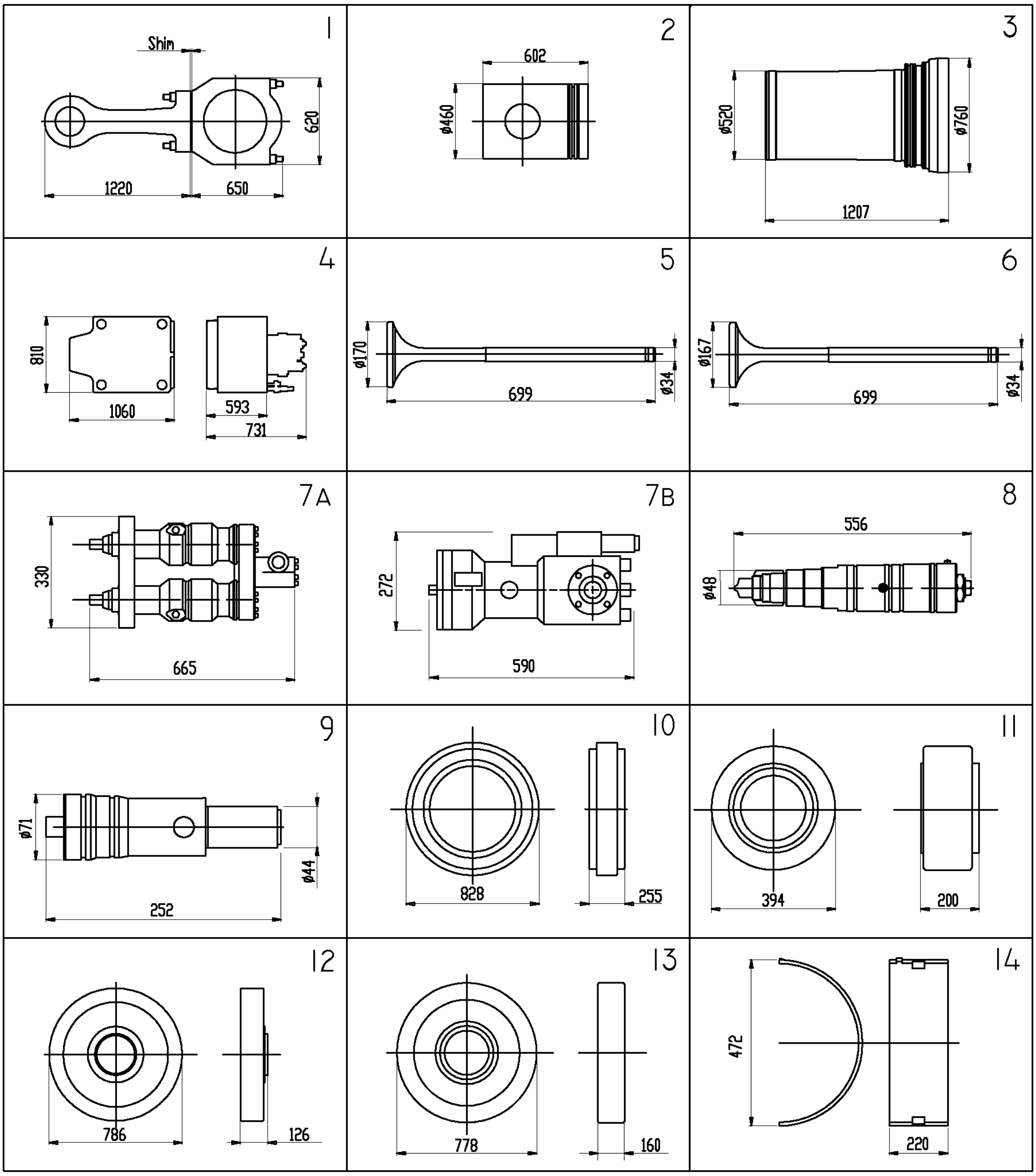
Engine	Turbocharger	A [mm]	B [mm]	E [mm]	F [mm]	Weight, complete [kg]	Weight, rotor block cartridge [kg]
6L46F	TPL 71	2000	950	790	530	1960	465
7-9L46F	TPL 76	2300	1340	1100	690	3660	815

Figure 19.4 Charge air cooler inserts



Engine	C [mm]	D [mm]	E [mm]	Weight [kg]
6L46F	1950	660	650	770
7-9L46F	1950	860	970	960

Figure 19.5 Major spare parts



Item	Description	Weight [kg]	Item	Description	Weight [kg]
1	Connecting rod	615	8	Injection valve	25
2	Piston	211	9	Starting valve	4.2
3	Cylinder liner	932	10	Crankshaft gear wheel	201
4	Cylinder head	1170	11	Small intermediate gear	111
5	Inlet valve	10	12	Large intermediate gear	214
6	Exhaust valve	11	13	Camshaft gear wheel	252
7 A	Injection pump, conventional	142	14	Main bearing shell	12
7 B	Injection pump, common rail	99			

20. Project guide attachments

This and other project guides can be accessed on the internet, from the Business Online Portal at www.wartsila.com. Project guides are available both in PDF and HTML format. Drawings are available in PDF and DXF format, and in near future also as 3D models. Consult your sales contact at Wärtsilä to get more information about the project guides on the Business Online Portal.

The attachments are not available in the printed version of the project guide.

21. ANNEX

21.1 Unit conversion tables

The tables below will help you to convert units used in this project guide to other units. Where the conversion factor is not accurate a suitable number of decimals have been used.

Table 21.1 Length conversion factors

Convert from	To	Multiply by
mm	in	0.0394
mm	ft	0.00328

Table 21.2 Mass conversion factors

Convert from	To	Multiply by
kg	lb	2.205
kg	oz	35.274

Table 21.3 Pressure conversion factors

Convert from	To	Multiply by
kPa	psi (lbf/in^2)	0.145
kPa	lbf/ft^2	20.885
kPa	inch H_2O	4.015
kPa	foot H_2O	0.335
kPa	mm H_2O	101.972

Table 21.4 Volume conversion factors

Convert from	To	Multiply by
m^3	in^3	61023.744
m^3	ft^3	35.315
m^3	Imperial gallon	219.969
m^3	US gallon	264.172
m^3	l (litre)	1000

Table 21.5 Power conversion factors

Convert from	To	Multiply by
kW	hp (metric)	1.360
kW	US hp	1.341

Table 21.6 Moment of inertia and torque conversion factors

Convert from	To	Multiply by
kgm^2	lbft^2	23.730
kNm	lbf ft	737.562

Table 21.7 Fuel consumption conversion factors

Convert from	To	Multiply by
g/kWh	g/hph	0.736
g/kWh	lb/hph	0.00162

Table 21.8 Flow conversion factors

Convert from	To	Multiply by
m^3/h (liquid)	US gallon/min	4.403
m^3/h (gas)	ft^3/min	0.586

Table 21.9 Temperature conversion factors

Convert from	To	Calculate
°C	F	F = 9/5 *C + 32
°C	K	K = C + 273.15

Table 21.10 Density conversion factors

Convert from	To	Multiply by
kg/m^3	lb/US gallon	0.00834
kg/m^3	lb/Imperial gallon	0.01002
kg/m^3	lb/ft^3	0.0624

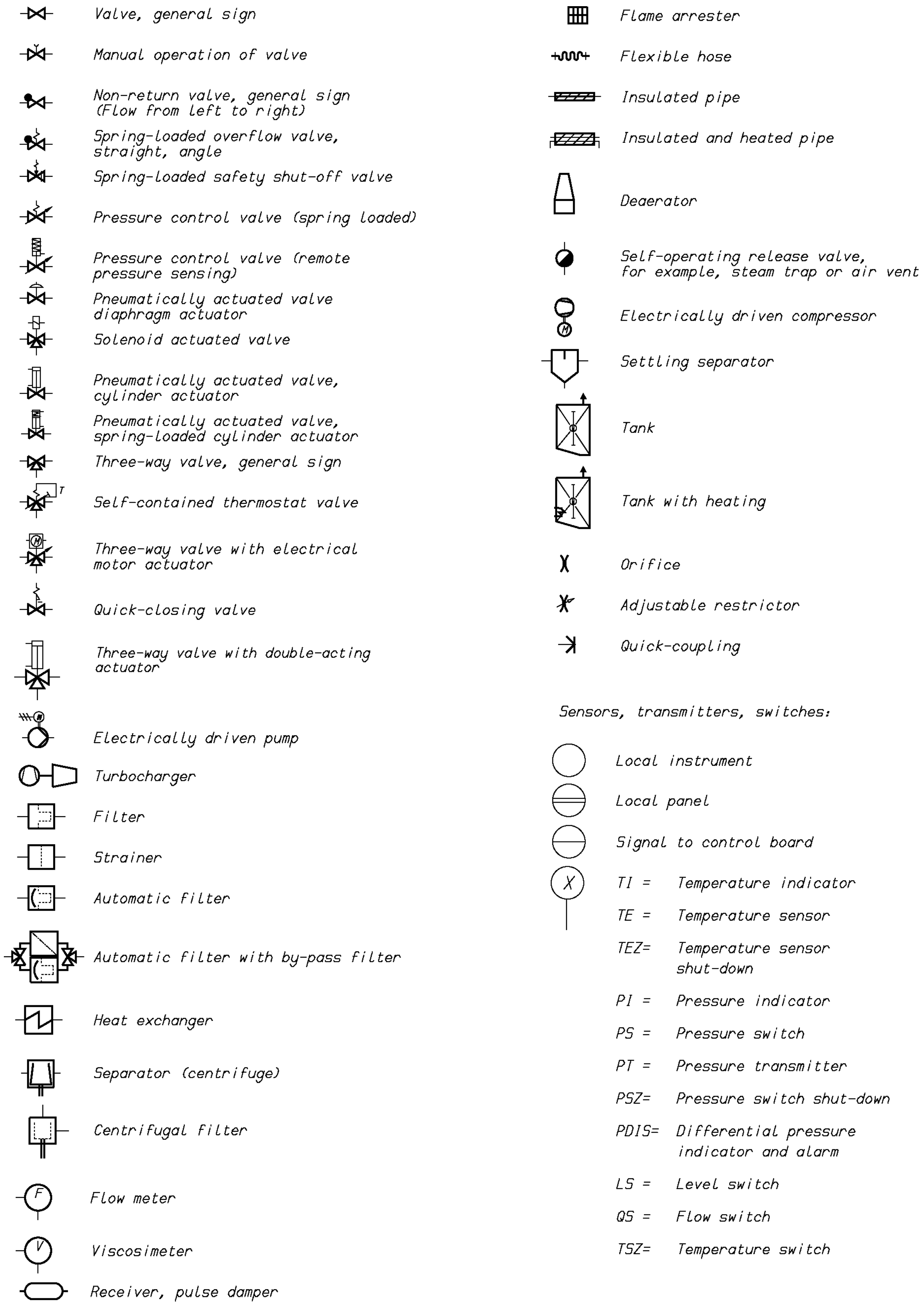
21.1.1 Prefix

Table 21.11 The most common prefix multipliers

Name	Symbol	Factor
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}

21.2 Collection of drawing symbols used in drawings

Figure 21.1 List of symbols (DAAE000806c)



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