MAN L32/40 GenSet

Project Guide – Marine

Four-stroke diesel engine compliant with IMO Tier II

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1 Introduction

1.1 Medium-speed marine GenSets

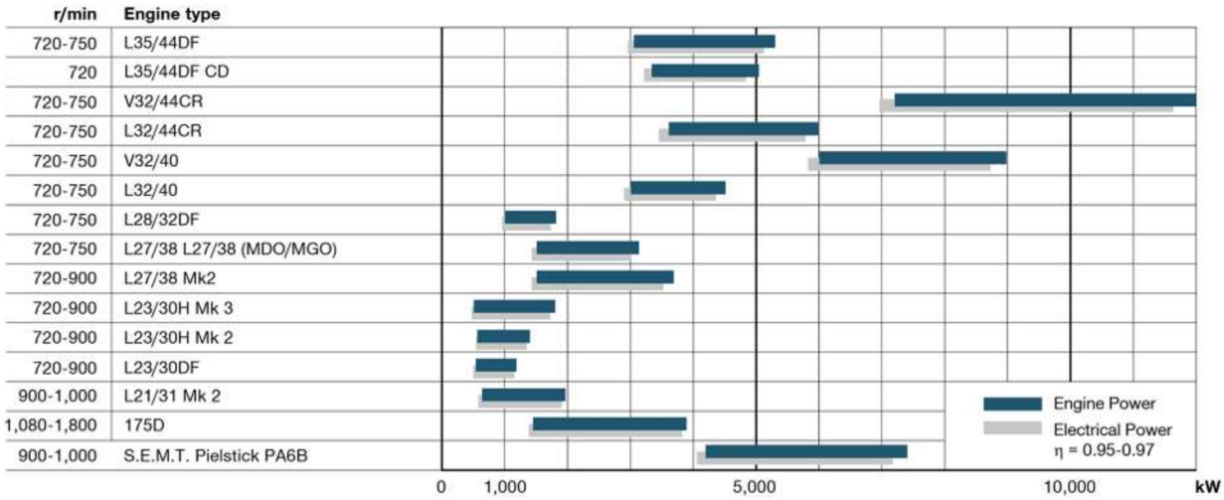

Figure 1: MAN Energy Solutions engine programme

GenSets

Applications for GenSets vary from auxiliary GenSets, GenSets for electric propulsion up to offshore applications.

Project specific demands to be clarified at early project stage.

1.2 Engine description MAN L32/40 GenSet IMO Tier II

General

The “Work Horse” MAN L32/40 is in service 24 hours a day. As a pure auxiliary GenSet engine it is available with an output range between 3,000 kW_{mech} and 4,500 kW_{mech}. The interacting of all important parts results to low wear rates and long maintenance intervals.

Auxiliary GenSet concept

The diesel engine and the alternator are placed on a common rigid base frame mounted on the ship's/erection hall's foundation by means of resilient supports, type conical. Each engine is equipped with an engine driven HT cooling water pump, an engine driven lube oil pump and an prelubrication pump (electrical). The installed, individual HT thermostatic valve (wax type) regulates the HT cooling water temperature leaving the engine. Lube oil cooler and oi filter are part of the GenSet front end.

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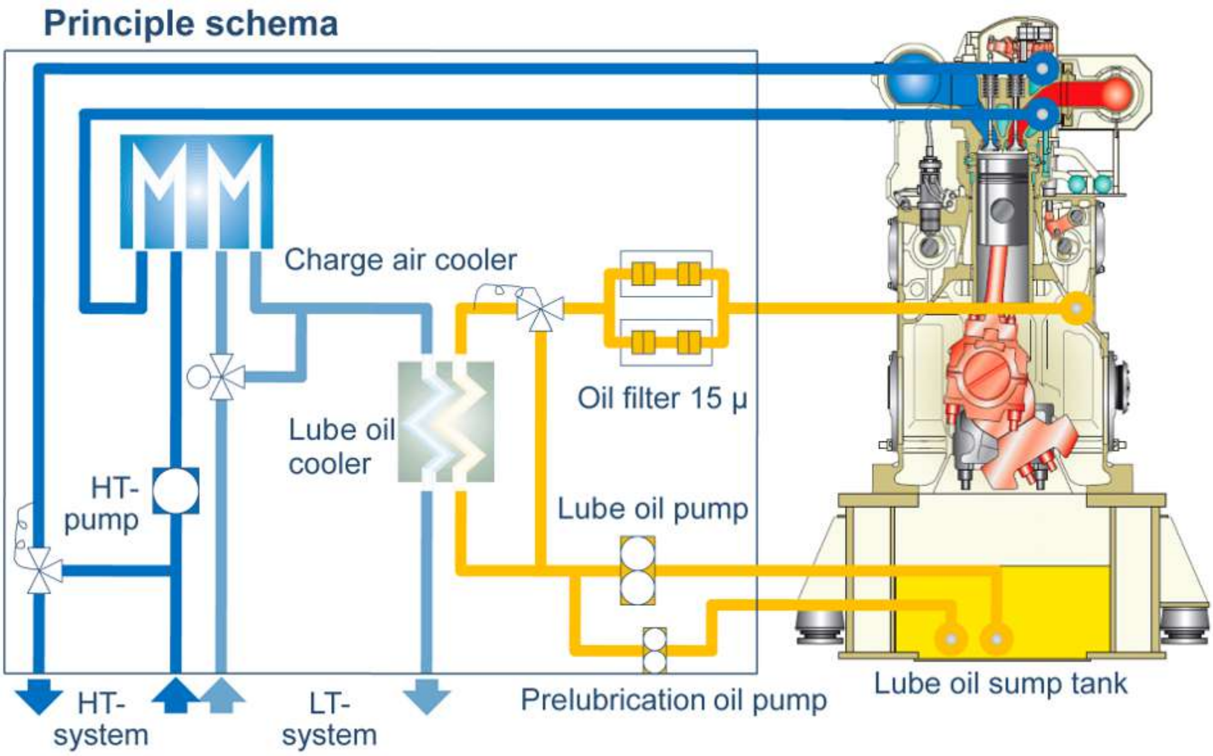

Figure 2: Auxiliary GenSet – Principle schema

Fuels

The MAN L32/40 GenSet can be operated with MGO (DMA), MDO (DMB) and with HFO up to a viscosity of 700 mm2/s (cSt) at 50°C. The fuel system is designed for fuel temperatures up to 150°C and starting and stopping the engine during HFO operation. Note the special chapters concerning synthetic fuels, FAME and residual marine fuels containing FAME.

Operation with FAME - transesterified biofuel (optional)

In case of intended use of FAME fuels according to EN-14214 or ASTM D6751 and according to the additional requirements of MAN Energy Solutions (see section FAME (transesterified biofuel) specification)

- Special considerations for fuel handling, storage and fuel preparation to be considered
- To be clarified, if special equipment on engine or within plant is needed
- Change of engine performance to be clarified

Contact MAN Energy Solutions if this option is needed.

Operation with synthetic fuels (optional)

Synthetic fuels such as HVO, BTL, CTL, GTL according to DIN EN 15940 differ in the procedure of production, but are identical in their fuel properties and need to comply to the requirements of MAN Energy Solutions (see section HVO)

In case of intended use of these synthetic diesel fuels:

- Special considerations for fuel handling, storage and fuel preparation have to be considered
- To be clarified, if special equipment on engine or within plant is needed

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- Change of engine performance to be clarified

Due to the lower volumetric heat value than DMA in case of fixed engine setting a minor increase of the specific fuel consumption ($\Delta be_{42700,ISO}$ <+1,5%, [g/kWh]) and a slight decrease of NO_X-emissions is expected.

Contact MAN Energy Solutions if this option is needed.

Stepped piston

Forged dimensionally stable steel crown (with shaker cooling) made from high grade materials and skirt in spheroidal graphite cast iron (skirt also available in steel upon request). The stepped piston and the fire ring together prevent “bore polishing” of the cylinder liner, thereby reducing operating costs by keeping lubricating oil consumption consistently low. Chromium ceramic coating of the first piston ring with wear resistant ceramic particles in the ring surface results in minimal wear and tear, ensuring extremely long periods between maintenance.

Cylinder head

The cylinder head has optimised combustion chamber geometry for improved injection spray atomisation. This ensures balanced air-fuel mixture, reducing combustion residue, soot formation and improving fuel economy.

Valves

Exhaust valves are designed with armoured, water cooled seats that keep valve temperatures down. Propellers on the exhaust valve shaft provide rotation by exhaust gas, resulting in the cleaning effect of the valve seat area during valve closing.

Cylinder liner

The precision machined cylinder liner and separate cooling water collar rest on top of the engine frame and is there isolated from any external deformation, ensuring optimum piston performance and long service life.

Device for variable injection timing (VIT)

The VIT is designed to influence injection timing and thus ignition pressure and combustion temperature. That enables engine operation in different load ranges well balanced between low NO_x emissions and low fuel consumption.

Sealed Plunger injection pumps (SP injection pumps)

The MAN L32/40 GenSet conventional injection system is equipped with Sealed Plunger injection pumps. SP injection pumps have been designed for an operation with all specified fuels.

Benefit:

+ The fuel and the lube oil within the injection pumps are completely separated and cannot get in contact with each other, so that the leakage fuel of the SP injection pumps can be completely reused again.

+ For the same reason, there is no need for sealing oil anymore in the case of continuous MGO operation.

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Note:
For reusing the operation leakage the fuel oil system must be changed. To specify the needed adaptions please contact MAN Energy Solutions for assistance.

Starting system – Starting air valves within cylinder head

The engine is equipped with starting air valves within some of the cylinder heads. On starting command, compressed air will be led in a special sequence into the cylinder and will push down the piston and turn thereby the crankshaft until a defined speed is reached.

Service friendly design

- Hydraulic tooling for tightening and loosening cylinder head nuts
- Clamps with quick release fasteners and/or clamp and plug connectors
- Generously sized access covers

MAN Energy Solutions turbocharging system

Industry leading designed constant pressure turbocharging system using state-of-the-art MAN Energy Solutions turbochargers with long bearing overhaul intervals. High efficiency at full and part loads results in substantial air surplus and complete combustion without residues and with low thermal stresses on the combustion chamber components.

Electronics – SaCoSone

The MAN L32/40 GenSet is equipped with the classification society compliant safety and control system SaCoSone. SaCoSone combines all functions of modern engine management into one complete system.

SaCoSone offers:

- Integrated self-diagnosis functions
- Future prove design
- Digital ready
- Maximum reliability and availability
- Simple use and diagnosis
- Quick exchange of modules
- Crankcase monitoring system plus oil mist detection

  As a standard for all our four-stroke medium-speed engines manufactured in Augsburg, these engines will be equipped with a crankcase monitoring system (CCM = splash oil & main bearing temperature) plus OMD (oil mist detection). OMD and CCM are integral part of the MAN Energy Solutions´ safety philosophy and the combination of both will increase the possibility to early detect a possible engine failure and prevent subsequent component damage.

Cyber security

The marine certified safety and control system SaCoSone is compliant to the IACS UR E27 requirements for cyber resilience on-board equipment, which will get mandatory for ships contracted for construction or after 1st July 2024. A confirmation of compliance will be given by the main classification societies, ensuring the utmost benefit for our customers.

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PrimeServ Assist - CEON (optional feature)

MAN PrimeServ Assist is our solution to support our customers in monitoring and assessing the condition of their equipment. Equipment connected to our MAN CEON cloud platform is monitored by MAN's advanced analytics running in the MAN CEON platform to detect degradations and optimisation potentials. MAN experts analyse root causes and define mitigating actions based on this data.

Benefits:

- Availability: Ensuring 24/7 engine availability by monitoring operating values and pro-actively advising on operating tasks.
- Efficiency: Optimize equipment performance and reduce fuel consumption and emissions by detecting degradations of performance influencing parameters over time.
- Maintenance: Reduce maintenance cost by evaluating aging of individual components over time and pro-active advising counter measures.

Core technologies in-house

As well as its expertise in engine design, development and manufacture, MAN Energy Solutions is also a leader in the engineering and manufacturing of the key technologies which determine the economic and ecological performance of a diesel engine and constitute the best offer for our customers:

- High-efficiency turbochargers
- Advanced-electronic fuel injection equipment
- Electronic hardware and software for engine control, monitoring and diagnosis
- High-performance exhaust gas after treatment systems

Our impressive array of computer aided design tools and one of the engine industry’s largest, best-equipped foundries allow us to decisively shorten product development and application engineering processes. Our mastery of these engine technologies is the firm foundation for:

- Low emissions
- Low-operating costs
- Low-life cycle costs
- Long-service life

Committed to the future

MAN Energy Solutions is closely following and anticipating the upcoming requirements of the market, new fuel types arising and stricter emissions regulations in the making.
Accordingly new technologies are already under development at MAN Energy Solutions.
With this level of commitment MAN Energy Solutions` customers can plan with confidence.
Available technologies of exhaust gas after treatment and battery hybrid systems expand already our portfolio.

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1.3 Engine overview

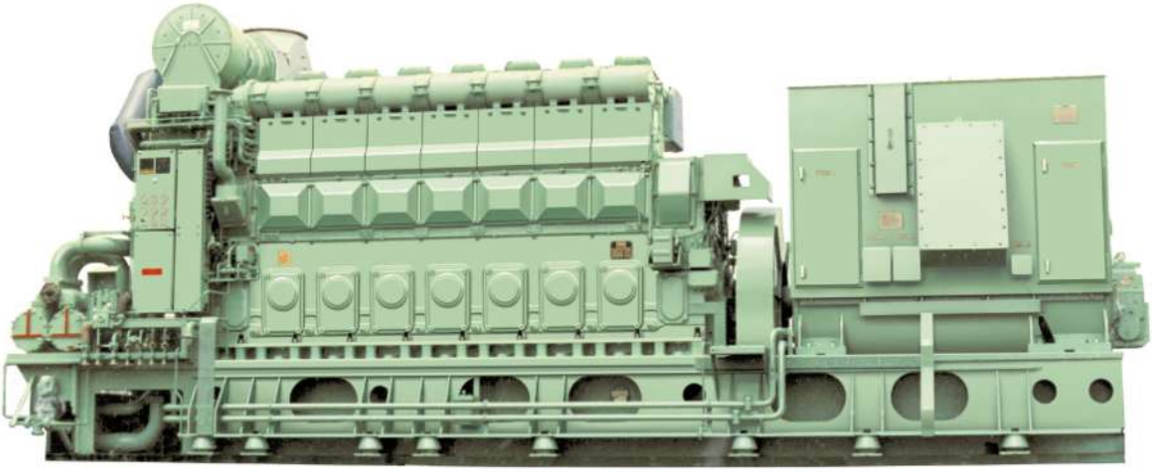
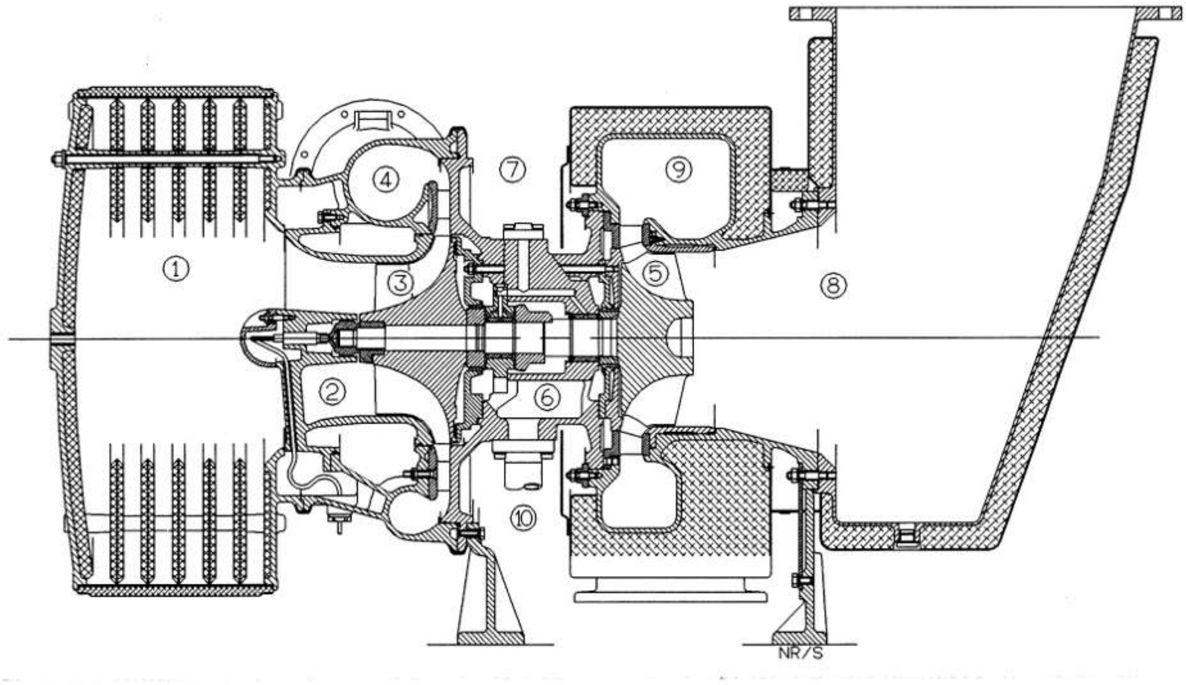


Figure 3: Engine overview, MAN L32/40 auxiliary GenSet left view

1.4 Turbocharger overview

1.4.1 View of a NR/S type turbocharger



1 Silencer
2 Insert piece
3 Compressor wheel
4 Compressor casing
5 Turbine rotor
6 Bearing casing (uncooled)
7 Lube oil supply
8 Gas outlet casing
9 Gas admission casing
10 Lube oil drain

Figure 4: NR/S type turbocharger

1.4.2 Compensator between turbine outlet (engine) and exhaust gas pipe (plant)

All turbocharger casing flanges, with the exception of the turbine outlet, may only be subjected to loads generated by the gas forces, and not to additional external forces or torques.

This necessitates the use of compensators directly at the turbine outlet.

The compensators must be pre-loaded in such a manner that thermal expansion of the pipes and casings does not exert forces or torques in addition to those generated by the air and gas.

- Forces and torques according to API standard 617.
- Operating direction implemented according to MAN Energy Solutions standard.
- Minimising the load as far as possible.
- Characteristic values include gas forces, masses and compensator.

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1.4.3 No additional masses allowed

In general no masses are to be fixed to any part of the engine/turbocharger, as these have an impact to the general vibration behaviour of the engine.

Additional loads and changed vibration behaviour can endanger the operational safety of the engine.

Consequently, for any questions in this regard consult MAN Energy Solutions in advance.

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2 Engine and operation

2.1 Approved applications and destination/suitability of the engine

Approved applications

The L32/40 GenSet has been approved by type approval as an auxiliary engine by all main classification societies (ABS, BV, CCS, ClassNK, CR, CRS, DNV, KR, LR, RINA).

As marine auxiliary engine it may be applied for electric power generation[1)] for auxiliary duties for applications as:

- Auxiliary GenSet[2)]

Note:
The engine is not designed for operation in hazardous areas. It has to be ensured by the ship's own systems, that the atmosphere of the engine room is monitored and in case of detecting a gas-containing atmosphere the engine will be stopped immediately.

[1)] See section Engine ratings (output) for different applications, Page 27.

[2)] Not used for emergency case or fire fighting purposes.

Offshore

For offshore applications it may be applied as auxiliary engine.

Due to the wide range of possible requirements such as flag state regulations, fire fighting items, redundancy, inclinations and dynamic positioning modes all project requirements need to be clarified at an early stage.

Note:
The engine is not designed for operation in hazardous areas. It has to be ensured by the ship's own systems, that the atmosphere of the engine room is monitored and in case of detecting a gas-containing atmosphere the engine will be stopped immediately.

Destination/suitability of the engine

Note:
Regardless of their technical capabilities, engines of our design and the respective vessels in which they are installed must at all times be operated in line with the legal requirements, as applicable, including such requirements that may apply in the respective geographical areas in which such engines are actually being operated.

Operation of the engine outside the specified operated range, not in line with the media specifications or under specific emergency situations (e.g. suppressed load reduction or engine stop by active "Override", triggered firefighting system, crash of the vessel, fire or water ingress inside engine room) is declared as not intended use of the engine (for details see engine specific operating manuals). If an operation of the engine occurs outside of the scope of supply of the intended use a thorough check of the engine and its components needs to be performed by supervision of the MAN Energy Solutions service department. These events, the checks and measures need to be documented.

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Electric and electronic components attached to the engine – Required engine room temperature

In general our engine components meet the high requirements of the marine classification societies.

Relevant design criteria for the engine room air temperature:

Minimum air temperature in the area of the engine and its components ≥ 5°C.

Maximum air temperature in the area of the engine and its components ≤ 45°C.

The electronic components are suitable for proper operation within an air temperature range from 5°C to 55°C.

For further information see also section Engine automation, Technical data, envirionmental conditions.

Note:
Condensation of the air at engine components must be prevented.

Note:
It can be assumed that the air temperature in the area of the engine and attached components will be 5–10 K above the ambient air temperature outside the engine room. If the temperature range is not observed, this can affect or reduce the lifetime of electrical/electronic components at the engine or the functional capability of engine components. Air temperatures at the engine > 55°C are not permissible.

2.2 Engine design

2.2.1 Engine cross section

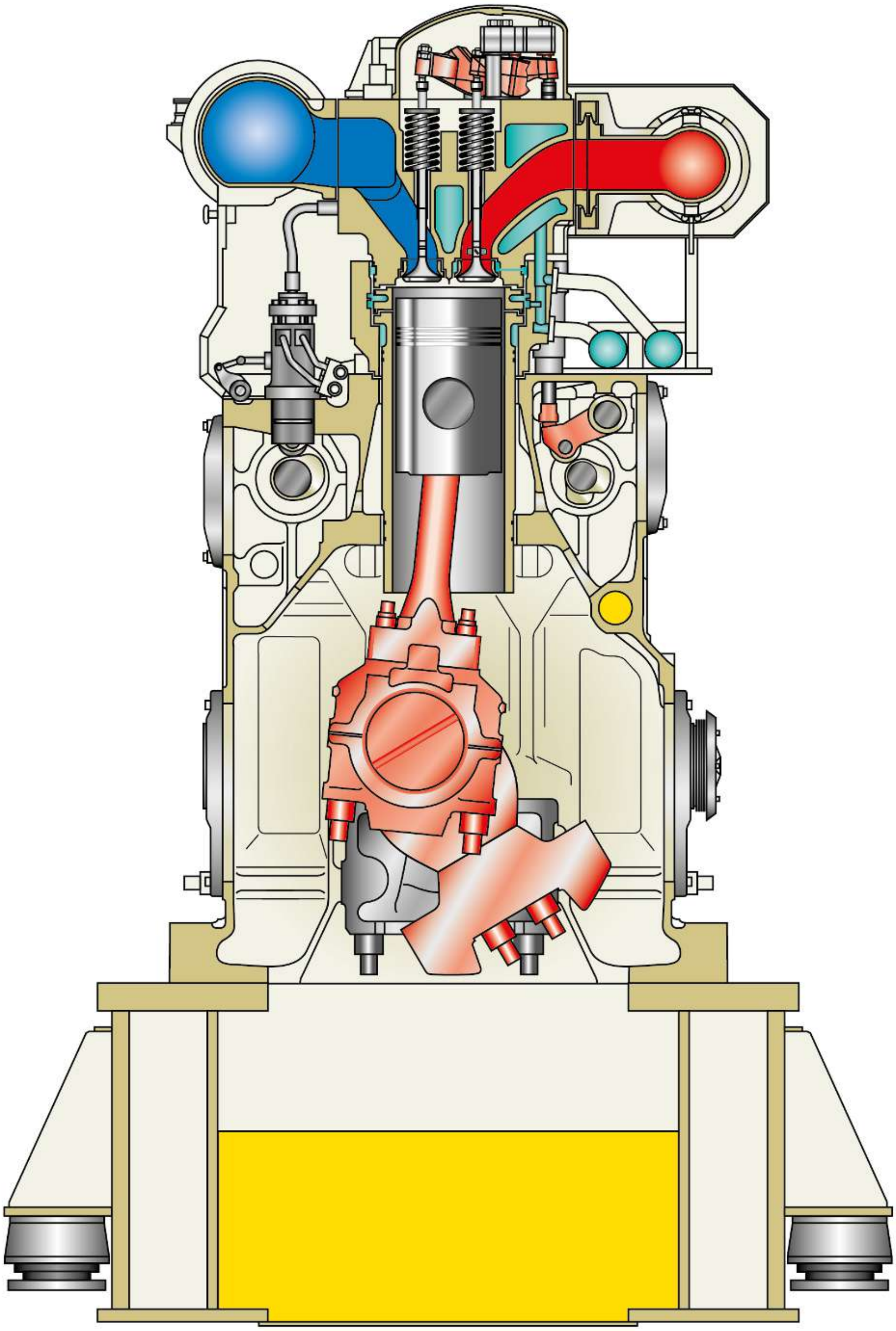


Figure 5: Cross section – Engine MAN L32/40 GenSet; view on counter coupling side

2.2.2 Engine designations – Design parameters

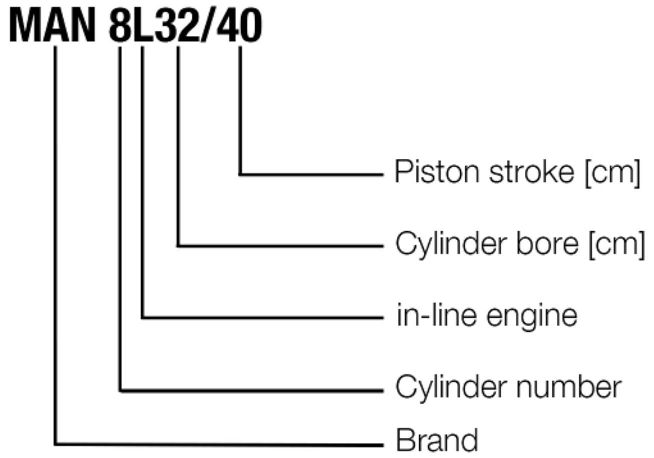


Figure 6: Example to declare engine designations

Parameter	Value	Unit
Number of cylinders	6, 7, 8, 9	-
Cylinder bore	320	mm
Piston stroke	400	
Displacement per cylinder	32.17	litre
Distance between cylinder centres	530	mm
Crankshaft diameter at journal, in-line engine	290	
Crankshaft diameter at crank pin	290	

Table 1: Design parameters

2.2.3 Turbocharger assignments

No. of cylinders, config.	MAN L32/40 GenSet
	500 kW/cyl., 720/750 rpm
6L	NR29/S
7L	NR29/S
8L	NR34/S
9L	NR34/S

Table 2: Turbocharger assignments

Turbocharger assignments mentioned above are for guidance only and may vary due to project-specific reasons. Consider the relevant turbocharger Project Guides for additional information.

2.2.4 Engine main dimensions, weights and views

Engine MAN L32/40 GenSet

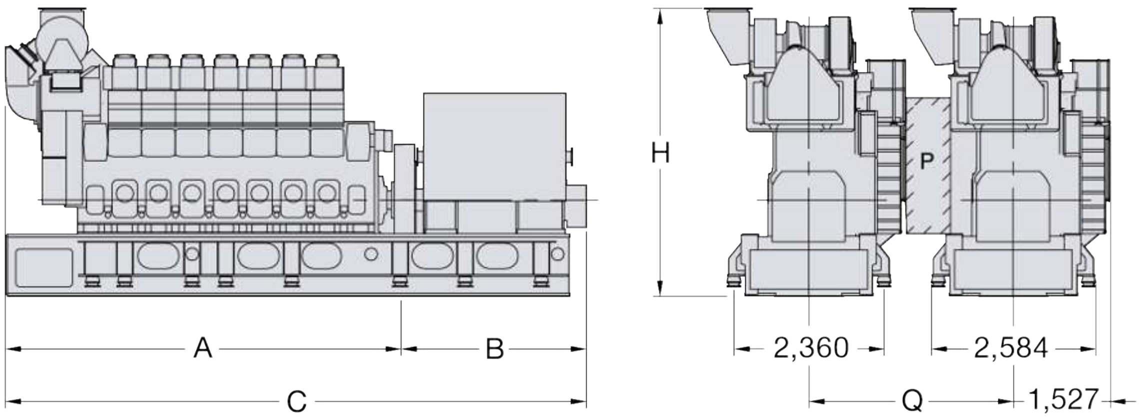


Figure 7: Main dimensions – L engine

No. of cylinders, config.	Lenght C[1)]	Lenght A	Lenght B[1)]	Height H	Weight[1)]
	mm				t
6L	9,755	6,340	3,415	4,622	70.5
7L	10,285	6,870			74.3
8L	11,035	7,400	3,635	4,840	81.8
9L	11,565	7,930			85.8

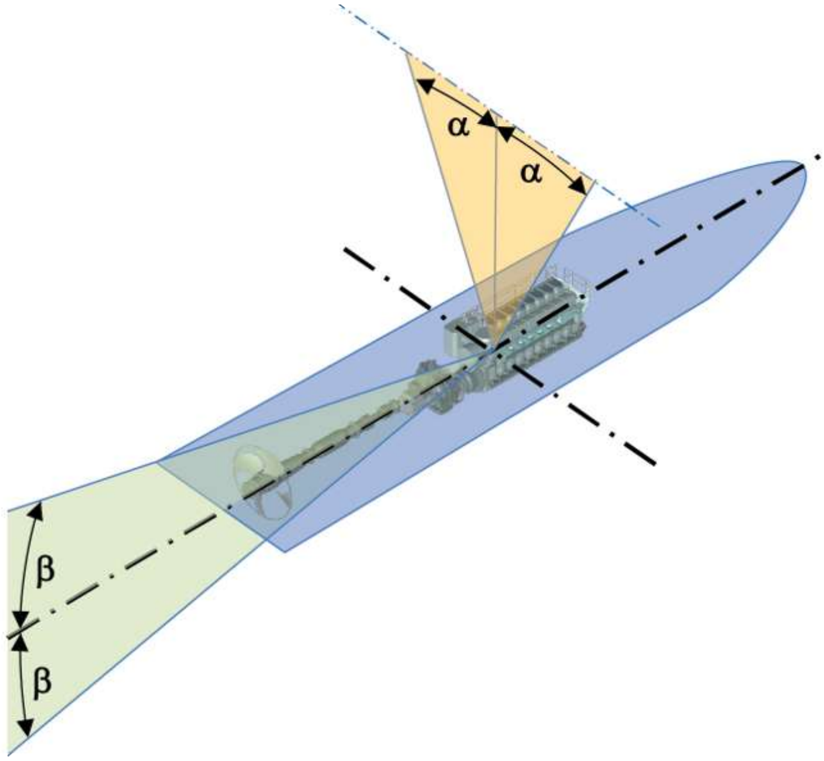
[1)] Depending on alternator applied.

Dimensions and weight specifications apply to GenSet (also known as Holeby-GenSet design) and are for guidance only (weight given without media filling of engine).

P Free passage between the engines, width 600 mm and height 2,000 mm.

Q: ~ min. distance between centre of engines: 2,835 mm (without gallery), ~ 3,220 mm (with gallery).

2.2.5 Engine inclination



α Athwartships β Fore and aft

Figure 8: Angle of inclination

Max. permissible angle of inclination [°][1]					
Application	**Athwartships α**		**Fore and aft β**		
	Heel to each side (static)	**Rolling to each side (dynamic)**	**Trim (static)[2]**		**Pitching (dynamic)**
			L < 100 m	**L > 100 m**	
Main engines	15	22.5	5	500/L	7.5

[1] Athwartships and fore and aft inclinations may occur simultaneously.

[2] Depending on length L of the ship.

Table 3: Inclinations

Note:
For higher requirements contact MAN Energy Solutions. Arrange engines always lengthwise of the ship.

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2.2.6 Engine equipment for various applications

Device/measure, (figure pos.)	Ship, auxiliary engines
Charge air blow-off (hot) for cylinder pressure limitation by continuous adjustable flap	Order related, required if intake air ≤ 0°C[1)]
Shut-off flap	O
Turbocharger – Compressor cleaning device (wet)	X
Turbocharger – Turbine cleaning device (dry)	X
Turbocharger – Turbine cleaning device (wet)	X
Two-stage charge air cooler	X
Jet assist	X
VIT	X
Oil mist detector	X
Splash oil monitoring	X
Main bearing temperature monitoring	X
Starting system – Starting air valves within cylinder head	X
Attached HT cooling water pump	X
Attached lube oil pump	X
X = required, O = optional [1)] MAN Energy Solutions recommends an engine room temperature of +5°C to avoid freezing wetness on intake air silencer filter mat and electronic equipment.	

Table 4: Engine equipment

Engine equipment for various applications – General description

Charge air blow-off (hot) for cylinder pressure limitation by continuous adjustable flap (see figure Overview flaps, Page 24)

If engines are operated at full load at low air intake temperature, the high air density leads to the danger of excessive charge air pressure and, consequently, to excessive cylinder pressure. In order to avoid such conditions, part of the charge air is withdrawn upstream (hot blow-off) of the charge air cooler and blown off.

Note:
Hot air withdrawn before charge air cooler has to be blown outside the engine room where it can not harm persons and property or may be used e.g. for intake air preheating.

Shut-off flap (see figure Overview flaps, Page 24)

The shut-off flap needs to be applied for engines where there is a risk of inflammable intake air. If the intake air contains combustible gases the engine cannot be stopped in normal way. In this exceptional situation the shut-off flap will be closed to shut off the intake air and to stop the engine reliably. A relief valve upstream of this flap may be applied for release of the compressed air.

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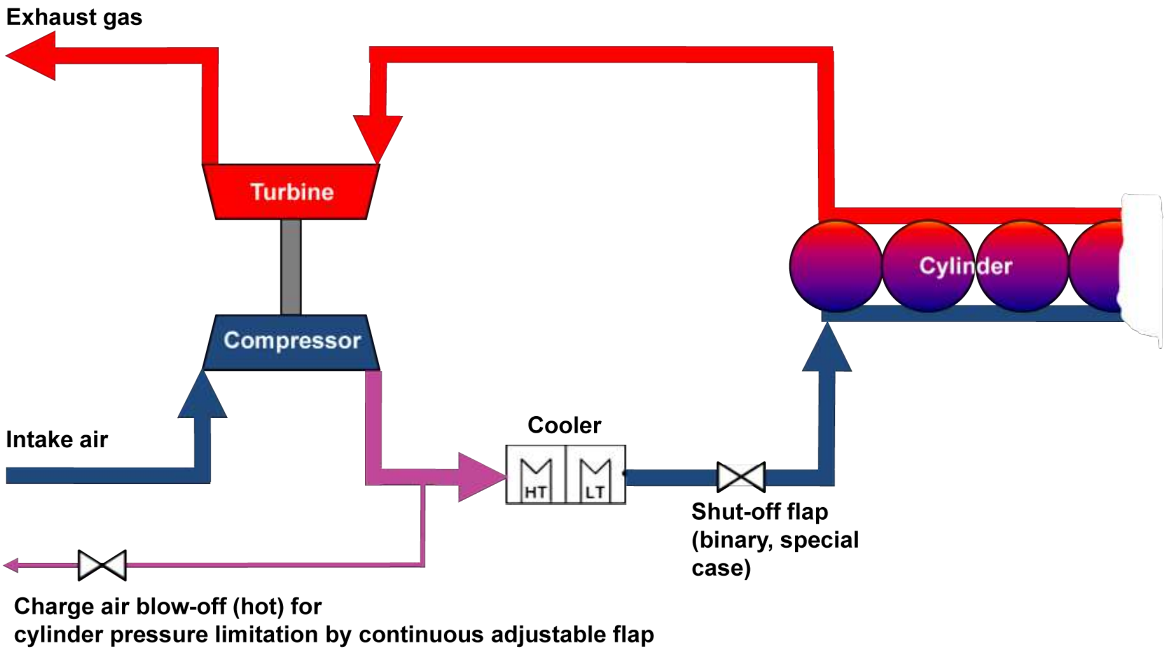

Figure 9: Overview flaps

Turbocharger – Compressor cleaning device (wet)	Depending on the quality of the intake air, deposits may be formed on the blades of the compressor wheel and diffuser. This contamination reduces the efficiency of the compressor. Cleaning of the compressor is carried out with water during operation at full load with a special compressor cleaning device.
Turbocharger – Turbine cleaning device (dry)	The turbochargers of engines operated with heavy fuel oil (HFO), marine diesel oil (MDO) or marine gas oil (MGO) must be cleaned prior to initial operation and at regular intervals to remove combustion residue from the blades of the turbine rotor and nozzle ring. Dry cleaning of the turbine should also be applied, in case of operation with inferior gas quality. Dry cleaning of the turbine is particularly suitable for cleaning the turbine rotor (turbine blades). Herefore a special cleaning device to be used.
Turbocharger – Turbine cleaning device (wet)	The turbochargers of engines operated with heavy fuel oil (HFO), marine diesel oil (MDO) or marine gas oil (MGO) must be cleaned prior to initial operation and at regular intervals to remove combustion residue from the blades of the turbine rotor and nozzle ring. Wet cleaning of the turbine is particularly suitable for cleaning the nozzle ring. Wet cleaning is carried out during operation at greatly reduced engine load in order to avoid overstressing the turbine materials (thermal shock). Herefore a special cleaning device to be used.
Two-stage charge air cooler	The two-stage charge air cooler consists of two stages which differ in the temperature level of the connected water circuits. The charge air is first cooled by the HT circuit (high temperature stage of the charge air cooler, engine) and then further cooled down by the LT circuit (low temperature stage of the charge air cooler, lube oil cooler).
Jet assist	Jet assist is used to improve the dynamic behavior of the engine to load steps and ramps. By means of nozzles in the turbocharger, compressed air is directed onto the compressor wheel to accelerate it. This results in a quicker adaption of the turbocharger to the new load condition. Jet assist is generally

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working with a compressed air pressure between 18 bar and 30 bar at the engine connection. However, it works most efficiently with a pressure of 27 bar.

Therefore, the pressure difference from the compressed air tanks to the engine connections should, in any case, not be higher than 3 bar.

Jet assist activating time: 3 seconds to 10 seconds (5 seconds on average).

VIT

For some engine types with conventional injection a VIT (Variable Injection Timing) is available allowing a shifting of injection start. A shifting in the direction of “advanced injection” is supposed to increase the ignition pressure and thus reduces fuel consumption. Shifting in the direction of “retarded injection” helps to reduce NO_x emissions.

Oil mist detector

Bearing damage, piston seizure and blow-by in combustion chamber leads to increased oil mist formation. As a part of the safety system the oil mist detector monitors the oil mist concentration in crankcase to indicate these failures at an early stage.

Splash oil monitoring

The splash oil monitoring system is a constituent part of the safety system. Sensors are used to monitor the temperature of each individual drive unit (or pair of drive at V engines) indirectly via splash oil.

Main bearing temperature monitoring

As an important part of the safety system the temperatures of the crankshaft main bearings are measured just underneath the bearing shells in the bearing caps. This is carried out using oil-tight resistance temperature sensors.

Starting system – Starting air valves within cylinder head

The engine is equipped with starting air valves within some of the cylinder heads. On starting command, compressed air will be led in a special sequence into the cylinder and will push down the piston and turn thereby the crankshaft untill a defined speed is reached.

2.3 Ratings (output) and speeds

2.3.1 General remark

The engine power which is stated on the type plate derives from the following sections and corresponds to $P_{Operating}$ as described in section Derating, definition of P Operating, Page 28.

2.3.2 Standard engine ratings

500 kW/cyl., 720/750 rpm

No. of cylinders, config.	Engine rating $P_{ISO, standard}$ [1) 2)]	
	720 rpm	750 rpm
	$kW_{mech.}$	$kW_{mech.}$
6L	3,000	3,000
7L	3,500	3,500
8L	4,000	4,000
9L	4,500	4,500
Note: Power take-off on engine free end up to 100% of rated output.		
[1)] $P_{ISO, standard}$ as specified in DIN ISO 3046-1, see paragraph Reference conditions for engine rating, Page 26.		
[2)] Engine fuel: Distillate according to ISO 8217 or RM-grade fuel, fulfilling the stated quality requirements. Contents of FAME or synthetic fuels are not considered for this reference, as they affect the volumetric heat value.		

Table 5: Engine ratings

Reference conditions for engine rating

According to ISO 15550; ISO 3046-1

Air temperature before turbocharger t_r	K/°C	298/25
Total atmospheric pressure p_r	kPa	100
Relative humidity Φ_r	%	30
Cooling water temperature inlet charge air cooler (LT stage)	K/°C	298/25

Table 6: Reference conditions for engine rating

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2.3.3 Engine ratings (output) for different applications

$P_{Application, ISO}$: Available output under ISO conditions dependent on application

	$P_{Application}$ Available output in percentage from ISO standard output	$P_{Application}$ Available output	Max. fuel admission (blocking)	Max. permissible speed reduction at maximum torque[1)]	Tropic conditions (tr/tcr/pr= 100 kPa)[2)]	Notes	Optional power take-off in percentage of ISO standard output
Kind of application	**%**	**kW/cyl.**	**%**	**%**	**°C**		**%**
Electricity generation							
Auxiliary engines in ships	100	500	110	-	45/38	3)	-

[1)] Maximum torque given by available output and nominal speed.

[2)] t_r = air temperature at compressor inlet of turbocharger.

t_{cr} = cooling water temperature before charge air cooler.

p_r = atmospheric pressure.

[3)] In accordance with DIN ISO 3046-1 and for further clarification of relevant sections within DIN ISO 8528-1, the following is specified:
- The maximum output (MCR) has to be observed by the power management system of the plant.
- The range of 100 % up to 110 % fuel admission may only be used for a short time for governing purposes (e.g. transient load conditions and suddenly applied load).

Table 7: Available outputs/related reference conditions MAN L32/40 GenSet

Note:
Power fluctuations in the electrical grid.
It is an intrinsic property of the powertrain of a generating set that it acts as a torsional vibration system. This complex system consists of the engine, coupling and generator (within or outside MAN Energy Solutions scope of supply) and the electric plant. Such electric power plant can be consisting of further power sources as well as consumers (such as electric motors), transformers, frequency converters, energy storage systems, bus bars or circuit breakers and the entire distribution system (within or outside MAN Energy Solutions scope of supply). The reciprocating engine, as well as the electric power distribution or the other consumers and power sources excite the system. As a consequence, the active power at the generator terminals is not completely constant over time and some additional power oscillations so-called power fluctuations occur. These power fluctuations do not affect the operational safety of the generating set, as long as the stability requirements of the electric system in regards to frequency and voltage meet the class requirements. In addition, this behavior is in accordance with ISO 8528-5 [1] and does as per MAN Energy Solutions experience not affect power system stability in an unacceptable range. Gas operated engines tend to show greater power fluctuations than engines operated with liquid fuels. This belongs to the typical cyclical fluctuations of the Otto combustion process that uses a premixed combustion. Note that MAN Energy Solutions quotations do not consider any specific limitations regarding power fluctuations. On request by the purchaser,

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MAN Energy Solutions provides support or further analysis of the overall system behavior, where the GenSets as well as the electric distribution and consumers should be included in the analysis.

[1] Reciprocating internal combustion engine driven alternating current generating sets – Part 5: Generating sets.

2.3.4 Derating, definition of P Operating

$P_{Operating}$: Available rating (output) under local conditions and dependent on application

Dependent on local conditions or special application demands a further load reduction of $P_{Application, ISO}$ might be required.

1. No derating

No derating necessary, provided that the conditions listed are met:

	No derating up to stated reference conditions (tropic), see 1.
Air temperature before turbocharger T_x	≤ 318 K (45°C)
Ambient pressure	≥ 100 kPa (1 bar)
Cooling water temperature inlet charge air cooler (LT stage)	≤ 311 K (38°C)
Intake air pressure before compressor	≥ –2 kPa[1)]
Exhaust gas back pressure after turbocharger	≤ 5 kPa[1)]
Relative humidity Φ_r	≤ 60%
[1)] Below/above atmospheric pressure.	

Table 8: Derating – Limits of ambient conditions

2. Derating

Contact MAN Energy Solutions:

- If limits of ambient conditions mentioned in the upper table Derating – Limits of ambient conditions, Page 28 are exceeded. A special calculation is necessary.
- If higher requirements for the emission level exist. For the permissible requirements see section Exhaust gas emission, Page 77.
- If special requirements of the plant for heat recovery exist.
- If special requirements on media temperatures of the engine exist.
- If any requirements of MAN Energy Solutions mentioned in the Project Guide cannot be met.

2.3.5 Engine speeds and related main data

Rated speed	rpm	720	750
Permissible range of speed		1)	
Alarm overspeed (110 % of nominal speed)		792	825

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Auto shutdown overspeed (115 % of nominal speed)		828	863
Speed adjusting range		See section Speed adjusting range	
Alternator frequency	Hz	60	50
Number of pole pairs	-	5	4
[1] According to section Operating range for GenSet/electric propulsion, Page 51 and figure Permissible frequency deviations and corresponding max. output, Page 53.			

Table 9: Engine speeds and related main data

2.3.6 Speed adjusting range

The following specification represents the standard settings. For special applications, deviating settings may be necessary.

	Drive	Speed droop	Maximum speed at full load	Maximum speed at idle running	Minimum speed
Electronic speed control	GenSets/electric propulsion plants				
	With load sharing via speed droop or	5 %	100 % (+0.5 %)	105 % (+0.5 %)	100 %[1]
	isochronous operation	0 %	100 % (+0.5 %)	100 % (+0.5 %)	100 %[1]
[1] Speed after start of the engine, before synchronisation.					

Table 10: Electronic speed control

2.4 Increased exhaust gas pressure due to exhaust gas after treatment installations

Resulting installation demands

If the recommended exhaust gas back pressure as stated in section Operating/service temperatures and pressures, Page 68 cannot be met due to exhaust gas after treatment installations following limit values need to be considered.

Exhaust gas back pressure after turbocharger	
Operating pressure Δp_{exh}, maximum specified	0–50 mbar
Operating pressure Δp_{exh}, range with increase of fuel consumption or possible derating	50–80 mbar
Operating pressure Δp_{exh}, where agreement and feedback of MAN Energy Solutions is required	> > 80 mbar

Table 11: Exhaust gas back pressure after turbocharger

Intake air pressure before turbocharger	
Operating pressure Δp_{intake}, standard	0 to –20 mbar
Operating pressure Δp_{intake}, range with increase of fuel consumption or possible derating	–20 to –40 mbar

Intake air pressure before turbocharger	
Operating pressure Δp_{intake}, where agreement and feedback of MAN Energy Solutions is required	< –40 mbar

Table 12: Intake air pressure before turbocharger

Sum of the exhaust gas back pressure after turbocharger and the absolute value of the intake air pressure before turbocharger	
Operating pressure Δp_{exh} + Abs(Δp_{intake}), standard	0–70 mbar
Operating pressure Δp_{exh} + Abs(Δp_{intake}), range with increase of fuel consumption or possible derating	70–120 mbar
Operating pressure Δp_{exh} + Abs(Δp_{intake}), where agreement and feedback of MAN Energy Solutions is required	> > 120 mbar

Table 13: Sum of the exhaust gas back pressure after turbocharger and the absolute value of the intake air pressure before turbocharger

Maximum exhaust gas pressure drop – Layout

- Supplier of equipment in exhaust gas line have to ensure that pressure drop Δp_{exh} over entire exhaust gas piping incl. pipe work, scrubber, boiler, silencer, etc. must stay below stated standard operating pressure at all operating conditions.
- It is recommended to consider an additional 10 mbar for consideration of aging and possible fouling/staining of the components over lifetime.
- A proper dimensioning of the entire flow path including all installed components is advised or even the installation of an exhaust gas blower if necessary.
- At the same time the pressure drop Δp_{intake} in the intake air path must be kept below stated standard operating pressure at all operating conditions and including aging over lifetime.
- For significant overruns in pressure losses even a reduction in the rated power output may become necessary.
- On plant side it must be prepared, that pressure sensors directly after turbine outlet and directly before compressor inlet may be installed to verify above stated figures.

By-pass for emergency operation

- Evaluate if the chosen exhaust gas after treatment installation demands a by-pass for emergency operation.
- For scrubber application, a by-pass is recommended to ensure emergency operation in case that the exhaust gas cannot flow through the scrubber freely.
- The by-pass needs to be dimensioned for the same pressure drop as the main installation that is by-passed – otherwise the engine would operated on a differing operating point with negative influence on the performance, e.g. a lower value of the pressure drop may result in too high turbocharger speeds.

Single streaming per engine recommended/multi-streaming to be evaluated project-specific

- In general each engine must be equipped with a separate exhaust gas line as single streaming installation. This will prevent reciprocal influencing of the engine as e.g. exhaust gas backflow into an engine out of operation or within an engine running at very low load (negative pressure drop over the cylinder can cause exhaust gas back flow into intake manifold during valve overlap).

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- In case a multi-streaming solution is realised (i.e. only one combined scrubber for multiple engines) this needs to be stated on early project stage. Hereby air/exhaust gas tight flaps need to be provided to safeguard engines out of operation. A specific layout of e.g. sealing air mass flow will be necessary and also a power management may become necessary in order to prevent operation of several engines at very high loads while others are running on extremely low load. A detailed analysis as HAZOP study and risk analysis by the yard becomes mandatory.

Engine to be protected from backflow of media out of exhaust gas after treatment installation

- A backflow of e.g. urea, scrubbing water, condensate or even rain from the exhaust gas after treatment installation towards the engine must be prevented under all operating conditions and circumstances, including engine or equipment shutdown and maintenance/repair work.

Turbine cleaning

- Both wet and dry turbine cleaning must be possible without causing malfunctions or performance deterioration of the exhaust system incl. any installed components such as boiler, scrubber, silencer, etc.

White exhaust plume by water condensation

- When a wet scrubber is in operation, a visible exhaust plume has to be expected under certain conditions. This is not harmful for the environment. However, countermeasures like reheating and/or a demister should be considered to prevent condensed water droplets from leaving the funnel, which would increase visibility of the plume.
- The design of the exhaust system including exhaust gas after treatment installation has to make sure that the exhaust flow has sufficient velocity in order not to sink down directly onboard the vessel or near to the plant. At the same time the exhaust pressure drop must not exceed the limit value.

Vibrations

- There must be a sufficient decoupling of vibrations between engine and exhaust gas system incl. exhaust gas after treatment installation, e.g. by compensators.

2.5 Starting

2.5.1 General remarks

Engine and plant installation need to be in accordance to the below stated requirements and the required starting procedure.

Note:
Statements are relevant for non arctic conditions.
For arctic conditions consider relevant sections and clarify undefined details with MAN Energy Solutions.

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2.5.2 Type of engine start

Normal start

The standard procedure of a monitored engine start in accordance to MAN Energy Solutions guidelines.

For details and requirements see section Starting conditions, Page 33.

Stand-by start

Shortened starting up procedure of a monitored engine start: Several preconditions and additional plant installations required.

This kind of engine start has to be triggered by an external signal: "Stand-by start required".

For details and requirements see section Starting conditions, Page 33.

Exceptional start (e.g. blackout start)

A monitored engine start (without monitoring of lube oil pressure) within one hour after stop of an engine that has been faultless in operation or of an engine in stand-by mode.

This kind of engine start has to be triggered by an external signal "Black Start" and may only be used in exceptional cases.

For details and requirements see section Starting conditions, Page 33.

Emergency start

Manual start of the engine at emergency start valve at the engine (if applied), without supervision by the SaCoS engine control. These engine starts will be applied only in emergency cases, in which the customer accepts, that the engine might be harmed.

2.5.3 Requirements on engine and plant installation

General requirements on engine and plant installation

As a standard and for the start-up in normal starting mode (preheated engine) following installations are required:

Engine
- Lube oil service pump (attached).

Plant
- Prelubrication pump (free-standing).
- Preheating HT cooling water system (60–90°C).
- Preheating lube oil system (> 40°C). For maximum admissible value see table Lube oil, Page 70.

Requirements on engine and plant installation for "Stand-by operation" capability

To enable in addition to the normal starting mode also an engine start from PMS (power management system) from stand-by mode with thereby shortened start-up time following installations are required:

Engine
- Lube oil service pump (attached).

Plant
- Prelubrication pump (free-standing) with low pressure before engine (0.3 bar < $p_{\text{Oil before engine}}$ < 0.6 bar).
- Preheating HT cooling water system (60–90°C).
- Preheating lube oil system (> 40°C). For maximum admissible value see table Lube oil, Page 70.
- Power management system with supervision of stand-by times engines.

Additional requirements on engine and plant installation for "Blackout start" capability

Following additional installations to the above stated ones are required to enable in addition a "Blackout start":

Engine

- HT CW service pump (attached) recommended.
- LT CW service pump (attached) recommended.
- Attached fuel oil supply pump recommended (if applicable).

Plant

- Regarding "Blackout start" fuel oil conditions, see table Fuel, Page 71.

If fuel oil supply pump is not attached to the engine:

- Air driven fuel oil supply pump or fuel oil service tanks at sufficient height or pressurised fuel oil tank.

2.5.4 Starting conditions

Type of engine start:	**Blackout start**	**Stand-by start**	**Normal start**
Explanation:	**After blackout**	**From stand-by mode**	**After stand-still**
Start-up time until load application:	**< 1 minute**	**< 1 minute**	**> 2 minutes**
General notes			
-	Engine start-up only within 1 h after stop of engine that has been faultless in operation or within 1 h after end of stand-by mode.	Maximum stand-by time 7 days[1]. Supervised by power management system plant. Stand-by mode is only possible after engine has been faultless in operation and has been faultless stopped.	Standard
Additional external signal:	Blackout start	Stand-by request	-
[1] If an engine has been in total for 7 days in stand-by mode, no extension of stand-by mode is allowed. The engine needs to be started and operated faultless before the next stand-by mode can be applied.			

Table 14: Starting conditions – General notes

Type of engine start:	**Blackout start**	**Stand-by start**	**Normal start**
General engine status	No start-blocking active	Engine in proper condition No start-blocking active Note: Start-blocking of engine leads to withdraw of "stand-by mode".	Engine in proper condition No start-blocking active
Engine to be turned before start?	No	No	Yes[1]
Engine to be preheated and prelubricated?	No[2]	Yes	Yes

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Type of engine start:	Blackout start	Stand-by start	Normal start
[1] It is recommended to install Slow Turn. Otherwise the engine has to be turned by turning gear.			
[2] Valid only, if mentioned above conditions (see table Starting conditions – General notes, Page 33) have been considered. Non-observance endangers the engine or its components.			

Table 15: Starting conditions – Required engine conditions

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Type of engine start:	Blackout start	Stand-by start	Normal start
Lube oil system			
Prelubrication period	No[1)]	Permanent	Yes, previous to engine start
Prelubrication pressure before engine	-	See section Operating/service temperatures and pressures, Page 68 limits according figure "Prelubrication/postlubrication lube oil pressure (duration > 10 min)"	See section Operating/service temperatures and pressures, Page 68 limits according figure "Prelubrication/postlubrication lube oil pressure (duration ≤ 10 min)"
Lube oil to be preheated?	No[1)]	Yes	Yes
HT cooling water			
HT cooling water to be preheated?	No[1)]	Yes	Yes
Fuel system			
For MGO/MDO operation	Sufficient fuel oil pressure at engine inlet required.	Supply pumps in operation or with starting command to engine.	
For HFO operation	Sufficient fuel oil pressure at engine inlet required. Emergency fuel supply pumps in MGO/MDO mode always.	Supply and booster pumps in operation, fuel preheated to operating viscosity. In case of permanent stand-by of liquid fuel engines or during operation of an DF engine in gas mode a periodical exchange of the circulating HFO has to be ensured to avoid cracking of the fuel. This can be done by releasing a certain amount of circulating HFO into the day tank and substituting it with "fresh" fuel from the tank.	
[1)] Valid only, if mentioned above conditions (see table Starting conditions – General notes, Page 33) have been considered. Non-observance endangers the engine or its components.			

Table 16: Starting conditions – Required system conditions

Additional remark regarding "Blackout start"

If additional requirements on engine and plant installation for "Blackout start" capability are fullfilled, it is possible to start up the engine in shorter time. But untill all media systems are back in normal operation the engine can only be operated according to the settings of alarm and safety system.

2.6 Start-up and load application

2.6.1 General remarks

In the case of highly-supercharged engines, load application is limited. This is due to the fact that the charge air pressure build-up is delayed by the turbocharger run-up. Besides, a low-load application promotes uniform heating of the engine.

In general, requirements of the International Association of Classification Societies (IACS) and of ISO 8528-5 are valid.

According to performance grade G2 concerning:

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- Dynamic speed drop in % of the nominal speed ≤ 10%.
- Remaining speed variation in % of the nominal speed ≤ 5%.
- Recovery time until reaching the tolerance band ±1% of nominal speed ≤ 5 seconds.

Clarify any higher project-specific requirements at an early project stage with MAN Energy Solutions. They must be part of the contract.

In a load drop of 100% nominal engine power, the dynamic speed variation must not exceed:

- 12% of the nominal speed.
- The remaining speed variation must not surpass 5% of the nominal speed.

To limit the effort regarding regulating the media circuits, also to ensure an uniform heat input it always should be aimed for longer load application times by taking into account the realistic requirements of the specific plant.

All questions regarding the dynamic behaviour should be clarified in close co-operation between the customer and MAN Energy Solutions at an early project stage.

Requirements for plant design:

- The load application behaviour must be considered in the electrical system design of the plant.
- The system operation must be safe in case of graduated load application.
- The load application conditions (E-balance) must be approved during the planning and examination phase.
- The possible failure of one engine must be considered, see section Generator operation/electric propulsion – Power management, Page 53.

2.6.2 Definitions and requirements

General remark

Prior to the start-up of the engine it must be ensured that the emergency stop of the engine is working properly. Additionally all required supply systems must be in operation or in stand-by operation.

Start-up – Cold engine

If an engine start has to be activated under cold engine conditions, following requirements have to be fullfilled as a minimum:

- Lube oil temperature > 20°C, HT cooling water temperature > 20°C.
- Distillate fuel must be used until warming up phase is completed.
- The engine is prelubricated. Due to the higher viscosity of the lube oil of a cold engine the prelubrication phase needs to be increased.

Before further use of the engine a warming-up phase is required to reach at least the level of the regular preheating temperatures (lube oil temperature > 40°C, cooling water temperature > 60°C). See diagrams in section Load application – Continuous loading, Page 38.

Note:

- It needs to be proven within plant layout, that lube oil circuit is capable to be operated at stated low lube oil temperature with accordingly high viscosity and high pressures.
- If engine cold start is frequently performed, wear could increase in a long-term perspective.
- “Start-Reliability” under stated cold start conditions is reduced and cannot be guaranteed, as the probability of a false start is increased.

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- If applicable, warming-up phase can be shortened if engine is operated at lower speed.

Start-up – Preheated engine

For the start-up of the engine it needs to be preheated:

- Lube oil temperature ≥ 40°C.
- HT cooling water temperature ≥ 60°C.

The required start-up time in normal starting mode (preheated engine), with the required time for starting-up the lube oil system and prelubrication of the engine is shown in the diagrams in section Load application – Continuous loading, Page 38 in connection with the information in figure(s) Duration of the load application – Continuous loading, Page 40.

Start-up – Engine in stand-by mode (Stand-by start)

For engines in stand-by mode no start preparation is needed and accordingly the engine start will be done just after the start request (if preconditions are fulfilled).

Required conditions media system:

- 0.3 bar < prelubrication pressure before engine < 0.6 bar.
- Lube oil temperature ≥ 40°C, see accordingly section Lube oil system
- HT cooling water temperature ≥ 60°C

Start-up (Exceptional start)

The engine start will be done just after the start request – but as previously stated without monitoring of lube oil pressure, and therefore this may only be used in exceptional cases.

Speed ramp-up

The standard speed ramp-up serves for all engine conditions and ensures a low opacity level of the exhaust gas.

A "fast speed ramp-up", that is near to the maximum capability of the engine, may be used in exceptional cases.

For liquid fuel engines:

- Exhaust gas will be visible (opacity > 60%).
- External signal from plant to be provided for request to SaCoSone.

Load ramp-up

The time needed for load ramp-up is in high extent dependent on the engine conditions:

- Cold

  (If applicable see "Start-up – Cold engine" for remarks and temperatures)
- Warm (= preheated)
  - Lube oil temperature ≥ 40°C.
  - HT cooling water temperature ≥ 60°C.
- Hot (= previously been in operation)
  - Lube oil temperature ≥ 40°C.
  - HT cooling water temperature ≥ 60°C.
  - Exhaust gas pipe engine and turbocharger > 320°C (within 1 h after engine stop).

Note:
Load application handled within plant automation:
The compliance of the load application with the specifications of MAN Energy Solutions has to be handled within the plant automation.
The SaCoS engine control will not interfere in the load ramp-up or load ramp-down initiated by the plant control.

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2.6.3 Load application – Continuous loading

The start procedure after "Starting request" is structured into following phases:

Start preparation (consists of phase 1, 2 and 3)

- Phase 1:
  Pressure formation in the lube oil system to gain specified lube oil pressure before engine.
- Phase 2:
  Prelubrication and pre-processing of the engine for specified time.
- Phase 3:
  "Slow Turn" function activated, if required.

Start process and running-up to minimum speed (consists of phase 4 and 5)

- Phase 4:
  Activation of starting system engine till engine is running.
- Phase 5:
  Increase of engine speed till specified minimum speed is reached.

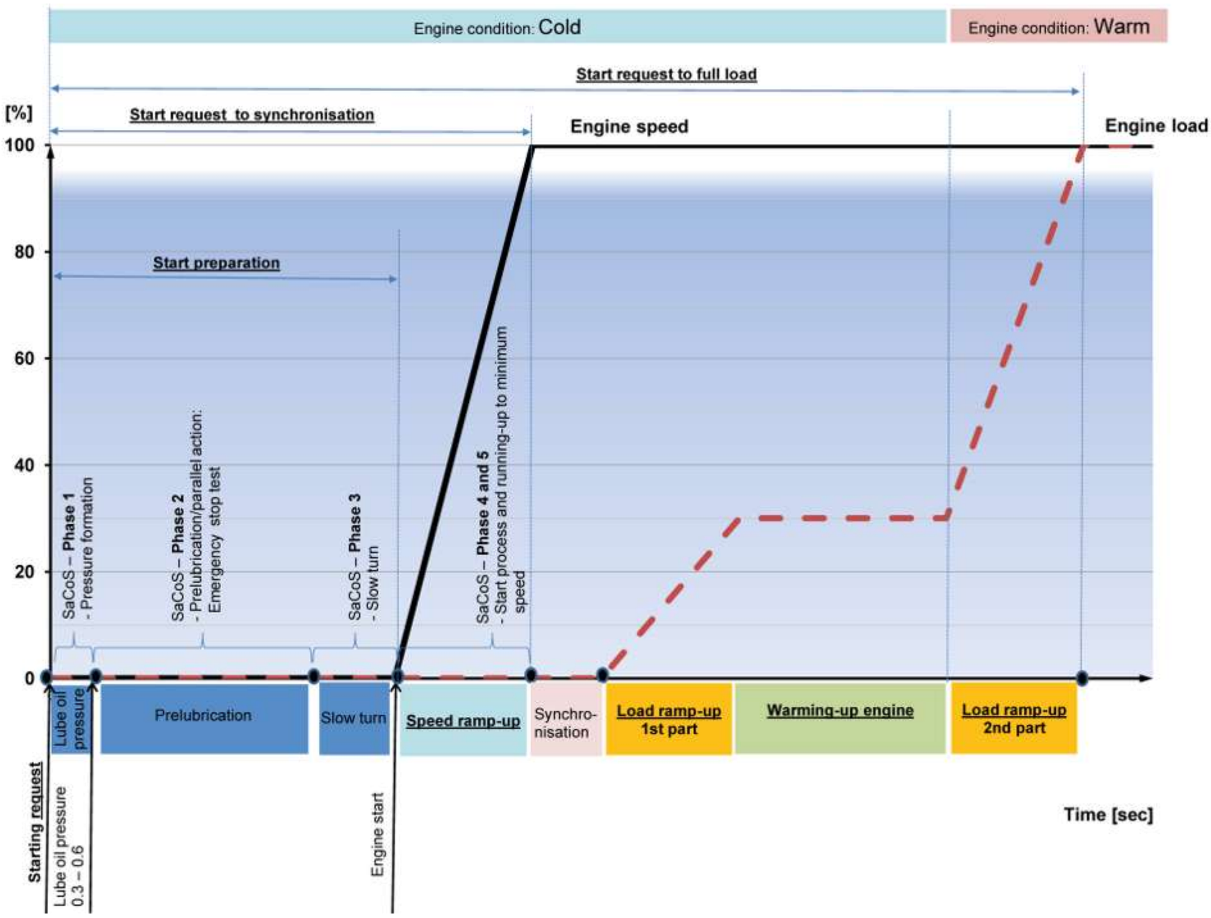

Figure 10: Start-up and load ramp-up for cold engine condition (emergency case)

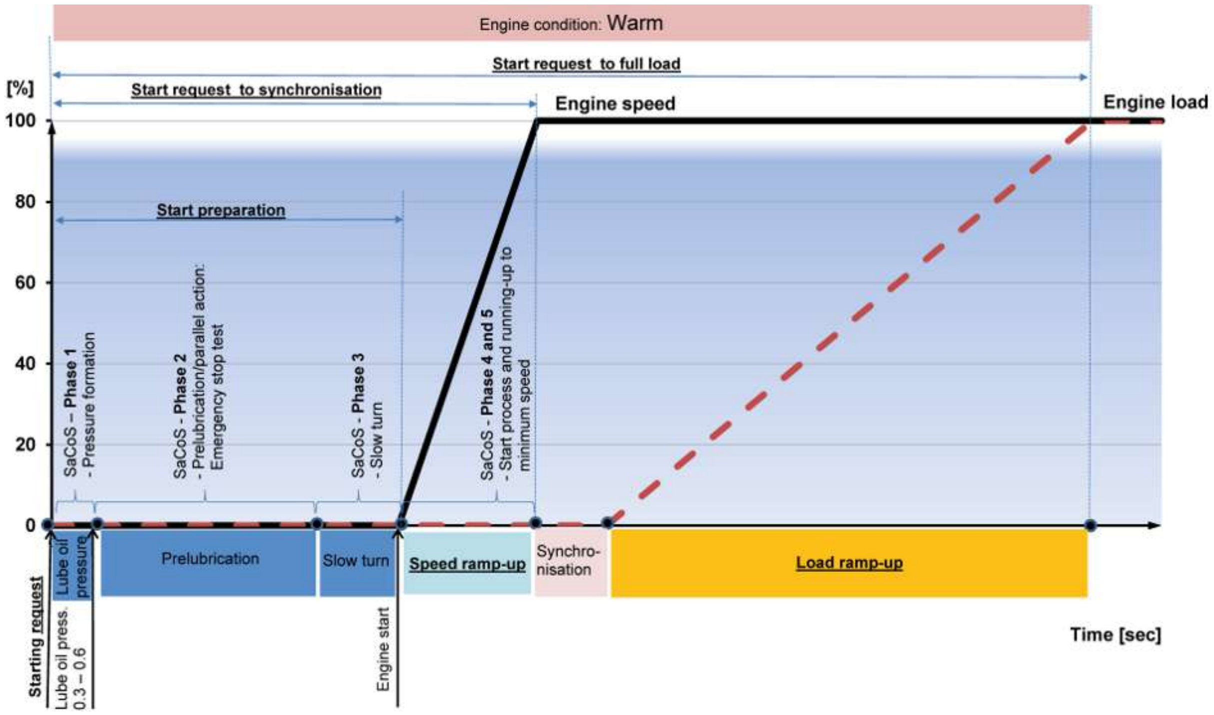

Figure 11: Start-up and load ramp-up for warm/hot engine condition

Find in the table below the relevant durations for the phases in above given diagrams.

Note:

- For "Phase 3" the engine needs to be equipped with "Slow Turn".
- Jet assist as engine equipment is recommended.
- If "fast speed ramp-up" is needed, the possibility of this has to be clarified on a project-specific basis.
- For "stand-by" special plant equipment is required.

MAN L/V32/40 – Duration "Start request to full load"								
	Engine condition/ (recommended time)	Start preparation [sec] Phase 1	Start preparation [sec] Phase 2	Start preparation [sec] Phase 3	Speed ramp-up [sec] Phase 4 and 5 () fast speed ramp-up	Synchronisation [sec]	Load ramp-up [sec] () Exceptional loading with clear visible smoke	Total [sec] Start request to 100 % load () Exceptional with clear visible smoke
Engine with/without jet assist	Cold	10	300	30	50	10	0 - 30%: 90 at 30%: 600 30% - 100%: 210 ∑ 900	1,300
	Warm/hot recommended times	10	60	30	50	10	300	460
Engine **without** jet assist	Warm	10	60	30	50	10	65	225
	Warm and stand-by	0	0	0	50 (14)	10	65 (40)	125 (64)
	Hot	10	60	30	50	10	60	220
	Hot and stand-by	0	0	0	50 (14)	10	60 (35)	120 (59)
Engine equipped **with** jet assist	Warm	10	60	30	50	10	65	225
	Warm and stand-by	0	0	0	50 (13)	10	65 (30)	125 (53)
	Hot	10	60	30	50	10	60	220
	Hot and stand-by	0	0	0	50 (13)	10	60 (25)	120 (48)

Figure 12: Duration of the load application – Continuous loading MAN L/V32/40

For further information or deviating engine condition/equipment contact MAN Energy Solutions.

2.6.4 Load application – Load steps (for electric propulsion/auxiliary GenSet)

Minimum requirements of classification societies and ISO rule

The specification of the IACS (Unified Requirement M3) contains first of all guidelines for suddenly applied load steps. Originally two load steps, each 50%, were described. In view of the technical progress regarding increasing mean effective pressures, the requirements were adapted. According to IACS and ISO 8528-5 a diagram is used to define – based on the mean effective pressure of the respective engine – the number of load steps for a load application from 0% load to 100% load. This diagram serves as a guideline for four stroke engines in general and is reflected in the rules of the classification societies.

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Be aware, that for marine engines load application requirements must be clarified with the respective classification society as well as with the shipyard and the owner.

Accordingly MAN Energy Solutions has specified the following table.

Declared power mean effective pressure of the engine (p_{me})	Number of load steps
> 18 bar up to 22.5 bar	4
> 22.5 bar up to 27 bar	5
> 27 bar	6
The size of each load step to be calculated as: 100 % load divided by "Number of load steps". For example: 100% load / "4" = 25% load increase per load step.	

Table 17: Number of load steps dependent on the p_{me} of the engine

Exemplary requirements

Minimum requirements concerning dynamic speed drop, remaining speed variation and recovery time during load application are listed below.

Classification society	Dynamic speed drop in % of the nominal speed	Remaining speed variation in % of the nominal speed	Recovery time until reaching the tolerance band ±1% of nominal speed
DNV	≤ 10%	≤ 5%	≤ 5 sec
RINA			
Lloyd´s Register			
American Bureau of Shipping			
Bureau Veritas			
ISO 8528-5			

Table 18: Minimum requirements of some classification societies plus ISO rule

In case of a load drop of 100% nominal engine power, the dynamic speed variation must not exceed 10% of the nominal speed and the remaining speed variation must not surpass 5% of the nominal speed.

Engine specific load steps – Maximum load step dependent on base load

If the engine has reached the engine condition hot, the maximum load step which can be applied as a function of the currently driven base load can be derived out of the below stated diagram(s).

Before an additional load step will be applied, at least 20 seconds waiting time after initiation of the previous load step needs to be considered.

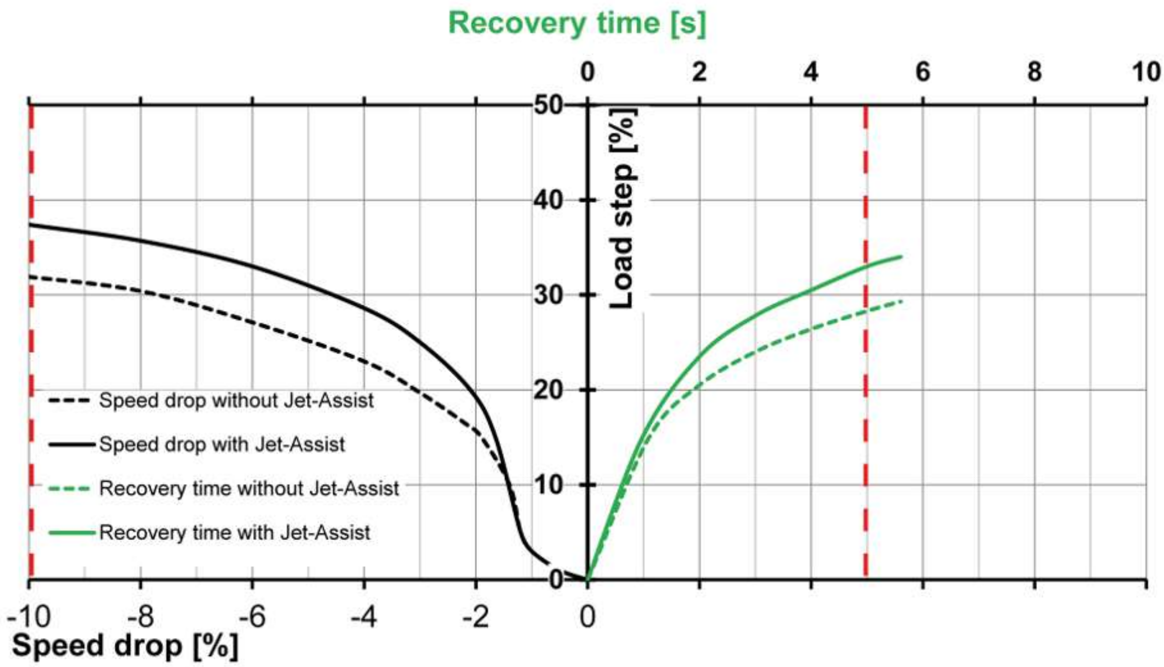

Figure 13: Load application by load steps – Speed drop and recovery time

Time between load steps of ≥ 20 sec. has to be ensured.

2.7 Low-load operation

Definition

Basically, the following load conditions are distinguished:

Overload:	> 100% (MCR) of the engine output (not admitted, see section Engine ratings (output) for different applications, Page 27)
Full load (MCR):	100% (MCR) of the engine output
Part load:	< 100% (MCR) of the engine output
Low load:	< 25% of the engine output

Correlations

The best operating conditions for the engine prevail under even loading in the range of 60% to 90% of full load.

During idle or no-load operation, combustion in the combustion chamber is incomplete.

This may result in the forming of deposits in the combustion chamber, which will lead to increased soot emission and to increasing cylinder contamination.

This process is more acute in low-load operation and during manoeuvring when the cooling water temperatures are not kept at the required level, and are decreasing too rapidly. This may result in too low charge air and combustion chamber temperatures, deteriorating the combustion at low loads especially in heavy fuel operation.

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Operation with heavy fuel oil (fuel of RM quality) or with MGO (DMA, DFA) or MDO (DMB, DFB)

Based on the above, the low-load operation in the range of < 25 % of the full load is subjected to specific limitations. According to figure Time limitation for low-load operation (left), duration of "relieving operation" (right), Page 43 immediately after a phase of low-load operation the engine must be operated at > 70 % of the full load for some time in order to reduce the deposits in the cylinders and the exhaust gas turbocharger again.

- Provided that the specified engine operating values are observed, there are no restrictions at loads > 25 % of the full load.
- Continuous operation at < 25 % of the full load should be avoided whenever possible.
- No-load operation, particularly at nominal speed (alternator operation) is only permissible for one hour maximum.

After 500 hours of continuous operation with liquid fuel, at a low load in the range of 20 % to 25 % of the full load, the engine must be run-in again.

See section Engine running in, Page 287.

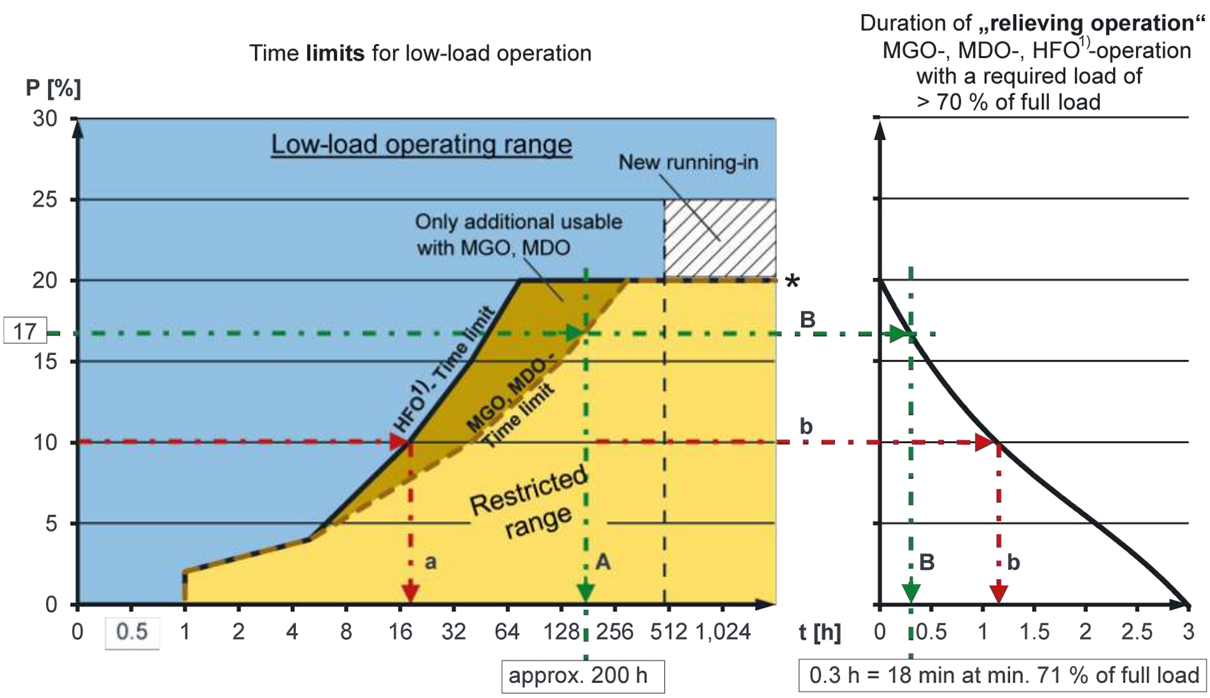

Figure 14: Time limitation for low-load operation (left), duration of "relieving operation" (right)

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P % of the full load

t Operating time in hours (h)

[1] If applicable

* Generally, the time limits in heavy fuel oil operation apply to all HFO grades according to the designated fuel specification. In certain rare cases, when HFO grades with a high ignition delay together with a high coke residues content are used, it may be necessary to raise the total level of the limiting curve for HFO from 20 % up to 30 %.

Example for heavy fuel oil (HFO, if applicable)

Line a

Time limits for low-load operation with heavy fuel oil:

At 10 % of the full load, operation on heavy fuel oil is allowable for 19 hours maximum.

Line b

Duration of "relieving operation":

Let the engine run at a load > 70 % of the full load appr. within 1.2 hours to burn the deposits formed.

Note:
The acceleration time from the actual load up to 70% of the full load must be at least 15 minutes.

Example for MGO (DMA, DFA), MDO (DMB, DFB)

Line A

Time limits for low-load operation with MGO/MDO:

At 17 % of the full load, operation on MGO/MDO is allowable appr. for 200 hours maximum.

Line B

Duration of "relieving operation":

Let the engine run at a load > 70 % of the full load appr. within 18 minutes to burn the deposits formed.

Note:
The acceleration time from the actual load up to 70% of the full load must be at least 15 minutes.

2.8 Engine load reduction

Sudden load shedding

For the sudden load shedding from 100% to 0% engine load, several requirements of the classification societies regarding the dynamic and permanent change of engine speed have to be fulfilled.

In case of a sudden load shedding and related compressor surging, check the proper function of the turbocharger silencer filter mat.

Recommended load reduction/stopping the engine

Figure Engine ramping down, generally, Page 45 shows the shortest possible times for continuously ramping down the engine.

Even with the stated shortest possible times for continuously ramping down (Phase 1 and Phase 2) the requirements of ISO 8528-5 G2 will be fulfilled.

To limit the effort regarding regulating the media circuits and also to ensure an uniform heat dissipation it always should be aimed for longer ramping down times by taking into account the realistic requirements of the specific plant.

Before final engine stop, the engine has to be operated for a minimum of 1 minute in no-load operation.

Run-down cooling

In order to dissipate the residual engine heat, the system circuits should be kept in operation after final engine stop.

	Minimum operation time after final engine stop
Lube oil circuit	15 min.

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	Minimum operation time after final engine stop
HT circuit[1)]	15 min.
LT circuit[2)]	15 min.

[2)] See accordingly for the layout of the HT cooling water pump: Table Minimum flow rate during preheating and post-cooling.

[3)] See accordingly for the layout of the LT cooling water pump section LT cooling water system.

Table 19: System circuit operation time after engine stop

If for any reason the HT cooling water stand-by pump is not in function, the engine has to be operated for 15 minutes at 0% to 10% load before final stop, so that with the engine driven HT cooling water pump the heat will be dissipated.

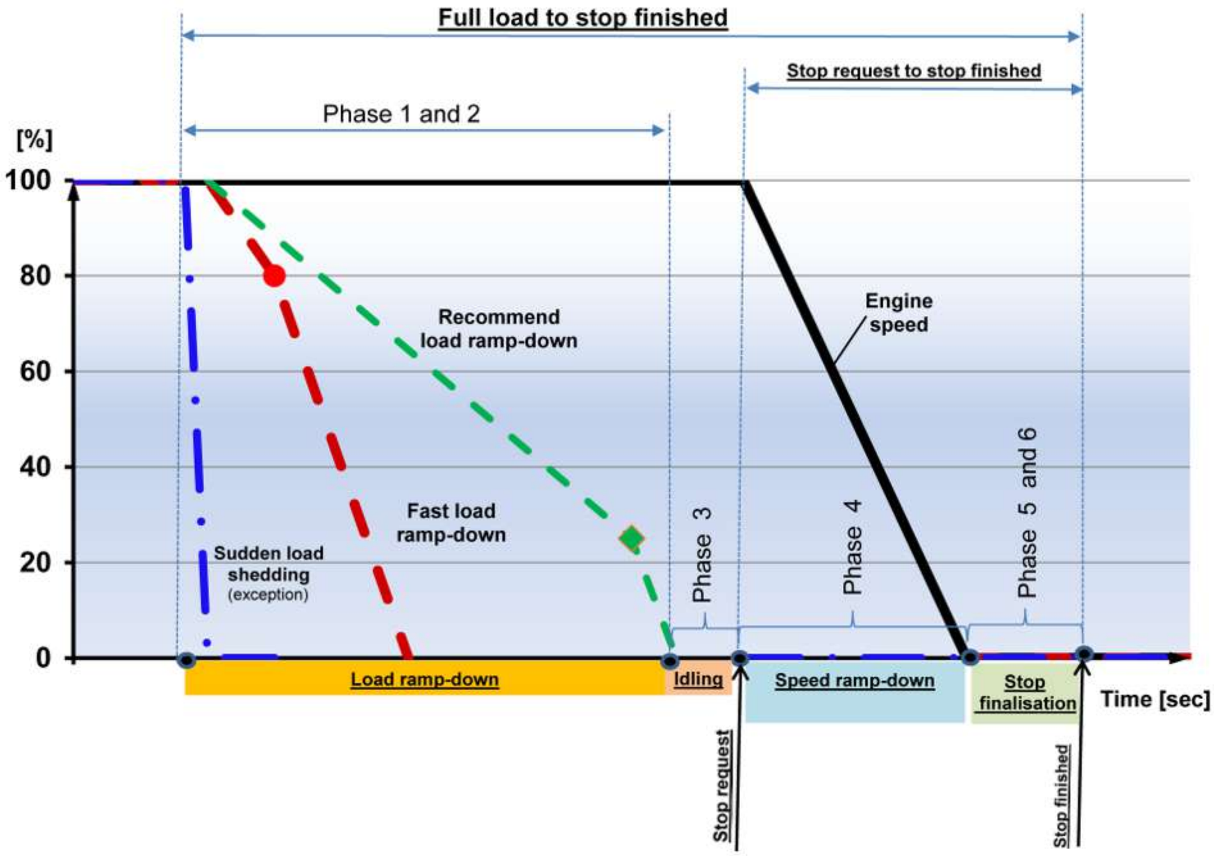

Figure 15: Engine ramping down, generally

<table>
<tr><th colspan="7">Duration "Full load to stop finished"</th></tr>
<tr><td>Phase</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5 + 6</td><td>-</td></tr>
<tr><td rowspan="2">Designation</td><td rowspan="2">Load ramp-down</td><td rowspan="2">Load ramp-down</td><td rowspan="2">Idling</td><td rowspan="2">Speed ramp-down</td><td>5) SaCoS stop process finalisation</td><td rowspan="2">Total duration ≥</td></tr>
<tr><td>6) Run down cooling and lubrication</td></tr>
<tr><td colspan="7">Fast stop</td></tr>
<tr><td>Speed [%]</td><td>100</td><td>100</td><td>100</td><td>100–0</td><td>0</td><td>-</td></tr>
<tr><td>Load [%]</td><td>100–80</td><td>80–0</td><td>0</td><td>0</td><td>0</td><td>-</td></tr>
<tr><td rowspan="2">Time [sec]</td><td rowspan="2">4</td><td rowspan="2">6</td><td rowspan="2">60</td><td rowspan="2">60</td><td>5) In case of active stand-by 60 sec otherwise: > 300 sec</td><td>430</td></tr>
<tr><td>6) 900 sec</td><td>1,030</td></tr>
<tr><td colspan="7">Recommended stop</td></tr>
<tr><td>Speed [%]</td><td>100</td><td>100</td><td>100</td><td>100–0</td><td>0</td><td>-</td></tr>
<tr><td>Load [%]</td><td>100–25</td><td>25–0</td><td>0</td><td>0</td><td>0</td><td>-</td></tr>
<tr><td rowspan="2">Time [sec]</td><td rowspan="2">115</td><td rowspan="2">5</td><td rowspan="2">10</td><td rowspan="2">///</td><td>5) In case of active stand-by 60 sec otherwise: > 300 sec</td><td>490</td></tr>
<tr><td>6) 900 sec</td><td>1,090</td></tr>
<tr><td colspan="7">[1] Run down cooling, for details see table System circuit operation time after engine stop, Page 44.</td></tr>
</table>

Table 20: Recommended load reduction/stopping the engine

2.9 Engine load reduction as a protective safety measure

Requirements for the power management system/propeller control

In case of a load reduction request due to predefined abnormal engine parameter (e.g. high exhaust gas temperature, high turbine speed, high lube oil temperature) the power output (load) must be ramped down as fast as possible to ≤ 60% load.

Therefore the power management system/propeller control has to meet the following requirements:

- After a maximum of 5 seconds after occurrence of the load reduction signal, the engine load must be reduced by at least 5%.
- Then, within the next time period of maximum 30 sec an additional reduction of engine load by at least 35% needs to be applied.

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- The “Prohibited range” shown in figure Engine load reduction as a protective safety measure, Page 47 has to be avoided.

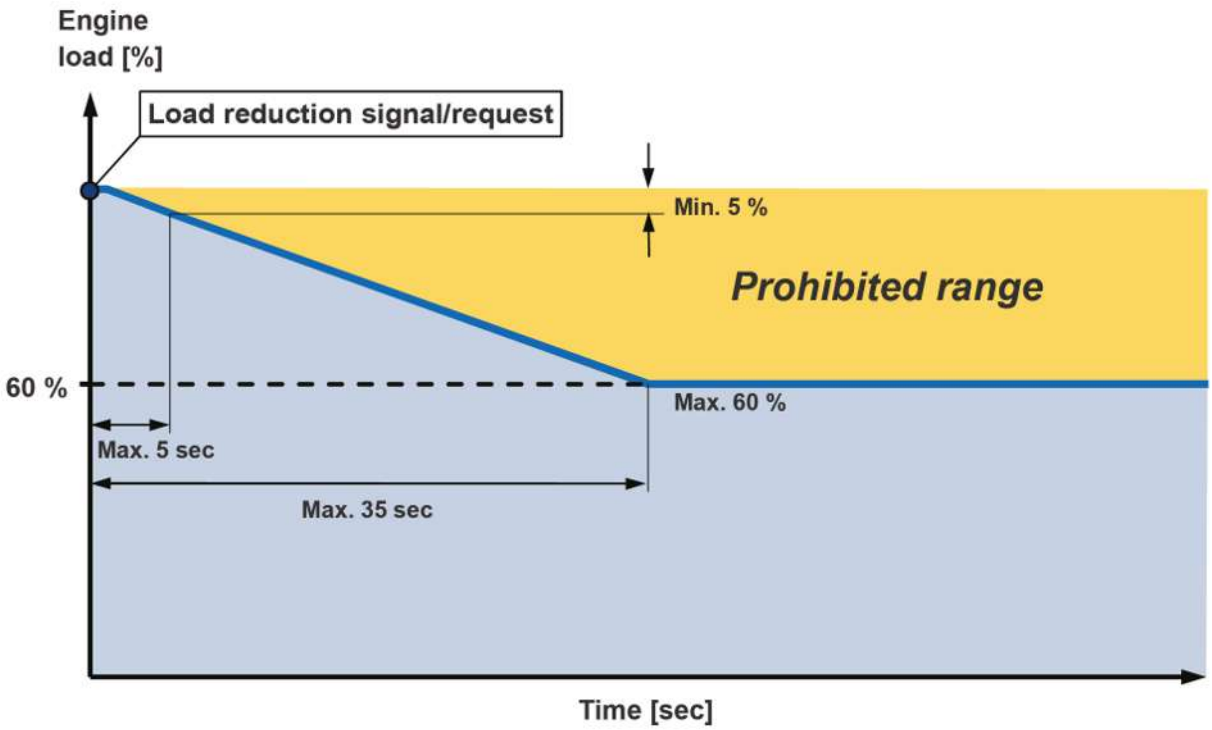

Figure 16: Engine load reduction as a protective safety measure

2.10 Engine operation under arctic conditions

Arctic condition is defined as:

Air intake temperatures of the engine below +5°C.

If engines operate under arctic conditions (intermittently or permanently), the engine equipment and plant installation have to hold certain design features and meet special requirements. They depend on the possible minimum air intake temperature of the engine and the specification of the fuel used.

Minimum air intake temperature of the engine, t_x:

- Category A

  +5 °C > t_x > −15 °C
- Category B

  −15 °C ≥ t_x > −35 °C
- Category C

  t_x ≤ −35 °C

Special engine design requirements

Charge air blow-off according to categories A, B or C.

If arctic fuel (with very low lubricating properties) is used, the following actions are required:

- The maximum permissible fuel temperatures and the minimum permissible viscosity before engine have to be kept.
- Fuel injection valve
  Switch off nozzle cooling to avoid corrosion caused by temperatures below the dew point.
- Valve seat lubrication
  Has to be equipped to the engine and to be activated to avoid increased wear of the inlet valves (dependent on engine type).

Engine equipment

SaCoSone

- SaCoSone equipment is suitable to be stored at minimum ambient temperatures of −15°C.
- In case these conditions cannot be met, protective measures against climatic influences have to be taken for the following electronic components:
  - EDS Data box
  - TFT-touchscreen
  - Emergency switch module

  These components have to be stored at places, where the temperature is above −15°C.
- A minimum operating temperature of ≥ 0°C has to be ensured. The use of an optional electric heating is recommended.

See environmental conditions in section Technical data.

Alternators

Alternator operation is possible according to suppliers specification.

Plant installation

Intake air conditioning

- Air intake of the engine and power house/engine room ventilation have to be two different systems to ensure that the power house/engine room temperature is not too low caused by the ambient air temperature.
- It is necessary to ensure that the charge air cooler cannot freeze when the engine is out of operation (and the cold air is at the air inlet side).
- Category A, B

  No additional actions are necessary. The charge air before the cylinder is preheated by the HT circuit of the charge air cooler (LT circuit closed).
- Category C

  An air intake temperature ≥ −35 °C has to be ensured by preheating.

  Additionally the charge air before the cylinder is preheated by the HT circuit of the charge air cooler (LT circuit closed).

Instruction for minimum admissible fuel temperature

- In general the minimum viscosity before engine of 1.9 cSt must not be undershoot.
- The fuel specific characteristic values “pour point” and “cold filter plugging point” have to be observed to ensure pumpability respectively filterability of the fuel oil.
- Fuel temperatures of ≤ −10°C are to be avoided, due to temporarily embrittlement of seals used in the engines fuel oil system. As a result they may suffer a loss of function.

Minimum engine room temperature

- Ventilation of engine room.

  The air of the engine room ventilation must not be too cold (preheating is necessary) to avoid the freezing of the liquids in the engine room systems.

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- Minimum power house/engine room temperature for design ≥ +5°C.

Coolant and lube oil systems

- Coolant and lube oil system have to be preheated for each individual engine, see section Starting conditions, Page 33.
- Design requirements for the preheater of HT systems:
  - Category A
    Standard preheater.
  - Category B
    50 % increased capacity of the preheater.
  - Category C
    100 % increased capacity of the preheater.
- Maximum permissible antifreeze concentration (ethylene glycol) in the engine cooling water.

  An increasing proportion of antifreeze decreases the specific heat capacity of the engine cooling water, which worsens the heat dissipation from the engine and will lead to higher component temperatures.

  Therefore, the antifreeze concentration of the engine cooling water systems (HT and LT) within the engine room, respectively power house, should be below a concentration of 40 % glycol. Any concentration of > 55 % glycol is forbidden.
- If a concentration of anti-freezing agents of > 50% in the cooling water systems is required, contact MAN Energy Solutions for approval.
- For information regarding engine cooling water, see section Specification for engine supplies, Page 119.

Insulation

The design of the insulation of the piping systems and other plant parts (tanks, heat exchanger, external intake air duct, and so on) has to be modified and designed for the special requirements of arctic conditions.

Heat tracing

To support the restart procedures in cold condition (for example, after unmanned survival mode during winter), it is recommended to install a heat tracing system in the pipelines to the engine.

Note:
A preheating of the lube oil has to be ensured. For plants taken out of operation and cooled down below temperatures of +5°C additional special measures are required. In this case contact MAN Energy Solutions.

Heat extraction HT system and preheater sizes

After engine start, it is necessary to ramp up the engine to the below specified Range II to prevent too high heat loss and resulting risk of engine damage.

Thereby Range I must be passed as quick as possible to reach Range II. Be aware that within Range II low-load operation restrictions may apply.

If operation within Range I is required, the preheater size within the plant must be capable to preheat the intake air to the level, where heat extraction from the HT system is not longer possible.

Example 1:

- Operation at 20% engine load and –45°C intake air temperature wanted.
- Preheating of intake air from –45°C up to minimum –16.5°C required.
  => According diagram preheater size of 9 kW/cyl. required.
- Ensure that this preheater size is installed, otherwise this operation point is not permissible.

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All preheaters need to be operated in parallel to engine operation until minimum engine load is reached.

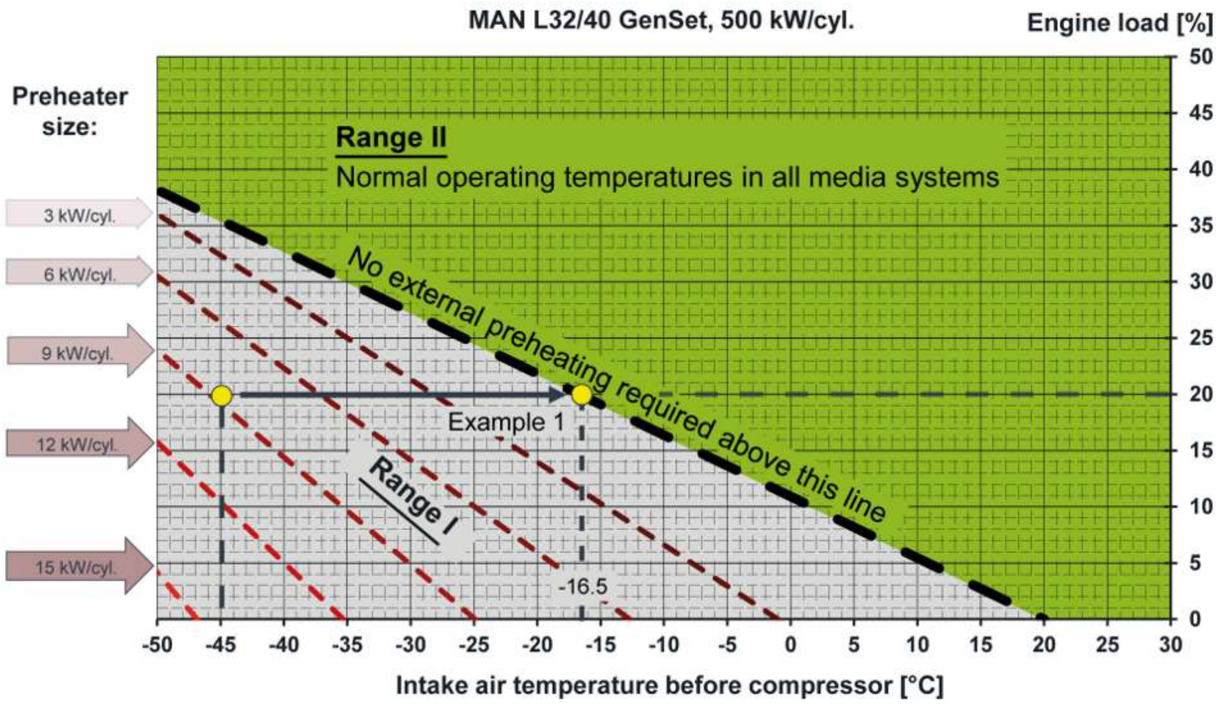

Figure 17: Required preheater size to avoid heat extraction from HT system

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2.11 GenSet operation

2.11.1 Operating range for GenSet/electric propulsion

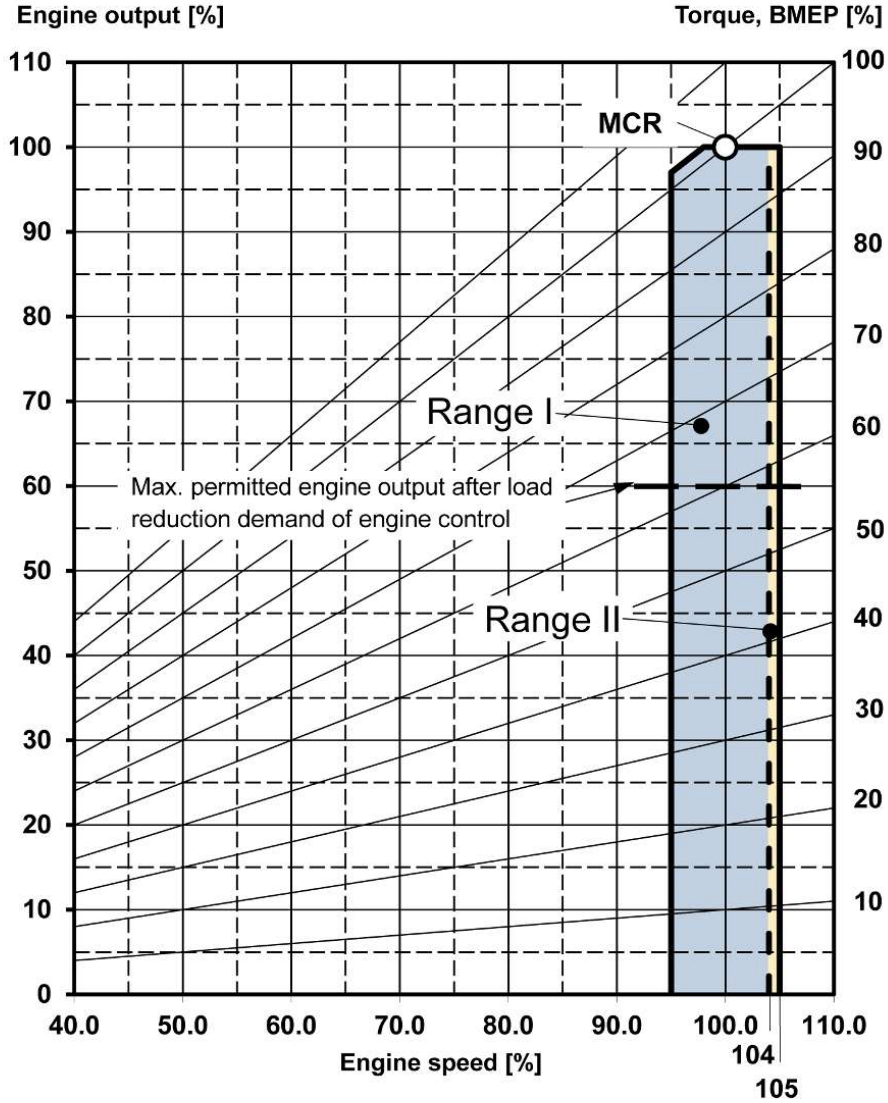

Figure 18: Operating range for GenSet/electric propulsion

- MCR[1]
  Maximum continuous rating.
- Range I
  Operating range for continuous service.
- Range II
  No continuous operation permissible.
  Maximum operating time less than 2 minutes.

[1] In accordance with DIN ISO 3046-1 and for further clarification of relevant sections within DIN ISO 8528-1, the following is specified:

- The maximum output (MCR) has to be observed by the power management system of the plant.

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- The range of 100% up to 110% fuel admission may only be used for a short time for governing purposes (for example, transient load conditions and suddenly applied load).

IMO certification for engines with operating range for auxiliary GenSet

Test cycle type D2 will be applied for the engine´s certification for compliance with the NO_x limits according to NO_x technical code.

2.11.2 Available outputs and permissible frequency deviations

General

Generating sets, which are integrated in an electricity supply system, are subjected to the frequency fluctuations of the mains. Depending on the severity of the frequency fluctuations, output and operation respectively have to be restricted.

Frequency adjustment range

According to DIN ISO 8528-5, operating limits of > 2.5% are specified for the lower and upper frequency adjustment range.

Operating range

Depending on the prevailing local ambient conditions, a certain maximum continuous rating will be available.

In the output/speed and frequency diagrams, a range has specifically been marked with “No continuous operation permissible in this area”. Operation in this range is only permissible for a short period of time, for example, for less than 2 minutes. In special cases, a continuous rating is permissible if the standard frequency is exceeded by more than 4%.

Limiting parameters

Max. torque

In case the frequency decreases, the available output is limited by the maximum permissible torque of the generating set.

Max. speed for continuous rating

An increase in frequency, resulting in a speed that is higher than the maximum speed admissible for continuous operation, is only permissible for a short period of time, that is, for less than 2 minutes.

For engine-specific information see section Ratings (output) and speeds, Page 26 of the specific engine.

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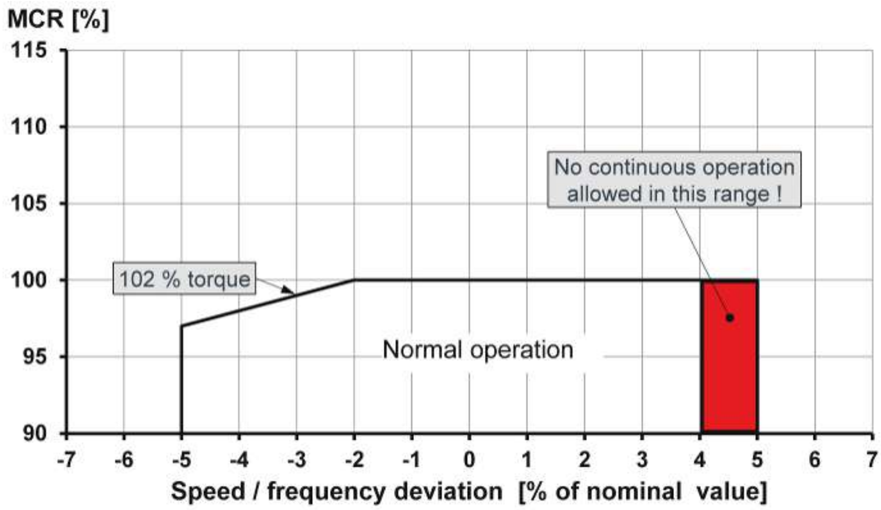

Figure 19: Permissible frequency deviations and corresponding max. output

2.11.3 Generator operation/electric propulsion – Power management

Operation of vessels with electric propulsion is defined as parallel operation of main engines with generators forming a closed system.

The power supply of the plant as a standard is done by auxilliary GenSets also forming a closed system.

In the design/layout of the plant a possible failure of one engine has to be considered in order to avoid overloading and under-frequency of the remaining engines with the risk of an electrical blackout.

Therefore we recommend to install a power management system. This ensures uninterrupted operation in the maximum output range and in case one engine fails the power management system reduces the propulsive output or switches off less important energy consumers in order to avoid under-frequency.

According to the operating conditions it is the responsibility of the ship's operator to set priorities and to decide which energy consumer has to be switched off.

The base load should be chosen as high as possible to achieve an optimum engine operation and lowest soot emissions.

The optimum operating range and the permissible part loads are to be observed (see section Low-load operation, Page 42).

Load application in case one engine fails

In case one engine fails, its output has to be made up for by the remaining engines in the system and/or the load has to be decreased by reducing the propulsive output and/or by switching off electrical consumers.

The immediate load transfer to one engine does not always correspond with the load reserve that the particular engine has available at the respective moment. That depends on the engine's base load.

Be aware that the following section only serves as an example and is definitely not valid for this engine type. For the engine specific capability please see figure(s) Load application by load steps – Speed drop and recovery time, Page 42.

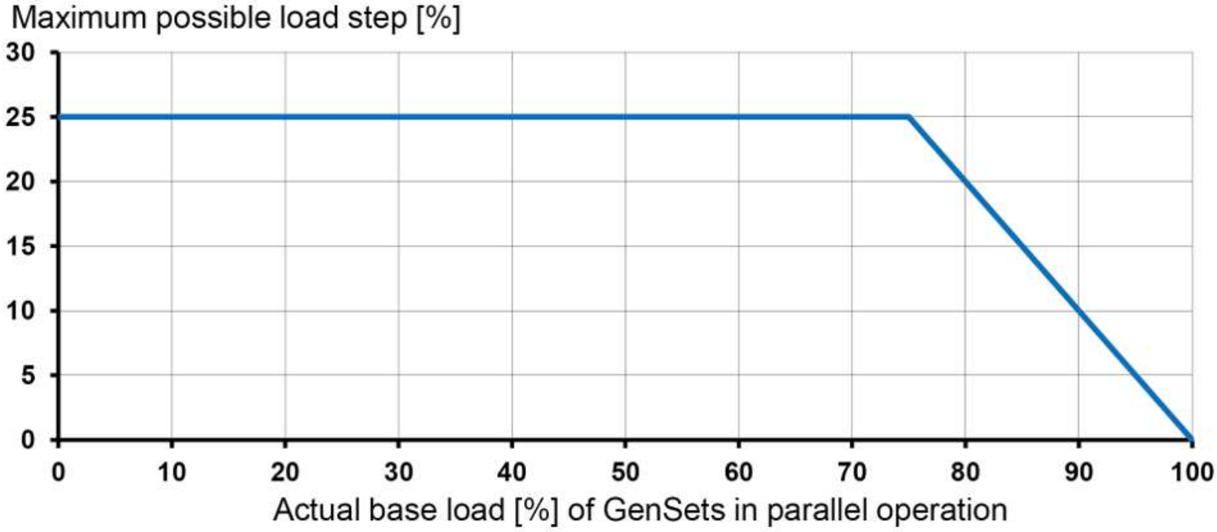

Figure 20: Maximum load step depending on base load (example may not be valid for this engine type)

Based on the above stated exemplary figure and on the total number of engines in operation the recommended maxium load of these engines can be derived. Observing this limiting maximum load ensures that the load from one failed engine can be transferred to the remaining engines in operation without power reduction.

Number of engines in parallel operation	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Recommended maximum load in (%) of P_{max}	50	75	80	83	86	87.5	89	90

Table 21: Exemplary – Recommended maximum load in (%) of P_{max} dependend on number of engines in parallel operation

2.11.4 Alternator – Reverse power protection

Definition of reverse power

If an alternator, coupled to a combustion engine, is no longer driven by this engine, but is supplied with propulsive power by the connected electric grid and operates as an electric motor instead of working as an alternator, this is called reverse power. The speed of a reverse power driven engine is accordingly to the grid frequency and the rated engine speed.

Demand for reverse power protection

For each alternator (arranged for parallel operation) a reverse power protection device has to be provided because if a stopped combustion engine (fuel admission at zero) is being turned it can cause, due to poor lubrication, excessive wear on the engine´s bearings. This is also a classifications` requirement.

Examples for possible reverse power occurences

- Due to lack of fuel the combustion engine no longer drives the alternator, which is still connected to the mains.

- Stopping of the combustion engine while the driven alternator is still connected to the electric grid.
- On ships with electric drive the propeller can also drive the electric traction motor and this in turn drives the alternator and the alternator drives the connected combustion engine.
- Sudden frequency increase, for example, because of a load decrease in an isolated electrical system -> if the combustion engine is operated at low load (for example, just after synchronising).

Adjusting the reverse power protection relay

The necessary power to drive an unfired diesel or gas engine at nominal speed cannot exceed the power which is necessary to overcome the internal friction of the engine. This power is called motoring power. The setting of the reverse-power relay should be, as stated in the classification rules, 50% of the motoring power. To avoid false tripping of the alternator circuit breaker a time delay has to be implemented. A reverse power >> 6% mostly indicates serious disturbances in the generator operation.

The following table Adjusting the reverse power relay, Page 55 provides a summary.

Admissible reverse power P_{el} [%]	Time delay for tripping the alternator circuit breaker [sec]
$P_{el} < 3$	30
$3 \leq P_{el} < 8$	3 to 10
$P_{el} \geq 8$	1.5

Table 22: Adjusting the reverse power relay

2.11.5 Earthing measures of diesel engines and bearing insulation on alternators

General

The use of electrical equipment on diesel engines requires precautions to be taken for protection against shock current and for equipotential bonding. These measures not only serve as shock protection but also for functional protection of electric and electronic devices (EMC protection, device protection in case of welding, etc.).

Earthing connections on the engine

Threaded bores M12, 20 mm deep, marked with the earthing symbol are provided in the engine foot on both ends of the engine.

It has to be ensured that earthing is carried out immediately after engine set-up. If this cannot be accomplished any other way, at least provisional earthing is to be effected right after engine set-up.

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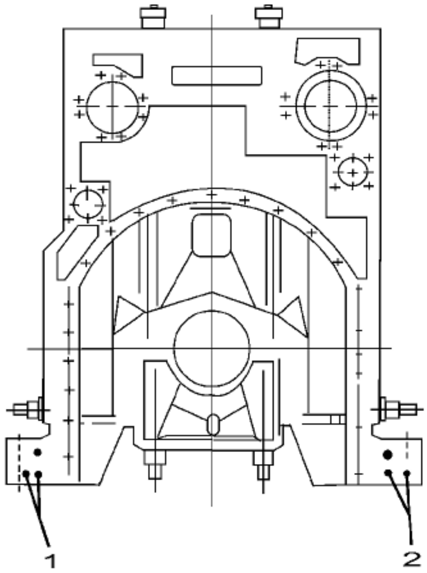

1 Connecting grounding terminal coupling side and engine free end (stamped symbol) M12

2 Connecting grounding terminal coupling side and engine free end (stamped symbol) M12

Figure 21: Earthing connection on engine (are arranged diagonally opposite each)

Measures to be taken on the alternator

Shaft voltages, for example, voltages between the two shaft ends, are generated in electrical machines because of slight magnetic unbalances and ring excitations. In the case of considerable shaft voltages (for example, > 0.3 V), there is the risk that bearing damage occurs due to current transfers. For this reason, at least the bearing that is not located on the drive end is insulated (valid for alternators > 1 MW output). For verification, the voltage available at the shaft (shaft voltage) is measured while the alternator is running and excited. With proper insulation, a voltage can be measured. In order to protect the prime mover and to divert electrostatic charging, an earthing brush is often fitted on the coupling side.

Observation of the required measures is the alternator manufacturer's responsibility.

Consequences of inadequate bearing insulation on the alternator and insulation check

In case the bearing insulation is inadequate, for example, if the bearing insulation was short-circuited by a measuring lead (PT100, vibration sensor), leakage currents may occur, which result in the destruction of the bearings. One possibility to check the insulation with the alternator at standstill (prior to coupling the alternator to the engine; this, however, is only possible in the case of single-bearing alternators) would be:

- Raise the alternator rotor (insulated, in the crane) on the coupling side.
- Measure the insulation by the megger test against earth.

Note:
Hereby the max. voltage permitted by the alternator manufacturer is to be observed.

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If the shaft voltage of the alternator at rated speed and rated voltage is known (for example, from the test record of the alternator acceptance test), it is also possible to carry out a comparative measurement.

If the measured shaft voltage is lower than the result of the “earlier measurement” (test record), the alternator manufacturer should be consulted.

Earthing conductor

The nominal cross section of the earthing conductor (equipotential bonding conductor) has to be selected in accordance with DIN VDE 0100, part 540 (up to 1 kV) or DIN VDE 0141 (in excess of 1 kV).

Generally, the following applies:

The protective conductor to be assigned to the largest main conductor is to be taken as a basis for sizing the cross sections of the equipotential bonding conductors.

Earthing conductors have to be provided at two diagonally opposite points of engine.

Flexible conductors have to be used for the connection of resiliently mounted engines.

Execution of earthing

The earthing must be executed by the shipyard, since generally it is not scope of supply of MAN Energy Solutions.

Earthing strips are also not included in the MAN Energy Solutions scope of supply.

Additional information regarding the use of welding equipment

In order to prevent damage on electrical components, it is imperative to earth welding equipment close to the welding area, that is, the distance between the welding electrode and the earthing connection should not exceed 10 m.

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2.12 Fuel oil, lube oil, starting air and control air consumption

2.12.1 Fuel oil consumption for emission standard: IMO Tier II

Engine MAN L32/40 auxiliary GenSet

500 kW/cyl., 720 rpm or 500 kW/cyl., 750 rpm

% Output	100	85 [1)]	75	50	25
Specific fuel consumption (g/kWh) with HFO or MDO (DMB) without attached pumps[2) 3) 4)]	186.0	183.0	190.0	197.0	210.0
Specific fuel consumption (g/kWh) with MGO (DMA) without attached pumps[2) 3) 4)]	187.0	183.8	190.7	197.1	210.0

[1)] Warranted fuel consumption at 85% MCR.

[2)] Tolerance +5%.

Note: The additions to fuel consumption must be considered before the tolerance for warranty is taken into account. For consideration of fuel leakage amount consider table Leak rate – MAN 32/40 with SP injection pumps, Page 73.

[3)] Based on reference conditions, see table Reference conditions for fuel consumption MAN L32/40 GenSet, Page 59.

[4)] Relevant for engine´s certification for compliance with the NO_x limits according D2 test cycle.

Table 23: Fuel oil consumption MAN L32/40 auxiliary GenSet

Additions to fuel consumption

1. Engine driven pumps increase the fuel consumption by:

$$be_{ISO\ with\ pumps} = be_{ISO\ without\ pumps} \times (1 + f_{pumps})$$

$$f_{pumps} = (f_{HT\ pump} + f_{LO\ pump}) \times \frac{500\ kW/cyl.}{nominal\ output\ per\ cyl.}$$

For HT CW service pump (attached)

$$f_{HT\ pump} = 0.0028 \times \left(\frac{100\%}{load\%}\right) \%$$

For all lube oil service pumps (attached)

GenSet:

$$f_{LO\ pumps} = 0.0150 \times \left(\frac{100\%}{load\%}\right) \%$$

f_{pumps}	Actual factor for impact of attached pumps	[-]
load%	Actual engine load	[%]
nominal output per cylinder	Insert the nominal output per cylinder	[kW/cyl.]

2. For exhaust gas back pressure after turbine > 50 mbar

Every additional 1 mbar (0.1 kPa) back pressure addition of 0.025 g/kWh has to be calculated.

Reference conditions for fuel consumption

According to ISO 15550; ISO 3046-1

Air temperature before turbocharger t_r	K/°C	298/25
Total atmospheric pressure p_r	kPa	100
Relative humidity Φ_r	%	30
Exhaust gas back pressure after turbocharger[1)]	kPa	5
Engine type specific reference charge air temperature before cylinder t_{bar}[2)]	K/°C	316/43
Net calorific value NCV[3)]	kJ/kg	42,700

[1)] Measured at 100% load, accordingly lower for loads < 100%.

[2)] Specified reference charge air temperature corresponds to a mean value for all cylinder numbers that will be achieved with 25°C LT cooling water temperature before charge air cooler (according to ISO).

[3)] Stated figures for MGO (DMA), MDO (DMB) or HFO valid for fuel type fulfilling the stated quality requirements and without contents of FAME or synthetic fuels, that may result in low volumetric heat values.

Table 24: Reference conditions for fuel consumption MAN L32/40 GenSet

IMO Tier II requirements:

For detailed information see section Water systems, Page 181.

IMO: International Maritime Organization

MARPOL 73/78; Revised Annex VI-2008, Regulation 13

Tier II: NO_x technical code on control of emission of nitrogen oxides from diesel engines.

2.12.2 Lube oil consumption

500 kW/cyl.; 720 rpm or 500 kW/cyl.; 750 rpm

Specific lube oil consumption:

$$0.5\ \text{g/kWh}^{1)} \times \frac{100\%}{\text{load\%}} \times \frac{500\ \text{kW/cyl.}}{\text{nominal output per cyl.}}$$

Load%	Actual engine load	[%]
Nominal output per cyl.	Insert the nominal output per cyl.	[kW/cyl.]

[1)] The value stated above is without any losses due to cleaning of filter and centrifuge or lube oil charge replacement. Tolerance for warranty +20%.

Example:

For nominal output 500 kW/cyl. and 100 % actual engine load: 0.50 g/kWh.

2.12.3 Starting air and control air consumption

No. of cylinders, config.		6L	7L	8L	9L
Control air consumption	Nm^3/h [1]	2.5			
Air consumption per start[2] $V_{Start\ Ref}$	Nm^3 [1]	2.9	2.6	3.2	4.0
Starting system active[3]	sec	5.0			
Reference moment of inertia for stated air consumption figures[2] J_{Ref}	kgm^2	1,475	1,720	1,966	2,212
Air consumption per jet assist activation[4] V_{Jet}	Nm^3 [1]	1.85	1.85	2.95	2.95
Air consumption jet assist in case of emergency loading[5][6]	Nm^3	To be considered: 20 jet assist activations during loading from 0% to 100% load			

[1] Nm^3 corresponds to one cubic metre of gas at 20°C and 100.0 kPa abs.

[2] The stated air consumption values are based on the "Reference moments of inertia" in this table according to the "Required minimum total moments of inertia" as stated in section Moments of inertia – Crankshaft, damper, flywheel, Page 89.

[3] Stated time duration for activated starting system only relevant for layout of starting air system
For layout of the starting air system, note:

- Starting air pressure stated within section Operating/service temperatures and pressures, Page 68.
- Maximum velocity (m/s) see section External pipe dimensioning, Page 159.
- Consider multiple start of engines and the temporal distribution of events, if needed.
- See section External compressed air system – Dimensioning starting air receivers, compressors, Page 241.

[4] The mentioned above air consumption per jet assist activation is valid for a jet duration of 5 seconds. The jet duration may vary between 3 sec and 10 sec, depending on the loading (average jet duration 5 sec).

[5] The mentioned above air consumption per jet assist activation is valid for a jet duration of 5 seconds. The jet duration may vary between 3 sec and 10 sec, depending on the loading (average jet duration 5 sec). See section External compressed air system – Jet assist, Page 243 for the different applications and accordingly needed consideration for the layout. Note: In the period of the "Normal Start", jet assist will not be activated.

[6] See accordingly section Load application – Load steps (for electric propulsion/auxiliary GenSet), Page 40.

Table 25: Starting air and control air consumption

Note:
See also section Starting air receivers, compressors, Page 241.

2.12.4 Recalculation of fuel consumption dependent on ambient conditions

In accordance to ISO standard ISO 3046-1 "*Reciprocating internal combustion engines – Performance, Part 1: Declarations of power, fuel and lube oil consumptions, and test methods – Additional requirements for engines for general use*" MAN Energy Solutions has specified the method for recalculation of fuel consumption for liquid fuel dependent on ambient conditions for single-stage turbocharged engines as follows:

$$\beta = 1 + 0.0006 \times (t_x - t_r) + 0.0004 \times (t_{bax} - t_{bar}) + 0.07 \times (p_r - p_x)$$

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The formula is valid within the following limits:	
Ambient air temperature	5°C–55°C
Charge air temperature before cylinder	25°C–75°C
Ambient air pressure	0.885 bar–1.030 bar

Table 26: Limit values for recalculation of liquid fuel consumption

$$b_x = b_r \times \beta \qquad b_r = \frac{b_x}{\beta}$$

β	Fuel consumption factor
t_{bar}	Engine type specific reference charge air temperature before cylinder see table Reference conditions for fuel consumption, Page 59

	Unit	Reference	At test run or at site
Specific fuel consumption	[g/kWh]	b_r	b_x
Ambient air temperature	[°C]	t_r	t_x
Charge air temperature before cylinder	[°C]	t_{bar}	t_{bax}
Ambient air pressure	[bar]	p_r	p_x

Table 27: Recalculation of liquid fuel consumption – Units and references

Example

Reference values:

b_r = 200 g/kWh, t_r = 25°C, t_{bar} = 40°C, p_r = 1.0 bar

At site:

t_x = 45°C, t_{bax} = 50°C, p_x = 0.9 bar

ß = 1+ 0.0006 (45 – 25) + 0.0004 (50 – 40) + 0.07 (1.0 – 0.9) = 1.023

b_x = ß x b_r = 1.023 x 200 = 204.6 g/kWh

2.12.5 Influence of engine aging on fuel consumption

The fuel oil consumption will increase over the running time of the engine. Timely service can reduce or eliminate this increase. For dependencies see following figure.

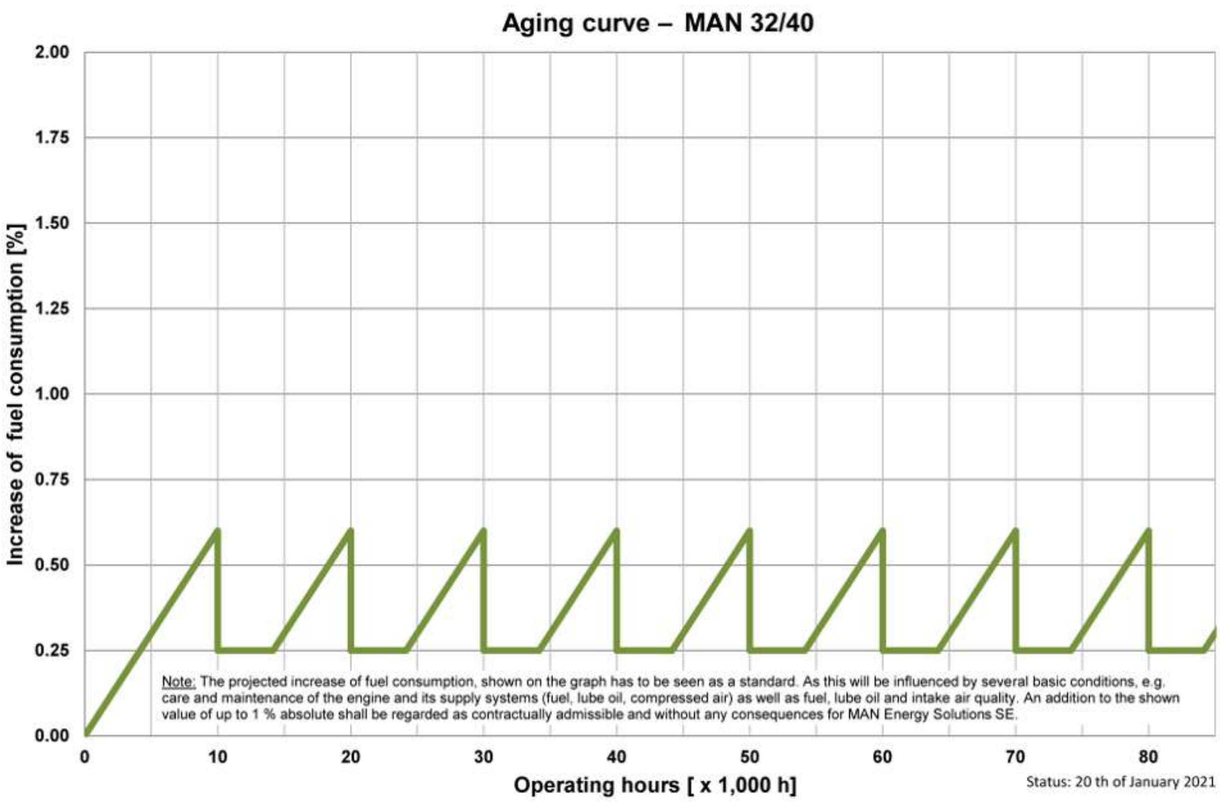

Figure 22: Influence of total engine running time and service intervals on fuel oil consumption

2.13 Planning data for emission standard IMO Tier II – Auxiliary GenSet

Note:
Stated figures are valid for a layout of the engine supply system as defined within this documentation. Any modifications that affect the media flow from attached pumps to the engine, required media flows, temperatures or pressures need to be agreed on by MAN Energy Solutions.

2.13.1 Nominal values for cooler specification – MAN L32/40 IMO Tier II – Auxiliary GenSet

500 kW/cyl., 720 rpm or 500 kW/cyl., 750 rpm

Reference conditions: Tropics		
Air temperature	°C	45
Cooling water temp. before charge air cooler (LT stage)		38
Total atmospheric pressure	mbar	1,000
Relative humidity	%	60

Table 28: Reference conditions: Tropics

No. of cylinders, config.		**6L**	**7L**	**8L**	**9L**
Engine output	kW	3,000	3,500	4,000	4,500

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No. of cylinders, config.		6L	7L	8L	9L
Speed	rpm	720/750			
Heat to be dissipated[1]					
Charge air: Charge air cooler (HT stage) Charge air cooler (LT stage)	kW	 868 424	 980 493	 1,136 576	 1,244 646
Lube oil cooler[2]		389	456	520	587
Jacket cooling		463	544	618	699
Nozzle cooling		12	14	16	18
Heat radiation engine (based on engine room temp. 55°C)		66	77	88	98
Flow rates[3]					
HT circuit (jacket cooling + charge air cooler HT)	m^3/h	36	42	48	54
LT circuit (lube oil cooler + charge air cooler LT)		57	70	74	85
Lube oil		97	108	118	129
Nozzle cooling water		1.0	1.2	1.4	1.6
Pumps					
a) Attached					
HT CW service pump	m^3/h	36	42	48	54
LT CW service pump		Not available			
Lube oil service pump for application with constant speed		120	120	141	141
b) Free-standing[4]					
HT CW stand-by pump	m^3/h	36	42	48	54
LT CW stand-by pump		Depending on plant design			
Lube oil stand-by pump		102+z	113+z	124+z	136+z
Prelubrication pump		19.5–22.5 +0.5z	21.5–25.0 +0.5z	23.5–27.5 +0.5z	25.5–30.0 +0.5z
Nozzle CW pump		1.0	1.2	1.4	1.6
MGO/MDO supply pump		2.2	2.6	3.0	3.4
HFO supply pump		1.2	1.4	1.6	1.8
HFO circulating pump		2.2	2.6	3.0	3.4

[1] Tolerance: +8% for rating coolers and heat radiation, +6% for central (HT-, LT- and lube oil system), -12% for heat recovery from HT- or LT- or lube oil system.

[2] Addition required for separator heat (e.g. 30 kJ/kWh).

[3] Basic values for layout design of the coolers.

[4] Tolerances of the pumps delivery capacities must be considered by the pump manufacturer.

z = flushing oil of the automatic filter.

Table 29: Nominal values for cooler specification – MAN L32/40 IMO Tier II – Auxiliary GenSet

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Note:
You will find further planning data for the listed subjects in the corresponding sections.

- Minimal heating power required for preheating HT cooling water see paragraph HE-027/Preheater, Page 196.
- Minimal heating power required for preheating lube oil see paragraph H-002/Lube oil preheater, Page 168.
- Capacities of preheating pumps see paragraph P-047/HT preheating pump, Page 196.

2.13.2 Flow scheme for cooler specification – MAN L32/40 IMO Tier II - Auxiliary GenSet

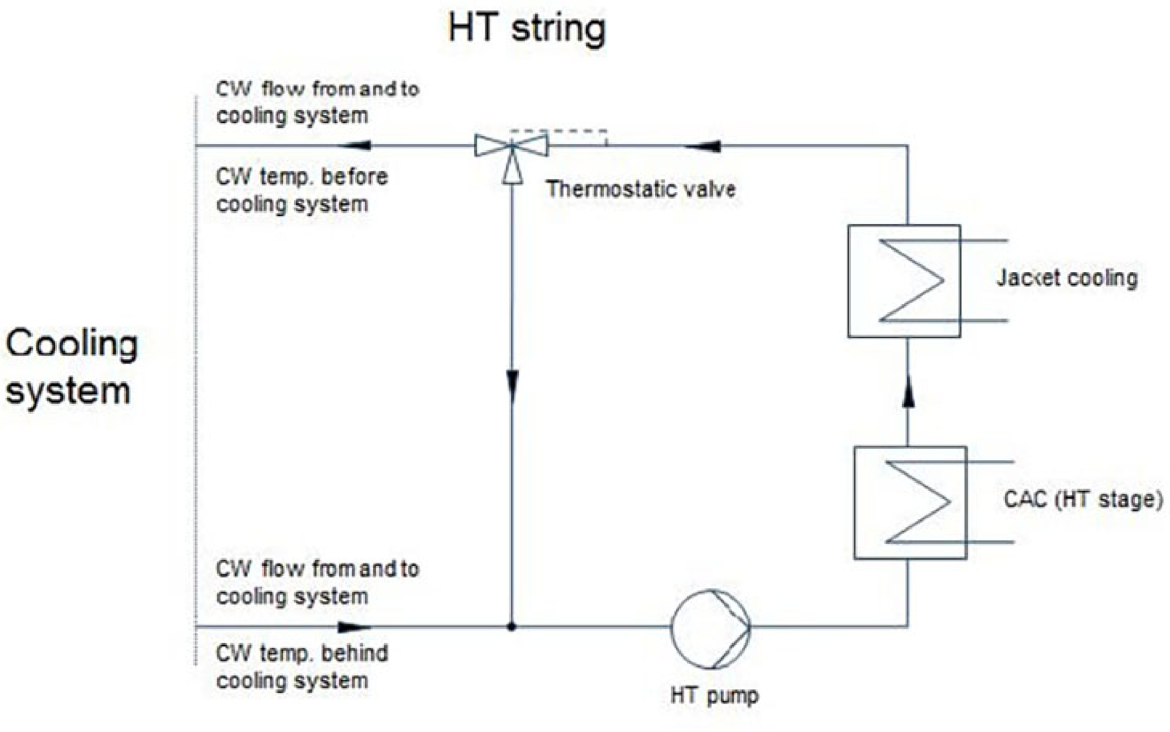

Figure 23: Flow scheme 2-string-HT-thermostat - MAN L32/40, exemplary

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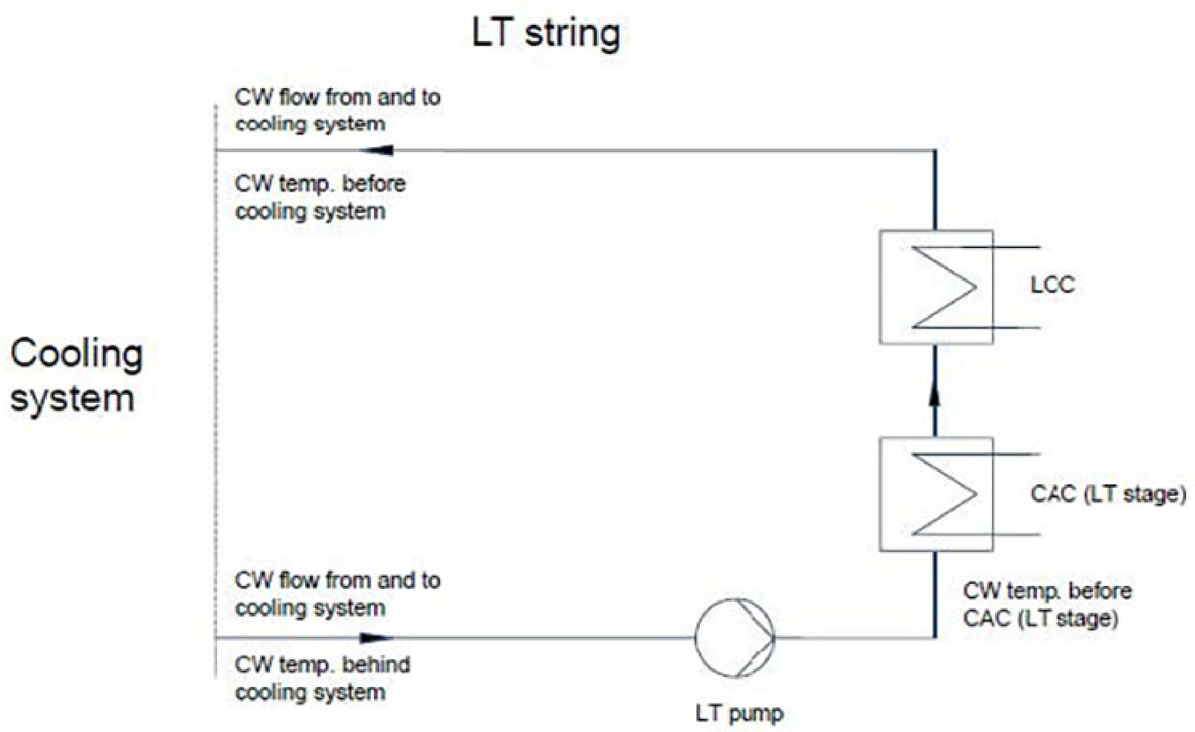

Figure 24: Flow scheme 2-string-LT-thermostat - MAN L32/40, exemplary

2.13.3 Temperature basis, nominal air and exhaust gas data – MAN L32/40 IMO Tier II – Auxiliary GenSet

500 kW/cyl., 720 rpm or 500 kW/cyl., 750 rpm

Reference conditions: Tropics		
Air temperature	°C	45
Cooling water temp. before charge air cooler (LT stage)		38
Total atmospheric pressure	mbar	1,000
Relative humidity	%	60

Table 30: Reference conditions: Tropics

No. of cylinders, config.		**6L**	**7L**	**8L**	**9L**
Engine output	kW	3,000	3,500	4,000	4,500
Speed	rpm	720/750			
Temperature basis					
HT cooling water engine outlet[1)]	°C	90 [2)]			
LT cooling water air cooler inlet		38°C (Setpoint 32°C)[3)]			
Lube oil engine inlet		65			
Nozzle cooling water engine inlet		60			
Air data					
Temperature of charge air at charge air cooler outlet	°C	59	60	59	60

No. of cylinders, config.		6L	7L	8L	9L
Air flow rate[4]	m^3/h	19,490	22,739	25,987	29,236
	t/h	21.3	24.9	28.4	32.0
Charge air pressure (absolute)	bar abs	4.14			
Air required to dissipate heat radiation (engine) ($t_2 - t_1$ = 10°C)	m^3/h	21,105	24,622	28,140	31,657
Exhaust gas data[5]					
Volume flow (temperature turbocharger outlet)[6]	m^3/h	40,002	46,744	53,361	60,107
Mass flow	t/h	21.9	25.6	29.3	32.9
Temperature at turbine outlet	°C	362	363	362	363
Heat content (190°C)	kW	1,128	1,324	1,507	1,704
Permissible exhaust gas back pressure after turbocharger (maximum)	mbar	50			

[1] HT cooling water flow first through water jacket and cylinder head, then through HT stage charge air cooler.

[2] Regulated by engine individual, installed HT thermostatic valve (wax type).

[3] For design see figures Cooling water system diagrams, Page 187.

[4] Under mentioned above reference conditions.

[5] All exhaust gas data values relevant for HFO operation. Tolerances: ±15°C for temperature at turbine outlet, ±4% for flow quantity.

[6] Calculated based on stated temperature at turbine outlet and total atmospheric pressure according mentioned above reference conditions.

Table 31: Temperature basis, nominal air and exhaust gas data – MAN L32/40 IMO Tier II – Auxiliary GenSet

2.13.4 Load specific values at ISO conditions – MAN L32/40 IMO Tier II – Auxiliary GenSet

500 kW/cyl., 720 rpm or 500 kW/cyl., 750 rpm

Reference conditions: ISO		
Air temperature	°C	25
Cooling water temp. before charge air cooler (LT stage)		25
Total atmospheric pressure	mbar	1,000
Relative humidity	%	30

Table 32: Reference conditions: ISO

Engine output	%	100	85	75	50
	kW	3,000	2,550	2,250	1,500
Speed	rpm	720/750			
Heat to be dissipated[1]					
Charge air: Charge air cooler (HT stage)[2] Charge air cooler (LT stage)[2]	kJ/kWh	 859 481	 740 461	 739 486	 378 446
Lube oil cooler[3]		416	486	544	773
Jacket cooling		455	485	509	612

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Engine output	**%**	**100**	**85**	**75**	**50**
	kW	**3,000**	**2,550**	**2,250**	**1,500**
Speed	**rpm**	**720/750**			
Nozzle cooling		14	14	14	14
Heat radiation engine (based on 35°C engine room temperature)		101	112	121	155
Air data					
Temperature of charge air: After compressor outlet At charge air cooler outlet	°C	 217 41	 190 38	 181 36	 126 31
Air flow rate	kg/kWh	7.44	7.70	8.27	8.50
Charge air pressure (absolute)	bar abs	4.16	3.65	3.41	2.27
Exhaust gas data[4]					
Mass flow	kg/kWh	7.64	7.89	8.48	8.72
Temperature at turbine outlet	°C	320	304	308	355
Heat content (190°C)	kJ/kWh	1,060	960	1,070	1,540
Permissible exhaust gas back pressure after turbocharger (maximum)	mbar	50	-		

[1] Tolerance: +8% for rating coolers and heat radiation, +6% for central cooler (HT-, LT- and lube oil system), −12% for heat recovery from HT- or LT- or lube oil system.

[2] The values of the particular cylinder numbers can differ depending on the charge air cooler specification.

[3] Addition required for separator heat (e.g. 30 kJ/kWh).

[4] Tolerances: ±15°C for temperature at turbine outlet, ±4% for flow quantity.

Table 33: Load specific values at ISO conditions – MAN L32/40 IMO Tier II – Auxiliary GenSet

2.13.5 Load specific values at tropical conditions – MAN L32/40 IMO Tier II – Auxiliary GenSet

500 kW/cyl., 720 rpm or 500 kW/cyl., 750 rpm

Reference conditions: Tropics		
Air temperature	°C	45
Cooling water temp. before charge air cooler (LT stage)		38
Total atmospheric pressure	mbar	1,000
Relative humidity	%	60

Table 34: Reference conditions: Tropics

Engine output	**%**	**100**	**85**	**75**	**50**
	kW	**3,000**	**2,550**	**2,250**	**1,500**
Speed	**rpm**	**720/750**			
Heat to be dissipated[1]					
Charge air: Charge air cooler (HT stage)[2] Charge air cooler (LT stage)[2]	kJ/kWh	 1,022 518	 907 508	 917 533	 551 464

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Engine output	%	100	85	75	50
	kW	3,000	2,550	2,250	1,500
Speed	rpm	720/750			
Lube oil cooler[3]		468	548	613	866
Jacket cooling		558	596	625	745
Nozzle cooling		14	14	14	14
Heat radiation engine (based on 55°C engine room temperature)		79	87	94	121
Air data					
Temperature of charge air: After compressor outlet At charge air cooler outlet	°C	 244 60	 216 56	 207 55	 148 47
Air flow rate	kg/kWh	7.11	7.35	7.90	8.12
Charge air pressure (absolute)	bar abs	4.13	3.62	3.38	2.25
Exhaust gas data[4]					
Mass flow	kg/kWh	7.31	7.55	8.11	8.34
Temperature at turbine outlet	°C	361	345	350	398
Heat content (190°C)	kJ/kWh	1,356	1,261	1,393	1,874
Permissible exhaust gas back pressure after turbocharger (maximum)	mbar	50	-		

[1] Tolerance: +8% for rating coolers and heat radiation, +6% for central cooler (HT-, LT- and lube oil system), −12% for heat recovery from HT- or LT- or lube oil system.

[2] The values of the particular cylinder numbers can differ depending on the charge air cooler specification.

[3] Addition required for separator heat (e.g. 30 kJ/kWh).

[4] Tolerances: ±15°C for temperature at turbine outlet, ±4% for flow quantity.

Table 35: Load specific values at tropical conditions – MAN L32/40 IMO Tier II – Auxiliary GenSet

2.14 Operating/service temperatures and pressures

Intake air (conditions before compressor of turbocharger)

	Connection number internal media schemata "Charge air and exhaust gas diagram"	Min.	Max.
Intake air temperature compressor inlet	TE6100	5°C[1]	45°C[2]
Intake air pressure compressor inlet	PT6100	−20 mbar	-

[1] Conditions below this temperature are defined as "arctic conditions" – see section Engine operation under arctic conditions, Page 47.

[2] In accordance with power definition. A reduction in power is required at higher temperatures/lower pressures.

Table 36: Intake air (conditions before compressor of turbocharger)

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Charge air (conditions within charge air pipe before cylinder)

	Connection number internal media schemata "Charge air and exhaust gas diagram"	Min.	Max.
Charge air temperature cylinder inlet[1]	TE6180	43°C	59°C
[1] Aim for a higher value in conditions of high air humidity (to reduce condensate amount).			

Table 37: Charge air (conditions within charge air pipe before cylinder)

HT cooling water – Engine

	Connection number internal media schemata "Cooling water system"	Min.	Max.
HT cooling water temperature at jacket cooling outlet[1]	3199, TE3180	90°C nominal[2]	95°C[3]
HT cooling water temperature engine inlet – Preheated before start	3161, 3105, TE3170	60°C	90°C
HT cooling water pressure engine inlet; nominal value 4 bar[4]	3161, 3105, PT3170	3 bar	6 bar
Pressure loss engine (total, for nominal flow rate)	-	-	1.35 bar
Only for information: Pressure loss engine (without charge air cooler) Pressure loss HT piping engine Pressure loss charge air cooler (HT stage)	-	 0.3 bar 0.2 bar 0.2 bar	 0.5 bar 0.45 bar 0.4 bar
Pressure rise attached HT cooling water pump (optional)	-	3.2 bar	3.8 bar
[1] SaCoSone measuring point is jacket cooling outlet of the engine. [2] Regulated temperature. [3] Operation at alarm level. [4] SaCoSone measuring point is jacket cooling inlet.			

Table 38: HT cooling water – Engine

HT cooling water – Plant

	Min.	Max.
Permitted pressure loss of external HT system (plant)	-	1.85 bar
Minimum required pressure rise of free-standing HT cooling water stand-by pump (plant)	3.2 bar	-
Cooling water expansion tank Pre-pressure due to expansion tank at suction side of cooling water pump Pressure loss from expansion tank to suction side of cooling water pump	 0.6 bar -	 0.9 bar 0.1 bar

Table 39: HT cooling water – Plant

LT cooling water – Engine

	Connection number Internal media schemata "Cooling water system"	Min.	Max.
LT cooling water temperature charge air cooler inlet (LT stage)	4171, TE4170	32°C[1]	38°C[2]

	Connection number Internal media schemata "Cooling water system"	Min.	Max.
LT cooling water pressure charge air cooler inlet (LT stage); nominal value 4 bar	4171, PT4170	2 bar	6 bar
Pressure loss charge air cooler (LT stage, for nominal flow rate) Only for information: Pressure loss LT piping engine Pressure loss charge air cooler (LT stage)	-	- 0.2 bar 0.1 bar	0.6 bar 0.3 bar 0.3 bar
Pressure rise attached LT cooling water pump (optional)	-	3.0 bar	4.0 bar
[1] Regulated temperature.			
[2] In accordance with power definition. A reduction in power is required at higher temperatures/lower pressures.			

Table 40: LT cooling water – Engine

LT cooling water – Plant

	Min.	Max.
Permitted pressure loss of external LT system (plant)	-	2.4 bar
Minimum required pressure rise of free-standing LT cooling water stand-by pump (plant)	3.0 bar	-
Cooling water expansion tank: Pre-pressure due to expansion tank at suction side of cooling water pump Pressure loss from expansion tank to suction side of cooling water pump	 0.6 bar -	 0.9 bar 0.1 bar

Table 41: LT cooling water – Plant

Nozzle cooling water

	Connection number internal media schemata "Cooling water system"	Min.	Max.
Nozzle cooling water temperature engine inlet	3471, TE3470	55°C	70°C[1]
Nozzle cooling water pressure engine inlet: Open system Closed system	 3471, PT3470 3471, PT3470	 2 bar 3 bar	 3 bar 5 bar
Pressure loss engine (fuel nozzles, for nominal flow rate)	-	-	1.5 bar
[1] Operation at alarm level.			

Table 42: Nozzle cooling water

Lube oil

	Connection number internal media schemata "Lubricating oil diagram"	Min.	Max.
Lube oil temperature engine inlet	2171, TE2170	65°C[1]	70°C[2]
Lube oil temperature engine inlet – Preheated before start	2171, TE2170	40°C	65°C[3]

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	Connection number internal media schemata "Lubricating oil diagram"	Min.	Max.
Lube oil pressure (during engine operation) Engine inlet Turbocharger inlet	 2171, PT2170 PT2570	 4 bar 1.3 bar	 5 bar 2.2 bar
Prelubrication/postlubrication (duration ≤ 10 min) lube oil pressure Engine inlet Turbocharger inlet	 2171, PT2170 PT2570	 0.3 bar[4)] 0.2 bar	 5 bar 2.2 bar
Prelubrication/postlubrication (duration > 10 min) lube oil pressure Engine inlet Turbocharger inlet	 2171, PT2170 PT2570	 0.3 bar[4)] 0.2 bar	 0.6 bar 0.6 bar
Lube oil pump (attached, free-standing) Design pressure Opening pressure safety valve	-	 7 bar -	 - 8 bar

[1)] Regulated temperature.

[2)] Operation at alarm level.

[3)] If higher temperatures of lube oil in system will be reached, e.g. due to lube oil separator operation, at engine start this temperature needs to be reduced as quickly as possible below alarm level to avoid a start failure.

[4)] Note: Oil pressure > 0.3 bar must be ensured also for lube oil temperatures up to 70°C.

Table 43: Lube oil

Fuel

	Connection number internal media schemata "Fuel system"	Min.	Max.
Fuel temperature engine inlet MGO (DMA) and MDO (DMB) according ISO 8217 HFO according ISO 8217	 5671, TE5070 5671, TE5070	 –10°C[1)] -	 45°C[2)] 150°C[2)]
Fuel viscosity engine inlet MGO (DMA) and MDO (DMB) according ISO 8217 HFO according ISO 8217	-	 1.9 cSt 1.9 cSt	 14.0 cSt 14.0 cSt
Fuel pressure engine inlet	5671, PT5070	5.0 bar	8.0 bar
Fuel pressure engine inlet in case of black out (only engine start idling)	5671, PT5070	0.6 bar	-
Differential pressure (engine inlet/engine outlet)	-	1.0 bar	-
Fuel return, fuel pressure engine outlet	5699	2.0 bar	-
Maximum pressure variation at engine inlet	-	-	±0.5 bar

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	Connection number internal media schemata "Fuel system"	Min.	Max.
HFO supply system Minimum required pressure rise of free-standing HFO supply pump (plant) Minimum required pressure rise of free-standing HFO circulating pump (booster pumps, plant) Minimum required absolute design pressure free-standing HFO circulating pump (booster pumps, plant)	-	 7.0 bar 7.0 bar 10.0 bar	 - - -
MDO/MGO supply system Minimum required pressure rise of free-standing MDO/MGO supply pump (plant)	-	10.0 bar	-
Fuel temperature within HFO day tank (preheating)	-	-[3]	90°C[4]
[1] Maximum viscosity not to be exceeded. "Pour point" and "Cold filter plugging point" have to be observed. [2] Not permissible to fall below minimum viscosity. [3] Minimum temperature to be considered for an optimum transfer by pumps to attached tanks. [4] If flash point is below 100°C, than the limit is: 10 degree distance to the flash point.			

Table 44: Fuel

Compressed air in the starting air system

	Connection number internal media schemata "Pressure air system"	Min.	Max.
Starting air pressure	7171, PT7170	15.0 bar[1]	30.0 bar[2] [3]
Jet assist pressure engine inlet	7177	18.0 bar[4]	30.0 bar
[1] Operation at alarm level. [2] Nominal value. [3] For layout of the starting air system, note: ▪ Starting air consumption and start duration stated within section Starting air and control air consumption, Page 60. ▪ Maximum velocity (m/s) see section External pipe dimensioning, Page 159 - consider multiple start of engines, if needed. [4] Below this value jet assist will be deactivated.			

Table 45: Compressed air in the starting air system

Compressed air in the control air system

	Connection number internal media schemata "Pressure air system"	Min.	Max.
Control air pressure engine inlet	7172, PT7400	5.5 bar[1]	7.0 bar
[1] Operation at alarm level.			

Table 46: Compressed air in the control air system

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Crankcase pressure (engine)

	Connection number internal media schemata "Lubricating oil diagram"	Min.	Max.
Pressure within crankcase	2898, PT2800	–2.5 mbar	3.0 mbar

Table 47: Crankcase pressure (engine)

	Connection number internal media schemata "Lubricating oil diagram"	Setting
Safety valve attached to the crankcase (opening pressure)	-	50–70 mbar

Table 48: Safety valve

Exhaust gas

	Min.	Max.
Exhaust gas temperature turbine outlet (normal operation under tropic conditions)	-	415°C
Exhaust gas temperature turbine outlet (with SCR within regeneration mode)	360°C	400°C
Exhaust gas temperature turbine outlet (emergency operation – According classification rules – One failure of TC)	-	546°C
Recommended design exhaust gas temperature turbine outlet for layout of exhaust gas line (plant)	450°C[1)]	-
Minimum exhaust gas temperature after recooling due to exhaust gas heat utilization	190°C[2)]	-
Exhaust gas back pressure after turbocharger (static)	-	50 mbar[3)]

[1)] Project specific evaluation required, figure given as minimum value for guidance only.

[2)] To avoid sulfur corrosion in exhaust gas line (plant).

[3)] If this value is exceeded by the total exhaust gas back pressure of the designed exhaust gas line, sections Derating, definition of P Operating, Page 28 and Increased exhaust gas pressure due to exhaust gas after treatment installations, Page 29 need to be considered.

Table 49: Exhaust gas

2.15 Leakage rate

Maximum operating leakage high pressure pumps		Maximum operating leakage injection nozzles		Burst leakage rate in case of pipe break (for max. 1 min)
l/h per cyl.		l/h per cyl.		l/min for each cyl. bank
HFO	MGO/MDO	HFO	MGO/MDO	HFO, MGO/MDO
0.4	1.0	0.5	1.0	4.0

Table 50: Leakage rate – MAN L32/40 GenSet with SP injection pumps

Note:

- High flow rates of dirty leakage oil will only occur in case of a pipe break and should occur for short time only. An alarm will be activated (< 1 min) and the operator must take actions. Special considerations have to be

taken for the layout of single engine plants.
This leakage can be reused, if the entire fuel treatment of separation and filtration is done.

- The operating leakage (clean) consists out of the operating leakage amount of the high-pressure pumps, plus the operating leakage of the injection valves, which occur during normal operation due to their function. This leakage can be reused, if the entire fuel treatment of separation and filtration is done.
- All other leakage amounts (dirt fuel oil from filters or from engine drains) have to be discharged into the sludge tank.

2.16 Filling volumes

Cooling water and oil volume – Turbocharger at counter coupling side[1]					
No. of cylinders		**6**	**7**	**8**	**9**
HT cooling water[2] approximately	litre	151	175	202	226
LT cooling water[3] approximately		46	49	51	52
Lube oil within base frame of GenSet		3,100	3,500	3,900	4,300

[1] Be aware: This is just the amount inside the engine. By this amount the level in the service or expansion tank will be lowered when media systems are put in operation.

[2] HT water volume engine: HT part of charge air cooler, cylinder unit, piping.

[3] LT water volume engine: LT part of charge air cooler, piping.

Table 51: Cooling water and oil volume of engine

Service tanks	Installation[1] height	Minimum effective capacity			
	m	m^3			
No. of cylinders		**6**	**7**	**8**	**9**
Cooling water cylinder	6 – 9	0.5			
Required diameter for expansion pipeline	-	≥ DN50 [2]			

[1] Installation height refers to tank bottom and crankshaft centre line.

[2] Cross sectional area should correspond to that of the venting pipes.

Table 52: Service tanks capacities

2.17 Venting amount of crankcase and turbocharger

A ventilation of the engine crankcase and the turbochargers is required, as described in section Crankcase vent and tank vent, Page 180.

For the layout of the ventilation system guidance is provided below:

Due to normal blow-by of the piston ring package small amounts of combustion chamber gases get into the crankcase and carry along oil mist.

- The amount of crankcase blow-by air is approximately 0.1% of the engine´s air flow rate.

In addition, the sealing air of the turbocharger needs to be vented.

- The amount of turbocharger blow-by air is approximately:
  - For single-stage turbocharged engines 0.2% of the engine´s air flow rate. (Accordingly see Planning data, Page 62).
  - For two-stage turbocharged engines 0.4% of the engine´s air flow rate. (Accordingly see Planning data, Page 62).
- The temperature of the crankcase and turbocharger blow-by air is approximately 15 K higher than the oil temperature at the engine´s oil inlet.

- The density of the crankcase and turbocharger blow-by air is 1.0 kg/m³ at the condition of approximately 70°C (343 K) and 1,013 mbar (assumption for calculation).

2.18 Exhaust gas emission

2.18.1 Maximum permissible NOx emission limit value IMO Tier II

IMO Tier II: Engine in standard version[1]

Rated speed	720 rpm	750 rpm
NO_x 1) 2) 3) IMO Tier II cycle D2/E2/E3	9.68 g/kWh4)	9.59 g/kWh4)
Note: The engine´s certification for compliance with the NO_x limits will be carried out during factory acceptance test as a single or a group certification.		
1) Cycle values, operation on DM grade fuel (marine distillate fuel: MGO or MDO) according ISO 8217, based on a LT charge air cooling water temperature of max. 32 °C at 25 °C reference seawater temperature. 2) Calculated as NO_2. D2: Test cycle for "constant-speed auxiliary engine application". E2: Test cycle for "constant-speed main propulsion application" including electric propulsion and all controllable pitch propeller installations. E3: Test cycle for "propeller-law-operated main and propeller-law-operated auxiliary engine” application. 3) Based on a LT charge air cooling water temperature of max. 32 °C at 25 °C seawater temperature. 4) Maximum permissible NO_x emissions for marine diesel engines according to IMO Tier II: $130 \leq n \leq 2{,}000 \rightarrow 44 * n^{-0.23}$ g/kWh (n = rated engine speed in rpm).		

Table 53: Maximum permissible NO_x emission limit value

[1] Marine engines are guaranteed to meet the revised International Convention for the Prevention of Pollution from Ships, "Revised MARPOL Annex VI (Regulations for the Prevention of Air Pollution from Ships), Regulation 13.4 (Tier II)" as adopted by the International Maritime Organization (IMO).

2.18.2 Smoke emission index (FSN)

Smoke index FSN for engine loads ≥ 25 % load well below limit of visibility (0.4 FSN).

Valid for:

- Distillate fuel according to ISO 8217 or RM-grade fuel, fulfilling the stated quality requirements.
- 50 mbar exhaust gas back pressure (at 100% output).

2.18.3 Exhaust gas – possible components and visibility

The exhaust gas of reciprocating internal combustion engines is composed of numerous constituents. These are derived from either the combustion air and fuel and lube oil used, or they are reaction products, formed during the combustion process. Only some of these are to be considered as harmful substances.

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The following listed exhaust gas components need to be seen as a general overview – the presence and amount of the singular component depends in large extends on the engine type, combustion process and fuel type.

Nitrogen N_2

Nitrogen (N_2) is with approximately 73–75 vol-% the main constituent of the exhaust gas.

Oxygen O_2

Approximately 21 vol-% of the ambient air is Oxygen (O_2).

Carbon dioxide CO_2

Carbon dioxide (CO_2) is a product of combustion.

Water vapour H_2O

The water in the exhaust comes from the combustion of the fuel and, to a lesser extent, from the moisture in the intake air. In diesel operation, the water vapour content is approximately 6 vol-%, in gas operation approximately 10 vol-%.

Inert gases Ar, Ne, He, etc.

Inert gases, such as Ar, Ne, He, etc., are constituents of the ambient air with a volume fraction of approximately 0.9 vol-%.

Sulphur oxides SO_X

Sulphur oxides (SO_x) are formed by the combustion of the sulphur contained in the fuel. The sulphur content in the fuel determines the SO_2 content in the exhaust gas.

Nitrogen oxides NO_X ($NO + NO_2$)

The high temperatures prevailing in the combustion chamber of an internal combustion engine cause the chemical reaction of nitrogen (contained in the combustion air as well as in some types of fuel) and oxygen (contained in the combustion air) to form nitrogen oxides (NO_X).

Carbon monoxide CO

Carbon monoxide (CO) is formed during incomplete combustion.

Hydrocarbons HC

The hydrocarbons (HC) contained in the exhaust gas are composed of a multitude of various organic compounds as a result of incomplete combustion.

Particulate matter PM

Particulate matter (PM) consists of soot (elemental carbon) and ash.

Formaldehyde CH_2O

Formaldehyde (CH_2O) is a gas known by its pungent smell. Its proportion in the exhaust gas depends on the fuel and the degree of combustion. If the proportion of formaldehyde (CH_2O) is high, it can be removed by an oxidation catalyst – this is only necessary for gas or methanol operation.

Nitrous oxide N_2O

Nitrous oxide (N_2O) is a gas that only might occur in relevant quantity in ammonia (NH_3) operation.

Visibility of the exhaust gas

The visibility of exhaust gas highly depends on ambient conditions and the observer's line of sight to the exhaust gas, background and the sun. The exhaust gas can either be seen or not depending on the ambient temperature, wind velocity, diameter and height of the chimney and the colouring of the background. It can be black, blue, brown, yellow or white depending on the components present in the exhaust gas. Black or gray exhaust gas is mainly due to the presence of carbon particles. A blue appearance is usually due to droplets resulting from the incomplete combustion of fuel or lubricating oil. A yellow or brown appearance can be caused by the presence of NO_2 in the exhaust gas. White exhaust gas may be caused by condensed water and/or liquid fuel.

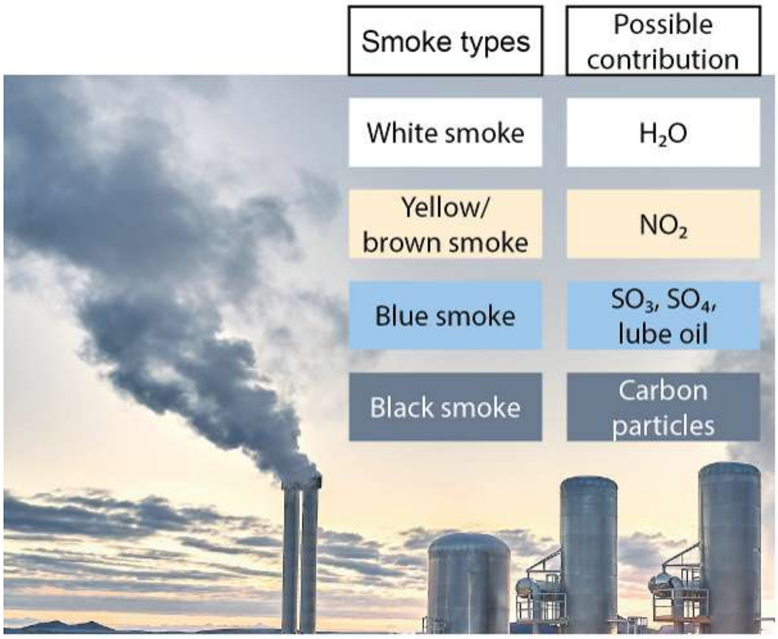

Figure 25: Possible components of the exhaust gas – Visibility

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2.18.4 Emission-related installation instruction for engines

Position of the exhaust gas sampling points

The sampling position shall be fitted:

- At least 10 times the diameter of the exhaust pipe after the outlet of the engine, turbocharger or last after-treatment device

- In a straight pipe segment:
  - With an inlet path length before sampling position of at least 5 times the diameter of the exhaust pipe after last bending/obstruction/diameter deviation
  - With a path length after sampling position of at least 2 times the diameter of the exhaust pipe
- At least 5 times the diameter of the exhaust pipe before end of exhaust pipe
- Sufficiently close to the engine to ensure that the exhaust gas temperature at the sampling position will be minimum 180°C

If this is not attainable, a deviation of these requirements is acceptable if:

- justified by good engineering practice
- an incorrect measurement is not expected

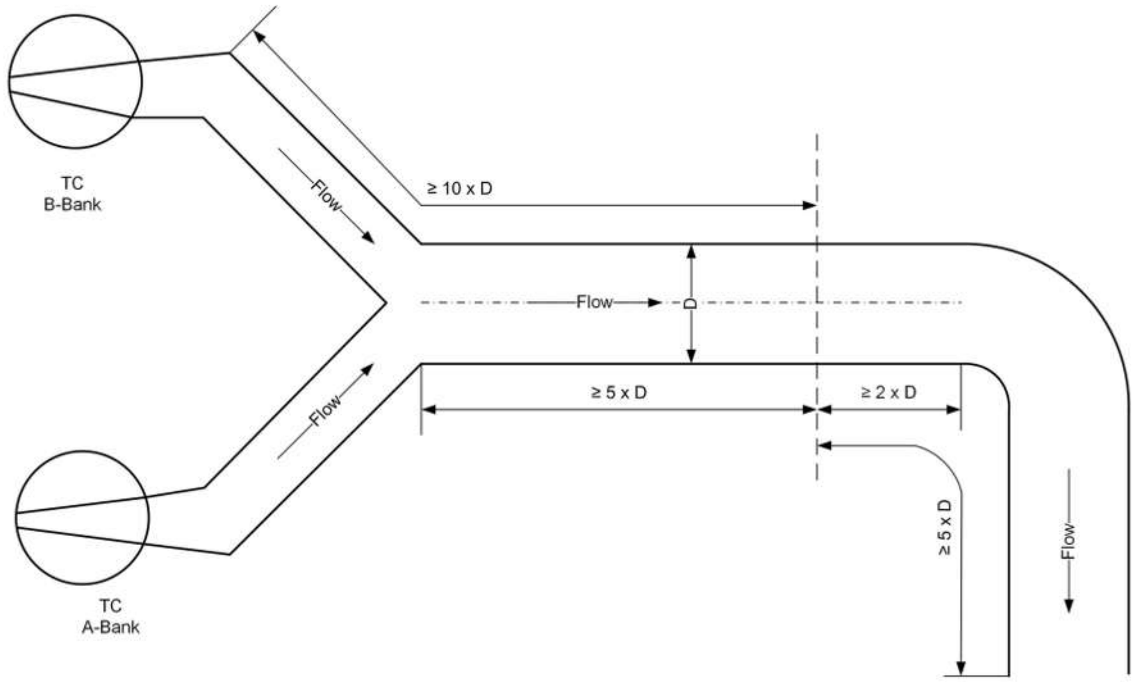

Figure 26: Position of sampling points (exemplary)

In the case an engine has distinct groups of manifolds, it is permissible to acquire a sample from each group individually and calculate an average exhaust emission. In this case, each sampling point must be designed as mentioned above.

The exhaust gas upstream the sampling point shall be free of any dilution from surrounding air or contamination from other exhaust gas systems.

Accessibility and working area at sampling point

The sampling point shall be accessible in a save way also during engine operation. In case the sampling point is covered by an insulation, the position shall be clearly visible marked on the insulation. The Insulation shall be designed in a way that it is easy to remove and to install again.

If necessary, a step has to be established.

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There shall be enough space to place and operate the measurement equipment.

Requirements regarding the working area:

- Minimum space requirements: about 2-m width, 2-m depth, 2-m height
- Sufficient floor load capacity (at least 200 kg per m²)
- Temperature at this working area should be within +5°C to + 40°C and well ventilated
- Not subjected to excessive vibrations
- If needed weather protection for personnel and equipment against sun, wind and rain

Depending on the measurement equipment it should be considered that during the measurements following items are available at the working area:

• Adequate lighting and ventilation

• Power supply

• Pressurised air (instrument quality, oil free)

• Lifting devices for raising and lowering the equipment, if necessary

Exhaust pipe connection

- 1 piece of pipe thread inner diameter G 3” (use for particulate measurements)
- 2 pieces of pipe thread inner diameter G ½" (use for gaseous emission measurements or for smoke number measurement)

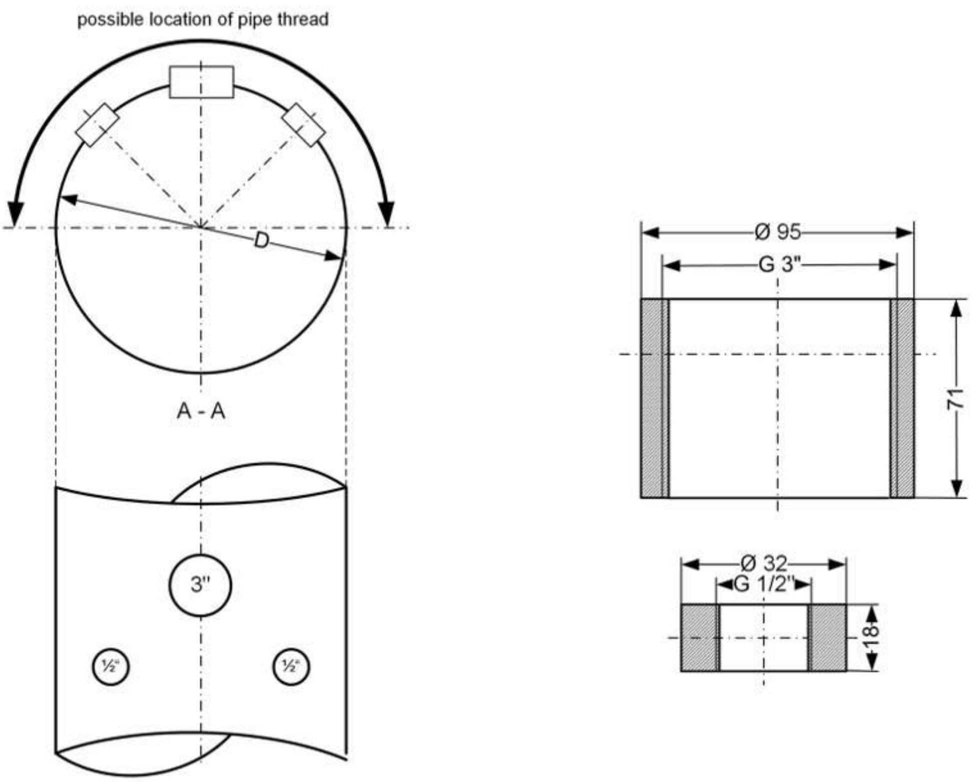

Figure 27: Sampling point, details

Installation of pipe thread G 3'' and G ½"

To establish an airtight connection, the pipe threads shall be welded at the exhaust gas pipe. In case of a horizontal orientated exhaust gas pipe the position shall be in the upper half of the exhaust gas pipe in radial direction to the centre line (see figure 2) and easy to access.

When the sampling points are not in use, a pipe plug shall close the pipe threads.

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2.19 Noise

2.19.1 Airborne noise

L engine

Sound pressure level Lp

Measurements

Approximately 20 measuring points at 1 metre distance from the engine surface are distributed evenly around the engine according to ISO 6798. The noise at the exhaust outlet is not included, but provided separately in the following sections.

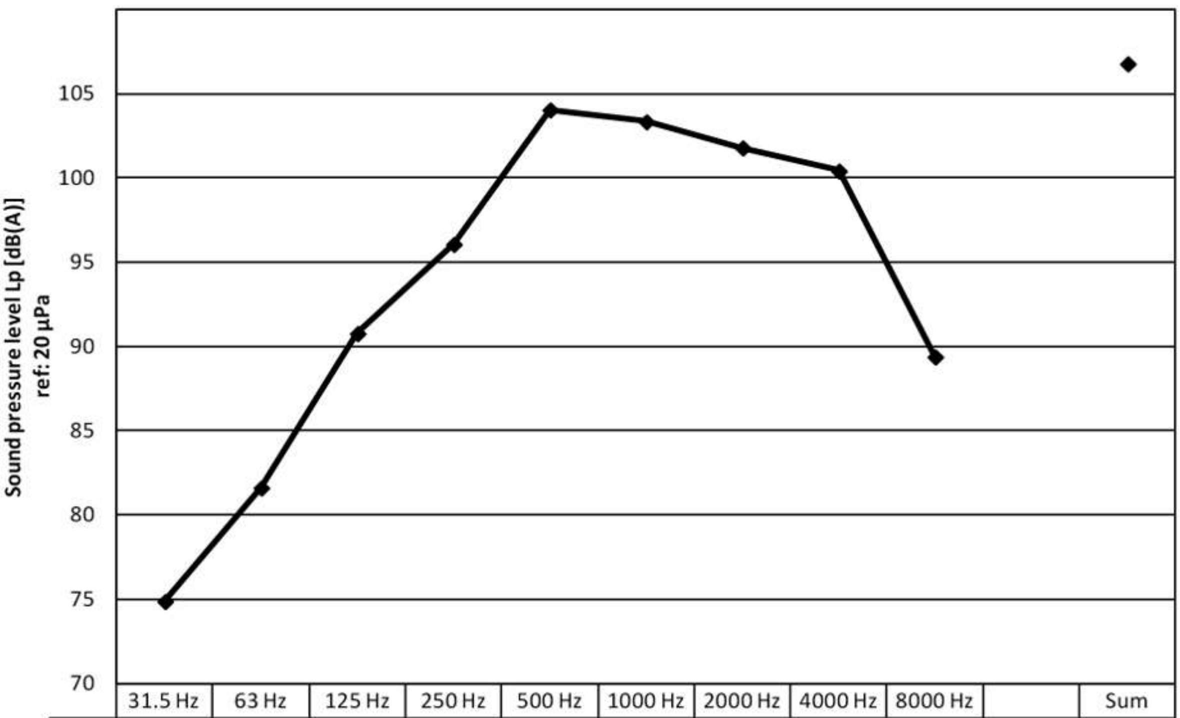
Octave level diagram

The expected sound pressure level Lp is below 107 dB(A) at 100% MCR.

The octave level diagram below represents an envelope of averaged measured spectra for comparable engines at the testbed and is a conservative spectrum consequently. No room correction is performed. The data will change depending on the acoustical properties of the environment.

Blow-off noise

Blow-off noise is not considered in the measurements, see below.



	31.5 Hz	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz		Sum
Lp	75	82	91	96	104	103	102	100	89		107

Figure 28: Airborne noise – Sound pressure level Lp – Octave level diagram L engine

2.19.2 Intake noise

L engine

Sound power level Lw

Measurements

The (unsilenced) intake air noise is determined based on measurements at the turbocharger test bed and on measurements in the intake duct of typical engines at the test bed.

Octave level diagram

The expected sound power level Lw of the unsilenced intake noise in the intake duct is below 143 dB at 100 % MCR.

The octave level diagram below represents an envelope of averaged measured spectra for comparable engines and is a conservative spectrum consequently. The data will change depending on the acoustical properties of the environment.

Charge air blow-off noise

Charge air blow-off noise is not considered in the measurements, see below.

These data are required and valid only for ducted air intake systems. The data are not valid if the standard air filter silencer is attached to the turbocharger.

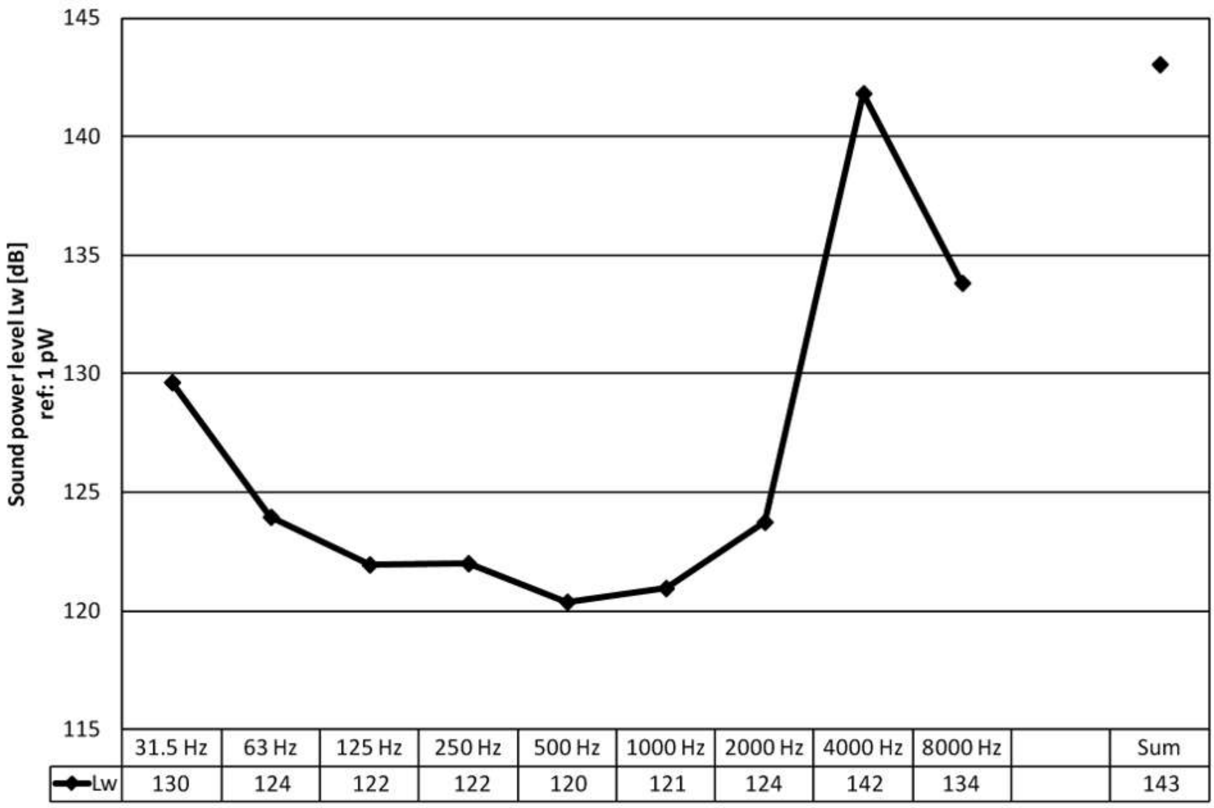


Figure 29: Unsilenced intake noise – Sound power level Lw – Octave level diagram L engine

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2.19.3 Exhaust gas noise

L engine

Sound power level Lw

Measurements

The (unsilenced) exhaust gas noise is measured according to internal MAN Energy Solutions guidelines at several positions in the exhaust duct.

Octave level diagram

The sound power level Lw of the unsilenced exhaust gas noise in the exhaust pipe is shown at 100% MCR.

The octave level diagram below represents an envelope of averaged measured spectra for comparable engines and is a conservative spectrum consequently. The data will change depending on the acoustical properties of the environment.

Acoustic design

To ensure an appropriate acoustic design of the exhaust gas system, the yard, MAN Energy Solutions, supplier of silencer and where necessary acoustic consultant have to cooperate.

Waste gate blow-off noise

Waste gate blow-off noise is not considered in the measurements, see below.

Figure 30: Unsilenced exhaust gas noise – Sound power level Lw – Octave level diagram L engine

2.19.4 Blow-off noise example

Sound power level Lw

Measurements

The (unsilenced) charge air blow-off noise is measured according to DIN 45635, part 47 at the orifice of a duct.

Throttle body with bore size 135 mm

Expansion of charge air from 3.4 bar to ambient pressure at 42°C

Octave level diagram

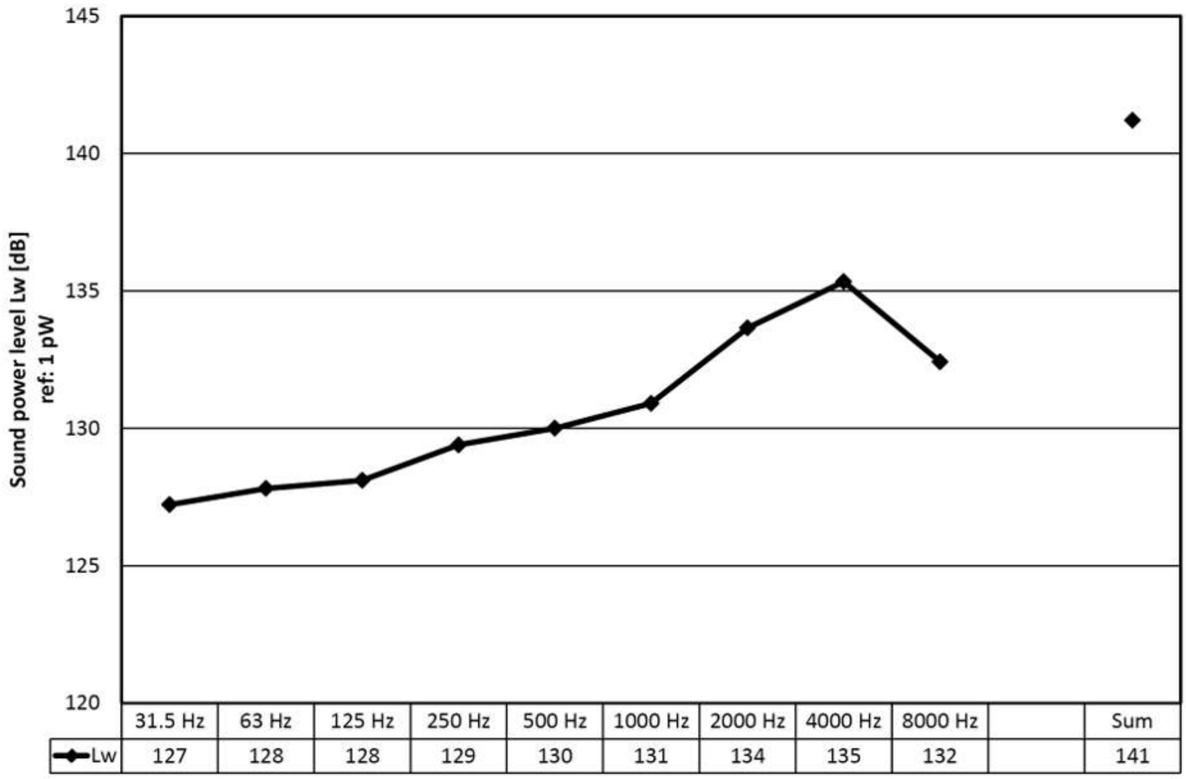

Figure 31: Unsilenced charge air blow-off noise – Sound power level Lw – Octave level diagram

2.19.5 Noise and vibration – Impact on foundation

Noise and vibration is emitted by the engine to the surrounding (see figure Noise and vibration – Impact on foundation, Page 87). The engine impact transferred through the engine mounting to the foundation is focused subsequently.

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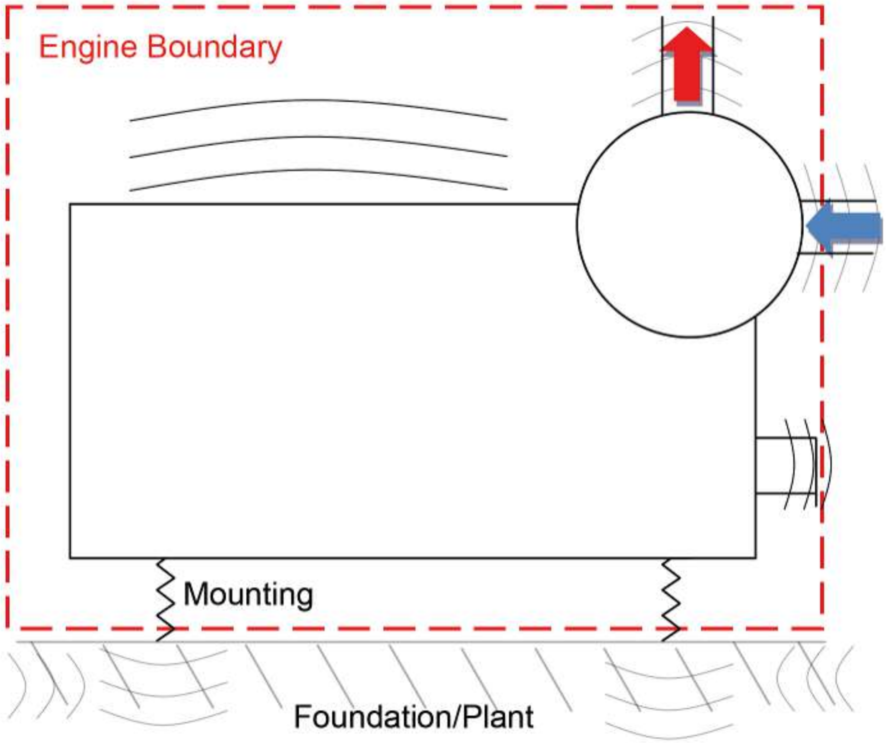

Figure 32: Noise and vibration – Impact on foundation

The foundation is excited to vibrations in a wide frequency range by the engine and by auxiliary equipment (from engine or plant). The engine is vibrating as a rigid body. Additionally, elastic engine vibrations are superimposed. Elastic vibrations are either of global (e.g. complete engine bending) or local (e.g. bending engine foot) character. If the higher frequency range is involved, the term "structure borne noise" is used instead of "vibrations".

Mechanical engine vibrations are mainly caused by mass forces of moved drive train components and by gas forces of the combustion process. For structure borne noise, further excitations are relevant as well, e.g. impacts from piston stroke and valve seating, impulsive gas force components, alternating gear train meshing forces and excitations from pumps.

For the analysis of the engine noise- and vibration-impact on the surrounding, the complete system with engine, engine mounting, foundation and plant has to be considered.

Engine related noise and vibration reduction measures cover e.g. counterbalance weights, balancing, crankshaft design with firing sequence, component design etc. The remaining, inevitable engine excitation is transmitted to the surrounding of the engine – but not completely in case of a resilient engine mounting, which is chosen according to the application-specific requirements. The resilient mounting isolates engine noise and vibration from its surrounding to a large extend. Hence, the transmitted forces are considerably reduced compared with a rigid mounting. Nevertheless, the engine itself is vibrating stronger in the low frequency range in general – especially when driving through mounting resonances.

In order to avoid resonances, it must be ensured that eigenfrequencies of foundation and coupled plant structures have a sufficient safety margin in relation to the engine excitations. Moreover, the foundation has to be designed as stiff as possible in all directions at the connections to the engine. Thus, the foundation mobility (measured according to ISO 7262) has to be as low as possible to ensure low structure borne noise levels. For low frequencies, the global connection of the foundation with the plant is focused for that matter. The dynamic vibration behaviour of the foundation is mostly essential for the mid frequency range. In the high frequency range, the foundation elasticity is mainly influenced by the local design at the engine mounts. E.g. for steel foundations, sufficient wall thicknesses and stiffening ribs at the connection positions shall be provided. The dimensioning of the engine foundation also has to be adjusted to other parts of the plant. For instance, it has to be avoided that engine vibrations are amplified by alternator foundation vibrations. Due to the scope of supply, the foundation design and its connection with the plant is mostly within the responsibility of the costumer. Therefore, the customer is responsible to involve MAN Energy Solutions for consultancy in case of system-related questions with interaction of engine, foundation and plant. The following information is available for MAN Energy Solutions customers, some on special request:

- Residual external forces and couples (Project Guide)

  Resulting from the summation of all mass forces from the moving drive train components. All engine components are considered rigidly in the calculation. The residual external forces and couples are only transferred completely to the foundation in case of a rigid mounting, see above.
- Static torque fluctuation (Project Guide)

  Static torque fluctuations result from the summation of gas and mass forces acting on the crank drive. All components are considered rigidly in the calculation. These couples are acting on the foundation dependent on the applied engine mounting, see above.
- Mounting forces (project-specific)

  The mounting dimensioning calculation is specific to a project and defines details of the engine mounting. Mounting forces acting on the foundation are part of the calculation results. Gas and mass forces are considered for the excitation. The engine is considered as one rigid body with elastic mounts. Thus, elastic engine vibrations are not implemented.
- Reference measurements for engine crankcase vibrations according to ISO 10816-6 (project-specific)
- Reference test bed measurements for structure borne noise (project-specific)

  Measuring points are positioned according to ISO 13332 on the engine feet above and below the mounting elements. Structure borne noise levels above elastic mounts mainly depend on the engine itself. Whereas structure borne noise levels below elastic mounts strongly depend on the foundation design. A direct transfer of the results from the test bed foundation to the plant foundation is not easily possible – even with the consideration of test bed mobilities. The results of test bed foundation mobility measurements according to ISO 7626 are available as a reference on request as well.
- Dynamic transfer stiffness properties of resilient mounts (supplier information, project-specific)

Beside the described interaction of engine, foundation and plant with transfer through the engine mounting to the foundation, additional transfer paths need to be considered. For instance with focus on the elastic coupling of the drive train, the exhaust pipe, other pipes and supports etc. Besides the engine, other sources of noise and vibration need to be considered as well (e.g. auxiliary equipment, propeller, thruster).

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2.20 Moments of inertia – Crankshaft, damper, flywheel

500 kW/cyl.; 720/750 rpm

Operation with constant speed

Engine						Required minimum total moment of inertia[1] $J_{Total\ min}$	Plant
No. of cylinders, config.	Maximum continuous rating	Moment of inertia crankshaft + damper J_1	Moment of inertia flywheel J_2	Mass of flywheel	Cyclic irregularity		Required minimum additional moment of inertia after flywheel[2]
	[kW]	[kgm²]	[kgm²]	[kg]		[kgm²]	[kgm²]
n = 720 rpm							
6L	3,000	512	897	2,515	404	1,475	66
7L	3,500	587			299	1,720	236
8L	4,000	635			441	1,966	434
9L	4,500	654			596	2,212	661
n = 750 rpm							
6L	3,000	512	897	2,515	468	1,359	-
7L	3,500	587			308	1,586	102
8L	4,000	635			456	1,812	280
9L	4,500	654			607	2,038	487

[1] Required minimum moment of inertia of engine, flywheel and arrangement after flywheel in total.

[2] Required additional moment of inertia after flywheel to achieve the required minimum total moment of inertia.

Table 54: Moments of inertia for electric propulsion plants – Crankshaft, damper, flywheel – MAN L32/40 GenSet

2.21 Arrangement of attached pumps

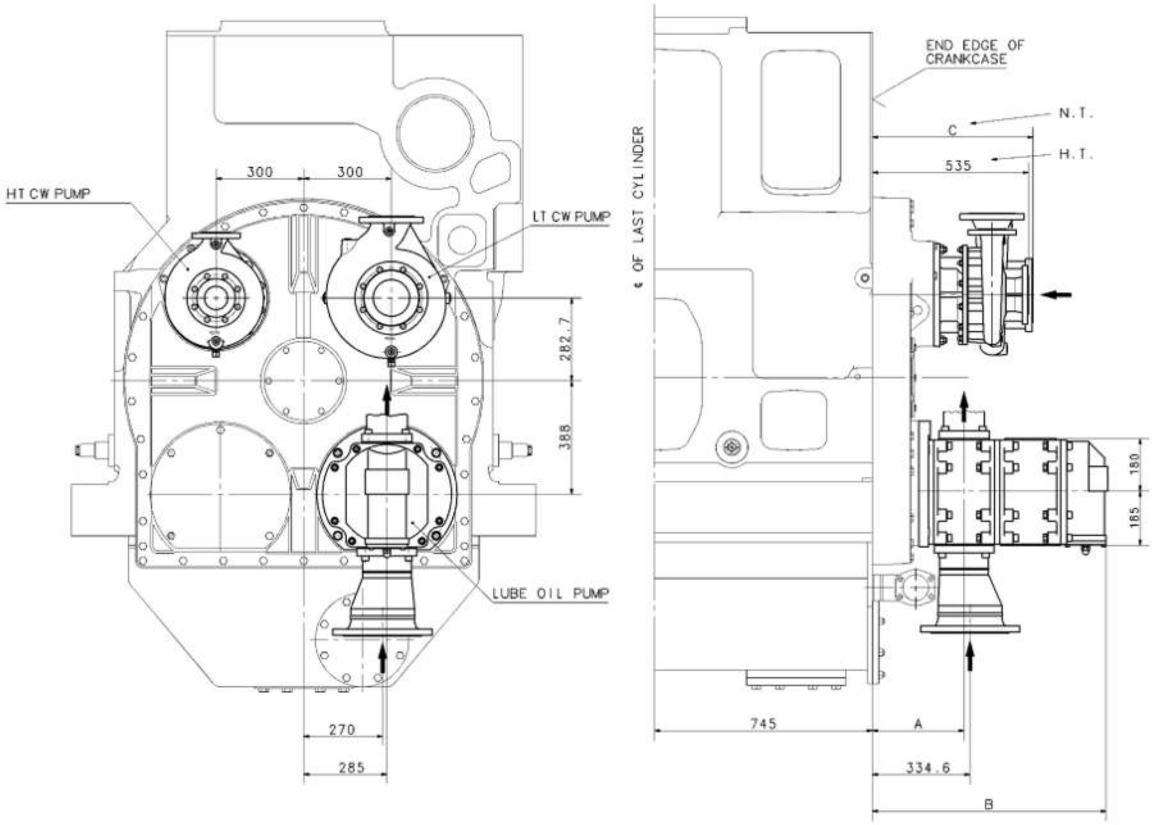

Figure 33: Attached pumps L engine

A	314 or 355 [1)]	C	510 or 550 [1)]
B	555 – 964 [1)]		
[1)] Depending from pump type.			

Note:
The final arrangement of the lube oil and cooling water pumps will be made at inquiry or order.

An attached LT CW pump is not available for the MAN L32/40 auxiliary GenSet.

2.22 Foundation

2.22.1 General requirements for engine foundation

Plate thicknesses

The stated material dimensions are recommendations, calculated for steel plates. Thicknesses smaller than these are not permissible. When using other materials (e.g. aluminium), a sufficient margin has to be added.

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Top plates

Before or after having been welded in place, the bearing surfaces should be machined and freed from rolling scale. Surface finish corresponding to Ra 3.2 peak-to-valley roughness in the area of the chocks shall be accomplished.

The thickness given is the finished size after machining.

Downward inclination outwards, not exceeding 0.7%.

Prior to fitting the chocks, clean the bearing surfaces from dirt and rust that may have formed. After the drilling of the foundation bolt holes, spotface the lower contact face normal to the bolt hole.

Foundation girders

The distance of the inner girders must be observed. We recommend that the distance of the outer girders (only required for larger types) is observed as well.

The girders must be aligned exactly above and underneath the tank top.

Floor plates

No manholes are permitted in the floor plates in the area of the box-shaped foundation. Welding is to be carried out through the manholes in the outer girders.

Top plate supporting

Provide support in the area of the frames from the nearest girder below.

Dynamic foundation requirements

The eigenfrequencies of the foundation and the supporting structures, including GenSet weight (without engine) shall be higher than 20 Hz. Occasionally, even higher foundation eigenfrequencies are required. For further information refer to section Noise and vibration – Impact on foundation, Page 86.

Note:
The requirements of the respective classification society have to be considered in addition.

2.22.2 Resilient mounting of GenSets

Resilient mounting of GenSets

On resilient mounted GenSets, the diesel engine and the alternator are placed on a common rigid base frame mounted on the ship's/erection hall's foundation by means of resilient supports, type conical.

All connections from the GenSet to the external systems should be equipped with flexible connections, and pipes, gangway etc. must not be welded to the external part of the installation.

Resilient support

A resilient mounting of the GenSet is made with a number of conical mountings. The number and the distance between them depend on the size of the plant. These conical mountings are bolted to brackets on the base frame see figure Resilient mounting of GenSets, Page 92.

The setting from unloaded to loaded condition is normally between 5 – 11 mm for the conical mounting.

The exact setting can be found in the calculation of the conical mountings for the plant in question. The support of the individual conical mounting can be made in one of the following three ways:

1. The support between the foundation and the base casting of the conical mounting is made with a loose steel shim. This steel shim is machined to an exact thickness (min. 40 mm) for each individual conical mounting.
2. The support can also be made by means of two steel shims, at the top a loose shim of at least 40 mm and below a shim of approximately 10 mm which are machined for each conical mounting and then welded to the foundation.
3. Finally, the support can be made by means of chockfast. It is recommended to use two steel shims, the top shim should be loose and have a minimum thickness of 40 mm, the bottom shim should be cast in chockfast with a thickness of at least 10 mm.

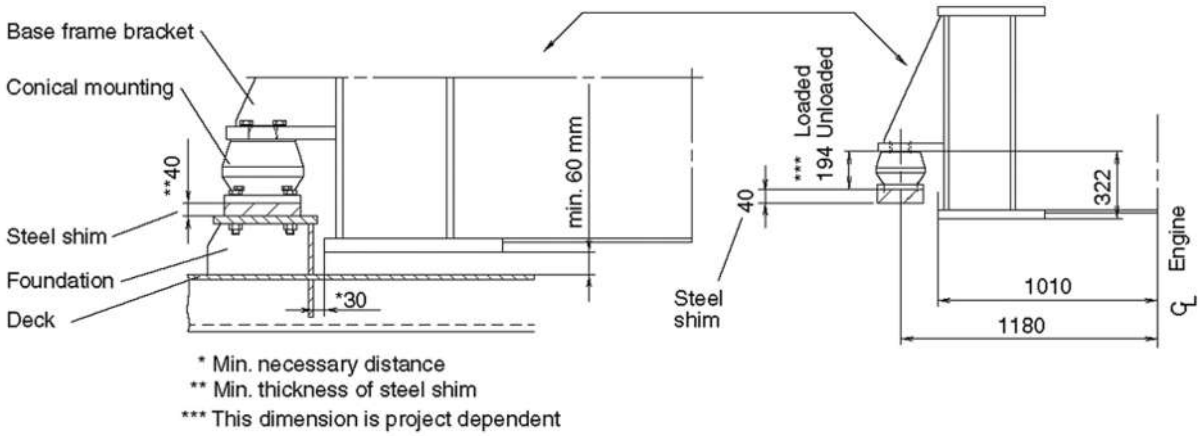

Figure 34: Resilient mounting of GenSets

Irrespective of the method of support, it is recommended to use a loose steel shim to facilitate a possible future replacement of the conical mountings.

Check of crankshaft deflection

The resilient mounted GenSet is normally delivered from the factory with engine and alternator mounted on the common base frame. Eventhough engine and alternator have been adjusted by the engine builder, with the alternator rotor placed correctly in the stator and the crankshaft deflection of the engine (autolog) within the prescribed tolerances, it is recommended to check the crankshaft deflection (autolog) before starting up the GenSet.

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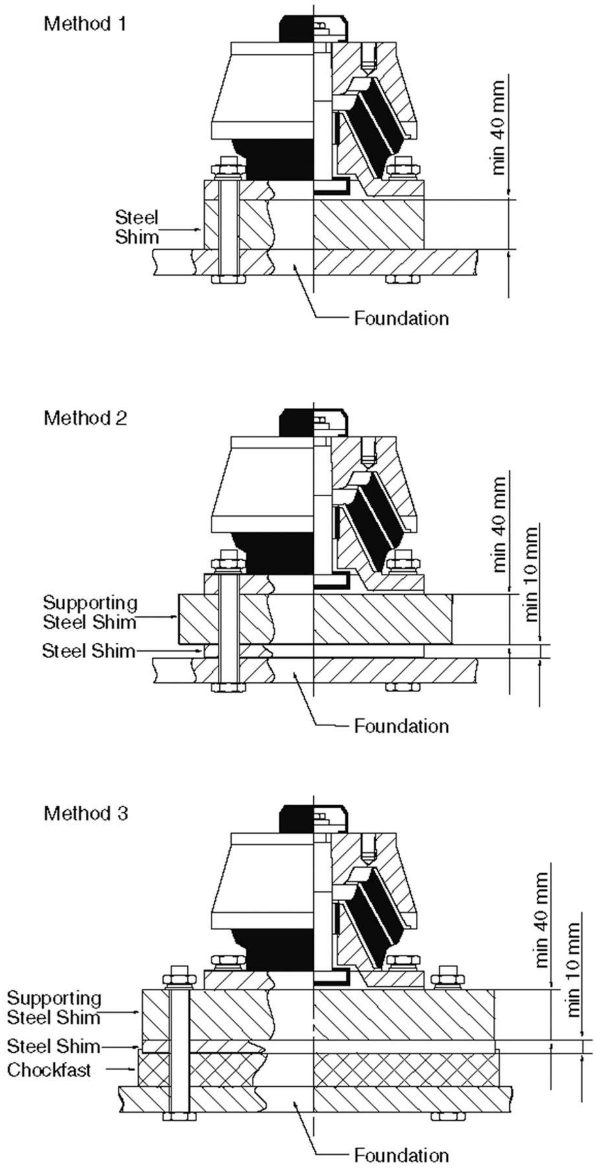

Figure 35: Support of conicals

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3 Engine automation

3.1 SaCoSone GenSet system overview

The monitoring and safety system SaCoSone GenSet serves for complete engine operation, control, monitoring, and safety of GenSets. Therefore all sensors and operating devices are wired to the system.

The SaCoSone design is based on high-reliable and approved components and modules specially designed for installation on medium-speed engines.

The used components are harmonised to a homogenously system. The whole system is attached to the engine cushioned against vibration.

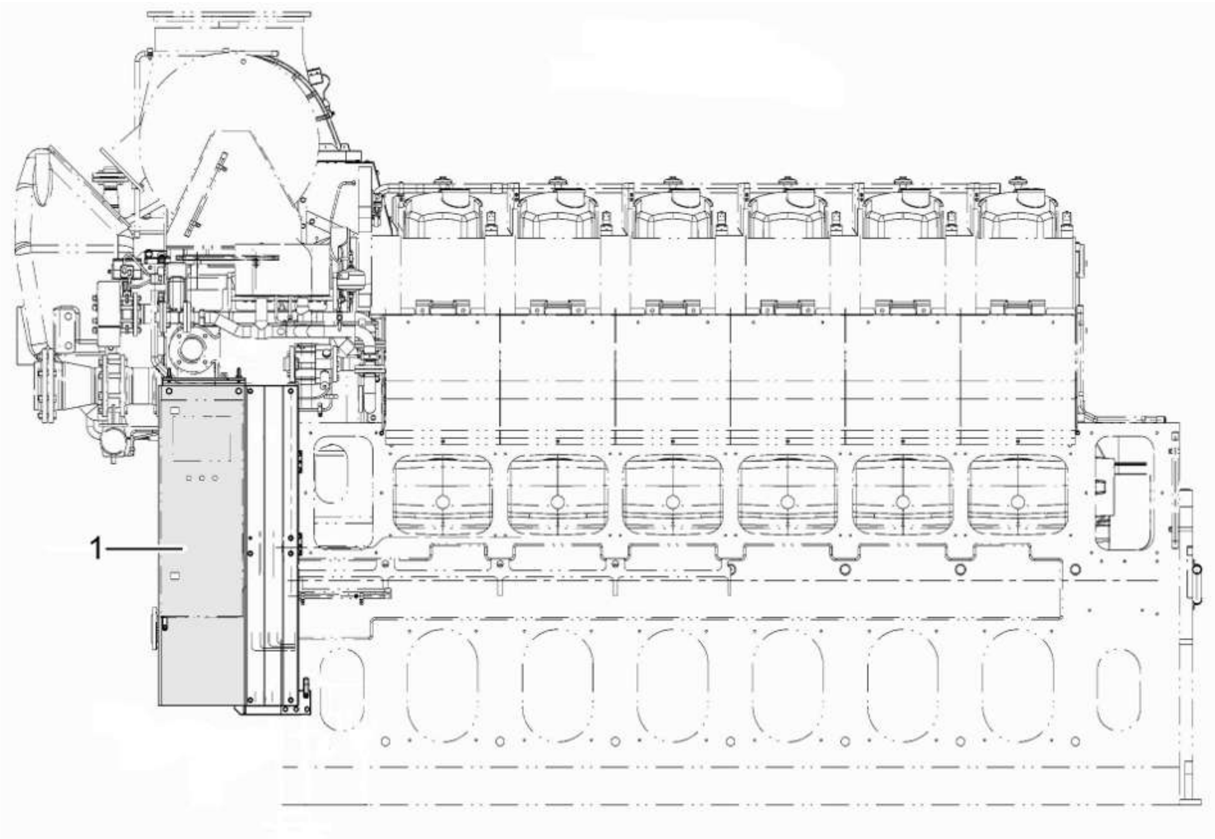

Figure 36: Overview on SaCoSone L-engine

1	Control Unit

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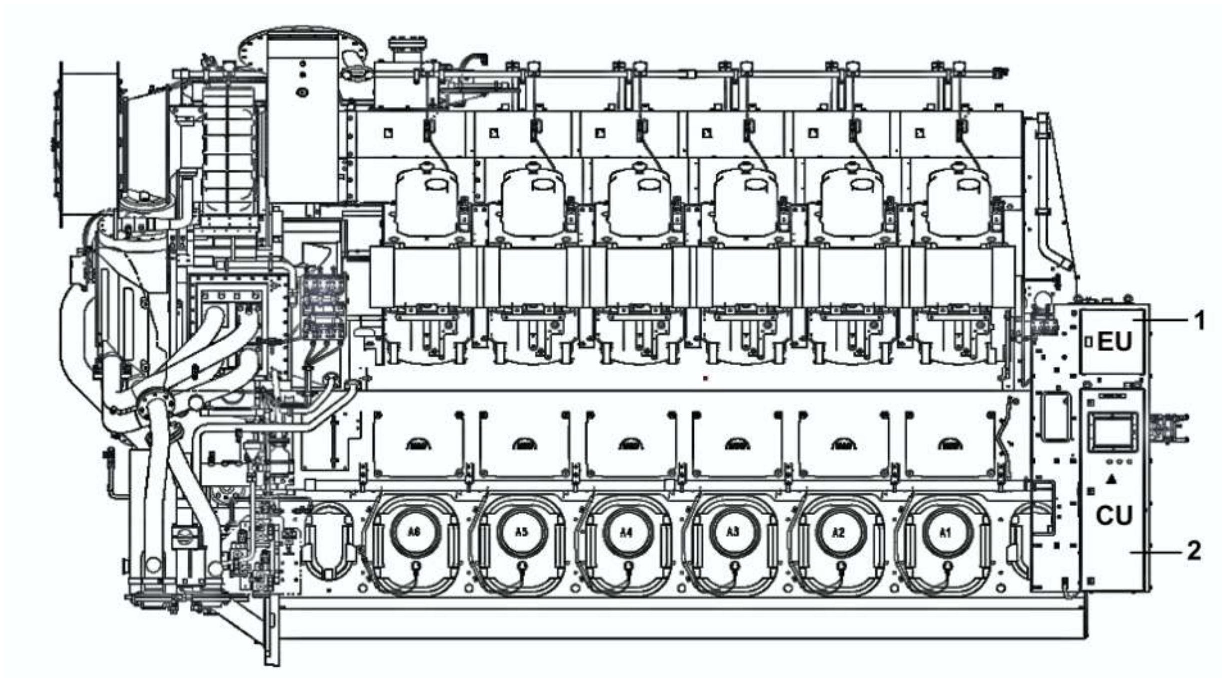

Figure 37: Overview on SaCoSone V-engine

1	Extension Unit
2	Control Unit

Control Unit

The Control Unit includes a highly integrated Control Module S for engine control, monitoring and alarm system (alarm limits and delay). The module collects engines measuring data and transfers most measurements and data to the ship alarm system via Modbus. Furthermore, the Control Unit is equipped with a Display Module. This module consists of a touchscreen and an integrated PLC for the safety system. The Display Module also acts as safety system for overspeed, low lube oil pressure and high cooling water temperature.
The Display Module provides the following functions:

- Safety system
- Visualisation of measured values and operating values on a touchscreen
- Engine operation via touchscreen

The safety system is electrically separated from the control system due to requirements of the classification societies. For engine operation, additional hardwired switches are available for relevant functions. The system configuration can be edited via an Ethernet interface at the Display Module. Additionally, the Control Unit contains the terminal blocks for the connection to external systems, such as the ship alarm system and the optional crankcase monitoring. It is the central connecting and distribution point for the 24 V DC power supply of the whole system.

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Figure 38: Control Unit

Multifunction Monitoring System (optional for L-engine)

The Multifunction Monitoring System (MMS) is part of the alarm and safety system and is connected via the redundant CAN bus to the Control Module S.

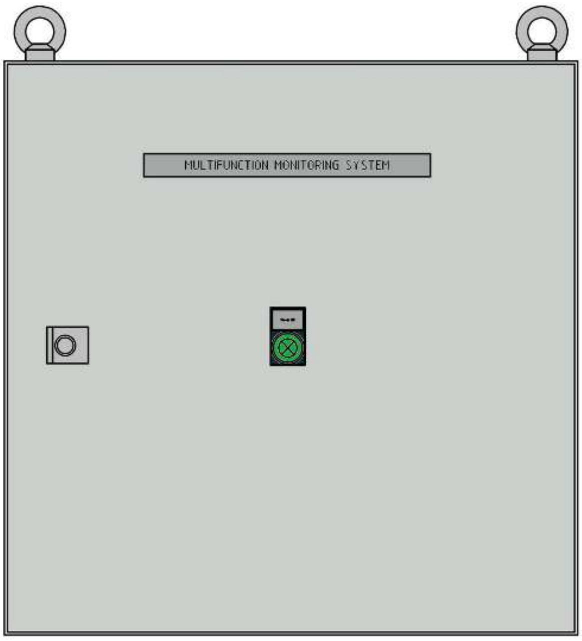

Figure 39: Multifunction Monitoring System

Extension Unit (only for V-engines)

The Extension Unit includes a highly integrated Control Module for control of the bank B. The module also collects engines measuring data from splash-oil, main bearing and exhaust gas and transfers most measurements and data to the ship alarm system via Modbus. The 4Q-driver module for the Heinzmann STG 180 speed actuator is also included in the Extension Unit.

System bus

SaCoSone GENSET is equipped with a redundant bus based on CAN. The bus connects all system modules. This redundant bus system provides the basis data exchange between the modules. The Control Module S operates directly with electro-hydraulic actuator.

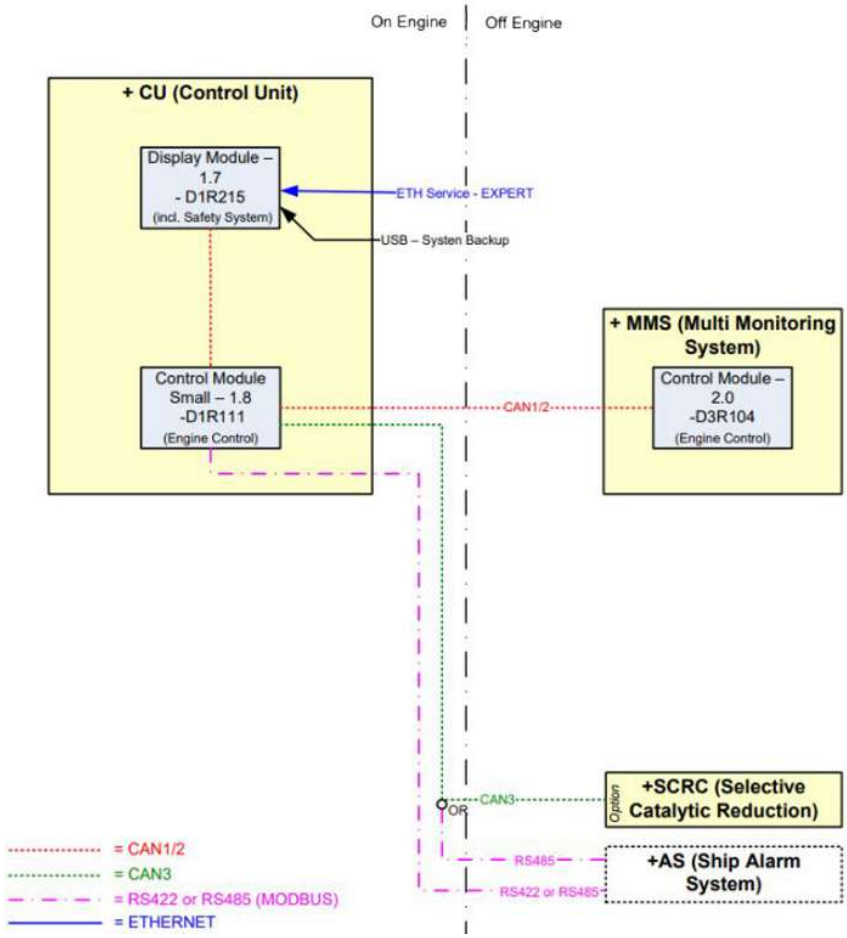

Figure 40: System bus diagram L-engine

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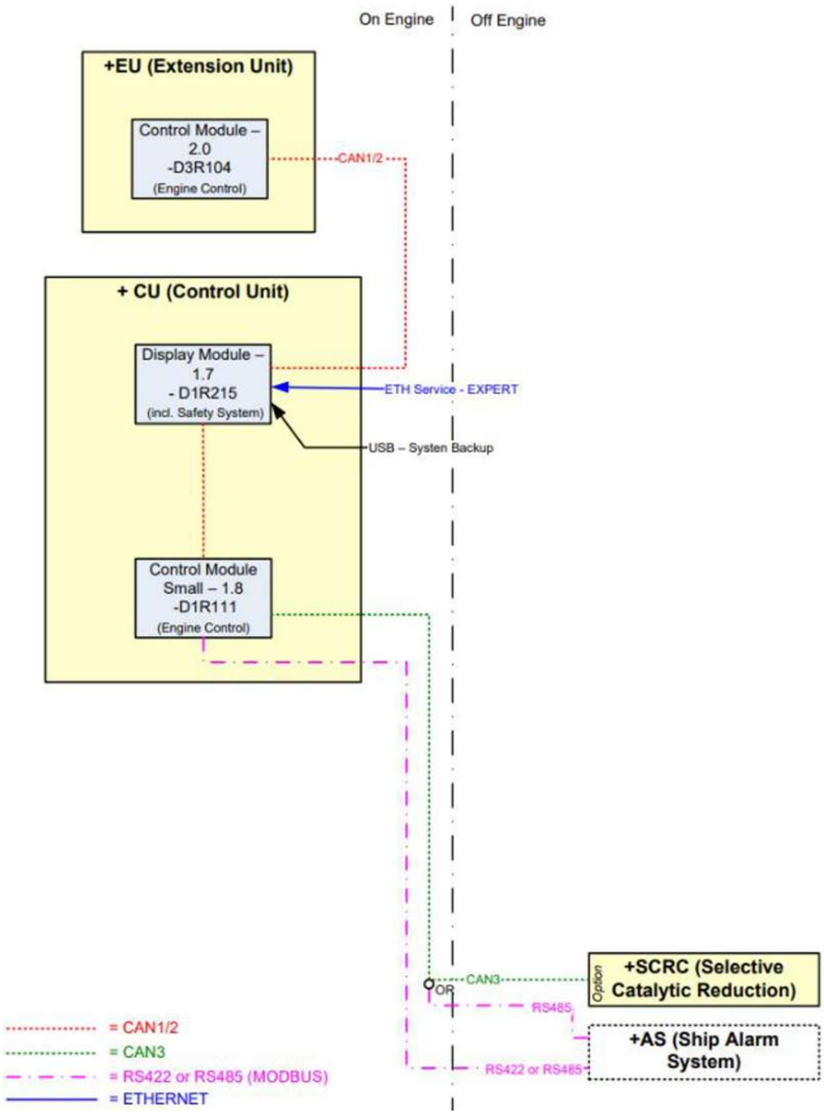

Figure 41: System bus diagram V-engine

3.1.1 Cybersecurity guidelines

3.1.1.1 Terms, abbreviations and definitions

Term, abbreviation	Definition
CM-S	Control module small (Note: A CM-E1 can also be used instead of the CM-S in some architectures. In this document, the designation CM-S is used to represent both modules)
CU	Control Unit
DM	Display module
ECR	Engine control room
ECU	Electronic control unit
ER	Engine room

Term, abbreviation	Definition
eToken	SaCoSone Security Token (Thales Group eToken 5110+)
EXPERT	MAN Energy Solutions tool for SaCoS parameterization
IAS	Integrated alarm system (see also "customer network")
IM	Injection module
LOP	Local operating panel
PMS	Power management system
SaCoSone	Safety and Control System on engine
SCR	Selective catalytic reduction
SDI	SaCoSone device image

Table 55: Terms, abbreviations, and definitions

3.1.1.2 System Overview

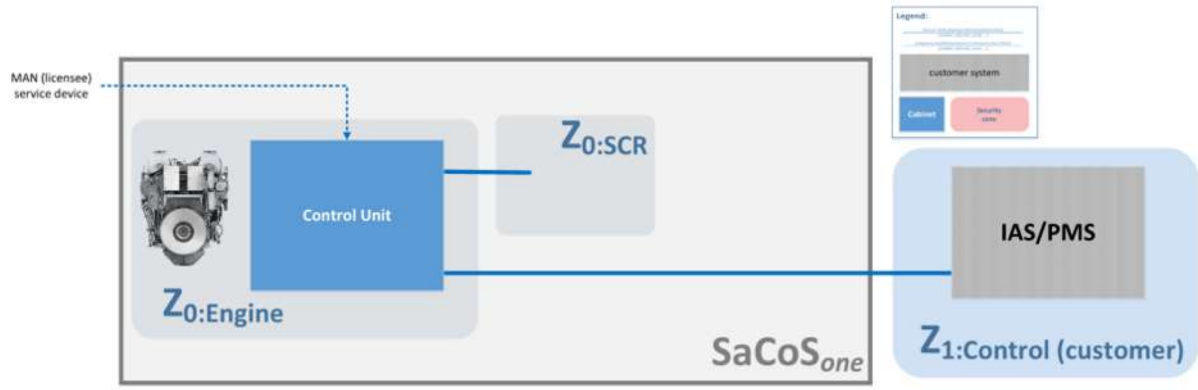

Figure 42: SaCoSone small-bore genset: Zones and connections (simplified)

Figure *SaCoSone small-bore genset: Zones and connections (simplified)*: Shows a simplified overview of the SaCoSone system (small-bore genset variant), as well as all zones and connections relevant for the cyber security analysis

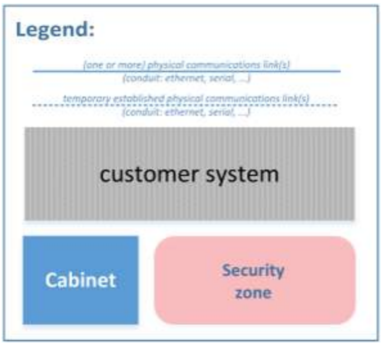

Figure 43: SaCoSone small-bore genset: Zones and connections (simplified) – Key

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Figure *SaCoSone small-bore genset: Zones and connections (simplified) – Key*:
Shows the key for the simplified overview of the SaCoSone system (small-bore genset variant).

The system is divided into the following main security zones:

- $Z_{0:Engine}$: Devices in this zone implement the main functionality of the engine control system
- $Z_{0:SCR}$: Devices in this zone implement the SCR functionality and enable local monitoring and control of the SCR system.
- $Z_{1:Control\ (customer)}$: This zone contains the ship's integrated alarm and/or power management system(s) (IAS/PMS)

The majority of SaCoS devices are installed in locked cabinets or units such as the control unit (CU). These must be installed in restricted areas such as engine rooms (ER).

Communication within and between zones is via ethernet, CAN, serial and/or hard-wired connections. Each connection in the figure *SaCoSone small-bore genset: Zones and connections (simplified)* is implemented as one or more such lines.

3.1.1.3 Physical security of SaCoS

Some SaCoSone devices and communication links must be physically protected against unauthorised access at all times (i.e., including during commissioning). Some module interfaces do not enforce user or device authentication or authorisation. Only authorised and authenticated personnel may have access to these devices and connections. These accesses must be logged. The resulting logs must also be stored securely for future audits. Further physical protection measures (walls, lockable doors, laying cables to protect against unauthorised access ...) must be implemented to prevent unauthorised access (personal and technical) and manipulations of SaCoSone hardware, software, cables, and data as well as to prevent any changes to the network topology.

The operator/integrator is responsible for assessing the security level of these protective measures; the system context, system purpose, system location, assumptions about actual and future threats to the operator's business operations, and applicable regulations shall be taken into account.

Such measures are necessary above all to protect the SaCoS components and communication connections, as these perform safety-critical functions; depending on the SaCoS variant, this may include the following components and connections:

- All system devices, including display modules (DM), control modules (CM-S/CM-E1), injection modules (IM), as well as WAGO modules
- CAN bus (including between CM-S and SCR) and any CAN repeaters.
- SaCoSone sensors and actuators
- Serial and network connections connecting devices in the system to each other or connecting the system to external zones (e.g. $Z_{1:Control(Customer)}$)

Failure to comply with these guidelines can have the following consequences, among others:

- The safety of the engine, the plant and its surroundings is impaired
- The engine can no longer be controlled by the operator and/or can be controlled by the attacker

- The operator loses access to (authentic) information about the status of the engine and the automation system (incl. alarm data), and/or an attacker gains access to this information
- Notes on possible impacts (here and further down in the document):
  - Depending on the means and resources available to the attacker, a *targeted* attack on SaCoSone may have serious consequences, up to and including the complete compromise of SaCoS and the systems connected to it
  - The list of possible effects is not exhaustive

3.1.1.4 Safety of the communication link with Z1:Control(Customer) and Z0:SCR

SaCoSone can be monitored remotely from $Z_{1:Control(Customer)}$ via a serial connection and also communicates with $Z_{0:SCR}$ via a CAN connection. For this purpose, the SaCoSone CM-S provides interfaces that can be used by devices in $Z_{1:Control(Customer)}$ and $Z_{0:SCR}$.

The integrator/operator must therefore ensure the following:

- Physical access to lines connecting SaCoSone with devices in $Z_{1:Control(Customer)}$ and $Z_{0:SCR}$ must be impossible for unauthorised persons
- Communication between SaCoSone and devices in $Z_{1:Control(Customer)}$ and $Z_{0:SCR}$ must not be accessible to potential aggressors (possibly infected, compromised, or otherwise untrustworthy devices).
- $Z_{0:SCR}$ and $Z_{1:Control(Customer)}$ must be trusted networks in the sense of IACS UR E27

Failure to comply with these guidelines can have the following consequences, among others:

- Operator loses access to (authentic) information about the status of the engine and the automation system (incl. alarm data), and/or an attacker gains access to this information
- Attacker influences the engine control unit or the SCR system by intercepting and then manipulating the communication between the two systems

3.1.1.5 Secure access and storage of SaCoS data

It is necessary to keep the data created by or for SaCoS (such as SDIs, parameter sets, or log data) secure and protected against access by third parties.

Secure access and retention of such data can be implemented, for example, by adhering to the following guidelines:

- Use different data carriers and devices (e.g. dedicated ‘MAN Energy Solutions Service Stick’ ...) for different purposes (e.g. storage of SDIs, parameterisation of SaCoSone ...)
- Never use such media and devices for other purposes and never connect them to other devices or networks
- Only connect data carriers and devices to trustworthy devices or networks
- Encrypt and/or authenticate SaCoS data held outside of SaCoS
- SaCoS devices in a physically protected, restricted-access location

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- Never pass on SaCoS-relevant access data, passwords, cryptographic keys as well as other sensitive or secret data to third parties. This includes the password of the SaCoSone Security Tokens (“eToken”), DM touch-screen passwords, or access data for additional devices managed by the operator and integrated into the SaCoSone system
- Data that is uploaded to the system (e.g. SDIs, parameter sets) shall be checked for authenticity

Failure to comply with these guidelines may have the following consequences, among others:

- Third parties learn details about the use, properties and condition of the system.
- Third parties are able to alter the engine condition, which may pose a risk to the engine's safety

3.1.1.6 Securing Z1:Control(Customer)

SaCoSone CM-S can be accessed via its serial interface without prior authentication, which enables the engine to be monitored. The zone from which this interface can be accessed is referred to below as $Z_{1:Control(Customer)}$ and must be secured by the operator/integrator so as not to lose access to information about the engine, among other things.

Securing this network is the responsibility of the operator/integrator

Therefore, the operator/integrator shall implement safeguards to secure this network, which may include, but are not limited to, the following:

- Connecting devices in $Z_{1:Control(Customer)}$ to SaCoS exclusively via the network interface of the CM-S
- Protecting and restricting physical and communicative access to the devices and their connections located in the customer network
- No wireless technologies
- In addition to the SaCoSone CM-S, only IAS/PMS devices may be in $Z_{1:Control(Customer)}$
- Separating the$Z_{1:Control(Customer)}$ zone from other networks, as well as internal segmentation of the network so that different engine and SCR systems connected to the network cannot influence each other
- Do not connect potential aggressor devices to $Z_{1:Control(Customer)}$ that are or may be potentially infected or compromised. Only then can this network be considered “trusted” by SaCoS in the sense of IACS E26/E27
- Establishing security measures and implement processes to ensure that devices and connections within $Z_{1:Control(Customer)}$ are never reconnected to other networks
- Securing all devices and connections within $Z_{1:Control(Customer)}$ according to a risk management plan established for that plant. Protective measures may include the use of anti-virus software, hardening measures, regular security updates, disabling USB ports, and maintaining an “air gap” (where possible)
- Avoiding the operation of other Modbus services within $Z_{1:Control(Customer)}$ in order to prevent erroneously established Modbus client connections to such services.

If these guidelines are not observed, the following effects may occur, among others:

- Attackers in the customer network can read the display on the operating panels and the devices in $Z_{1:Control(Customer)}$

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- Attackers in $Z_{1:Control(Customer)}$ may be able to deactivate the CM-S, which leads to an engine stop

In addition, a compromised SaCoS can pose a threat to customer networks and devices, by infecting/compromising the customer systems within. Although the corresponding risk is assessed as low by MAN Energy Solutions in the context of a risk analysis (in the context of Security Level 1 according to IEC 62443), the operator/integrator can implement additional measures to protect themselves against this risk. Such protective measures may include, but are not limited to:

- Installing additional network security devices (e.g. firewall, intrusion protection system) to protect the connections between SaCoS and the customer networks. This allows, for example, any communication between SaCoS and the customer networks to be monitored for suspicious or unusual activity
- Implementing hardening measures for devices in $Z_{1:Control(Customer)}$ under the assumption that SaCoS can act as aggressor
- Not making sensitive data or services available in $Z_{1:Control(Customer)}$, e.g. those that enable the control of other plants

3.1.1.7 Securing the operating panels

The SaCoSone operating panels are not “hardened”, are not regularly provided with security updates, and their communication with the rest of the system is not secured against attackers.

The operator/integrator is therefore advised to adhere to the following guidelines:

- Physical access to the operating panels must be strictly controlled and only allowed to authorised personnel
- Physical access to the communication connections and interfaces of the operating panels (incl. USB and network interfaces) must be restricted to authorised service employees only. The operator/integrator may neither change the connections set up by MAN Energy Solutions nor connect their own devices to the operating panels
- When entering the password on the DM, care must be taken to ensure that unauthorised persons cannot read the entered password from the display

The service personnel authorised to configure the password-protected engine parameterisation functions are also required to check the default values of the relevant security parameters (such as the time until the user is automatically logged out) and/or to change them in accordance with the security policy applicable to the system.

If these guidelines are not adhered to, the following effects may occur, among others (for further possible effects, see also Section Securing Z1:Control(Customer), Page 103):

- Operational safety of the engine is impaired
- The operator loses control of the engine and/or the attacker takes control of the engine
- Data manipulated by the attacker is displayed on operating panels and/or transmitted to devices in the customer network.
- Operating panels are not functional

3.1.1.8 Maintaining network segmentation

Network segmentation is one of SaCoSone's key protection measures. Therefore, the network structure set up by MAN Energy Solutions must not be changed.

Specifically, the following guidelines shall be adhered to:

- Individual network segments must not be bridged
- No additional devices may be connected to the network segments of SaCoS

If these guidelines are not followed, SaCoS can be compromised by an attacker and the operational safety of the engine can be compromised.

3.1.1.9 Preparation for security incidents

Residual risks may remain even if the present guidelines are followed. The operator shall prepare for possible security incidents in order to be able to react to them promptly. This includes the creation of an incident response plan, which shall address the following points, among others:

- Obtain spare parts to replace SaCoSone modules that have failed or been compromised due to an attack.
- If changes are made to the system (e.g. parameterisation of the system), these changes must be saved accordingly.
- Report the security incident to the engine manufacturer’s 1st level support via a secure channel and follow the instructions.
- Save all relevant data for all causes. This includes, but is not limited to, the access logs and general audit logs generated by the customer devices and the plant.
- Analyse the data and take steps to address the vulnerability that led to the incident.

The operator is also instructed to monitor the system for indications of a possible security incident as far as possible. Any of the following indicators can point to a possible security incident:

- The data displayed on the operating panels and/or reported by SaCoS to devices in $Z_{1:Control(Customer)}$ is inconsistent, unrealistic, or unexpected.
- The system and/or the engine behave abnormally, which can be attributed to engine control commands that do not originate from the operator
- The system can no longer be controlled
- The engine stops unexpectedly
- The system alerts the operator to the failure of a DM or CM-S
- The system alerts the operator to a network flood attack on the DM

In order to address such incidents in the short term, the operator can consider the following countermeasures after the corresponding operational safety assessment:

- Putting the engine in a safe state appropriate to the situation (e.g.shut down the engine, switch off the system ...), informing service of the incident and not resuming normal operation until the problem has been rectified
- If continued operation of engine is intended, the system can be set to island mode by physically disconnecting the connections at the DM network interfaces as well as connections to SCR and IAS/PMS

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- If the above measures do not achieve the desired effect, the affected modules (e.g. the CM-S) can be restarted or replaced.
- One of the security mechanisms is to switch off the network interface of a DM in the event of a network flood. As a result, the DM must be restarted to reopen the ports

By violating these guidelines, potentially emerging security incidents can remain undetected for longer or, in the worst case, go completely undetected. MAN Energy Solutions therefore recommends complying with/fulfilling the aforementioned guidelines as far as possible.

3.1.1.10 Secure disposal

When disposing of SaCoSone devices, it shall be noted that they store sensitive information such as engine parameters, log data, and cryptographic keys, which could be extracted. The operator is responsible for the security of this data when disposing of the devices.

3.1.1.11 User account management

Most SaCoSone devices do not allow interactive access by the user, with the following exceptions:

- DM service access with an EXPERT eToken (only for authorised service personnel with an eToken)
- Privileged access to DM via touchscreen for engine parameterisation

The management of DM touchscreen passwords is the responsibility of the operator and service personnel. Passwords shall be long and randomly generated, stored in a secure, access-protected location, and not reused on other accounts or devices. The passwords shall be set when the module is integrated by authorised service personnel, and communicated via a secure channel to the operator who is authorised for engine parameterization.

If there is any suspicion of unlawful use, the password must be changed immediately.

3.1.1.12 Security Incident Report

Security incidents affecting SaCoSone shall be reported to the engine manufacturer's 1st level support.

3.2 Power supply and distribution

The plant has to provide electric power for the automation and monitoring system. In general an uninterrupted 24 V DC power supply is required for SaCoSone.

For V-engines an additional 48 V DC power supply is required for the 4Q-driver module for the Heinzmann STG 180 speed actuator in the Extension Unit.

For marine main engines, an uninterrupted power supply (UPS) is required which must be provided by two individual supply networks. According to classification requirements it must be designed to guarantee the power supply to the connected systems for a sufficiently long period if both supply networks fail.

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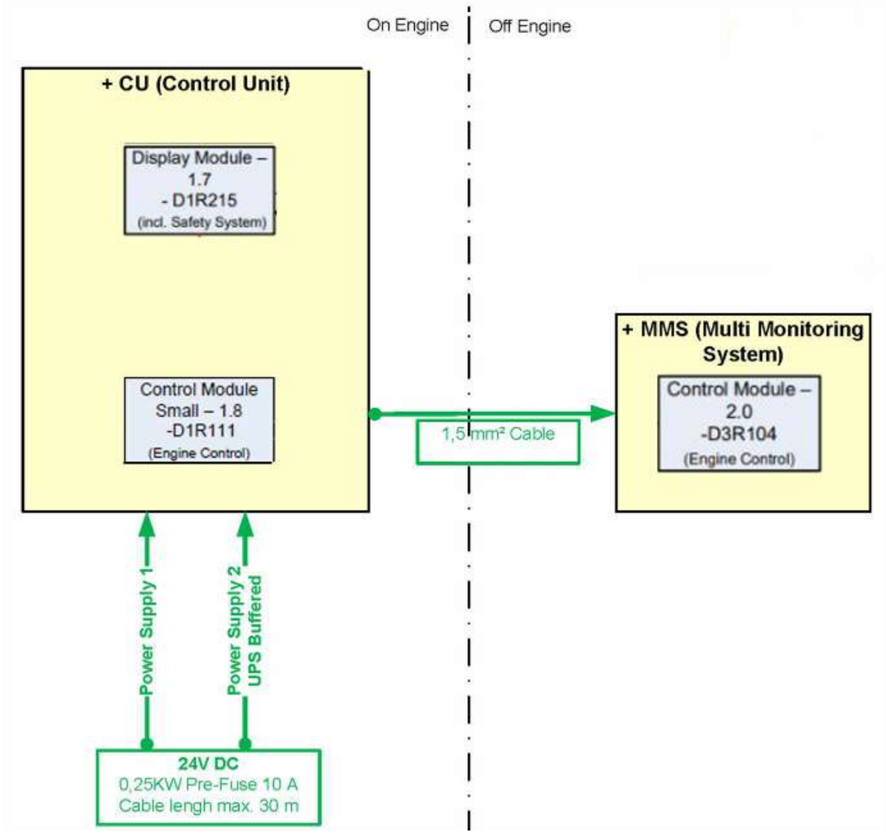

Figure 44: Power supply diagram L32/40

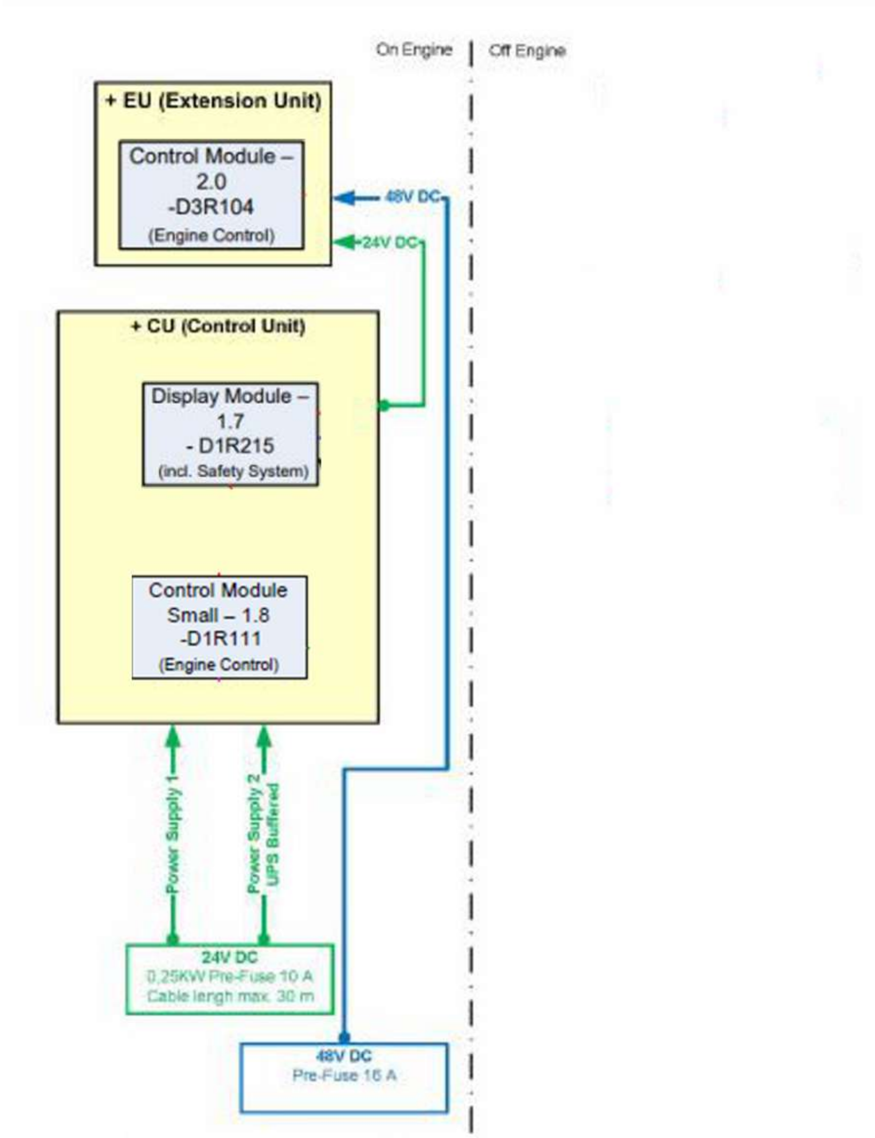

Figure 45: Power supply diagram V32/40

Required power supplies

Voltage	Consumer	Notes
24 V DC	Control Unit	All SaCoSone components, Multifunction Monitoring System
24 V DC UPS buffered	Control Unit	All SaCoSone components, Multifunction Monitoring System
48 V DC (only V-engine)	Extension Unit	All SaCoS components, 4Q-driver module for speed actuator Heinzmann STG 180
230 V 50/60 Hz	Terminal box on engine	Power supply for trace heating of fuel oil leakage pipe

Table 56: Required power supplies

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3.3 Operation

Control station changeover

The operation and control can be done from the Local Operating Panel. On the touchscreen, all the measuring points acquired by means of SaCoSone can be shown in clearly arranged drawings and figures. It is not necessary to install additional speed indicators separately.

The operating rights can be handed over to an external automatic system.

Speed setting

In case of operating with the SaCoSone panel, the engine speed setting is carried out manually by a decrease/increase switch button.
If the operation is controlled by an external system, the speed setting can be done either by means of binary contacts (e.g. for synchronisation) or by an active 4 – 20 mA analogue signal alternatively. The signal type for this is to be defined in the project planning period.

Operating modes

For alternator applications:

- Droop (5-percent speed increase between nominal load and no load)

The operating mode is pre-selected via the SaCoS interface and has to be defined during the application period.

Details regarding special operating modes on request.

3.4 Functionality

Safety system

Safety functions

The safety system monitors all operating data of the engine and initiates the required actions, i.e. engine shutdown, in case the limit values are exceeded.

The safety system is integrated the Display Module. The safety system directly actuates the emergency shutdown device and the stop facility of the speed governor.

Auto shutdown

Auto shutdown is an engine shutdown initiated by any automatic supervision of engine internal parameters.

Emergency stop

Emergency stop is an engine shutdown initiated by an operator manual action like pressing an emergency stop button. An emergency stop button is placed at the Control Unit on engine.

Note:
A manual emergency stop stops the engine, but does not affect the interface signals requesting the auxiliary units. During the integration, the respective integrator must determine how the system reacts.

Engine shutdown

If an engine shutdown is triggered by the safety system, the emergency stop signal has an immediate effect on the emergency shut-down device and the speed control. At the same time the emergency stop is triggered, SaCoSone issues a signal resulting in the alternator switch to be opened.

Shutdown criteria

- Engine overspeed

- Failure of both engine speed sensors
- Lube oil pressure at engine inlet low
- HT cooling water temperature outlet too high
- High bearing temperature/deviation from Multifunction Monitoring System (optional)
- High alternator winding temperature from Multifunction Monitoring System (optional)
- High splash-oil temperature/deviation from Multifunction Monitoring System (optional)
- High oilmist concentration in crankcase (optional)
- Remote Shutdown (optional)
  - Differential protection (optional)
  - Earth connector closed (optional)
  - Gas leakage (optional)

Load reduction request

SaCoSone GENSET requests a load reduction from PMS in case of VIT errors. The load reduction has to be carried out by the PMS. For safety reason SaCoSone GENSET will not reduce the load by itself.

Alarm/monitoring system

Alarming

The alarm function of SaCoSone supervises all necessary parameters and generates alarms to indicate discrepancies when required. The alarms will be transferred to ship alarm system via Modbus data communication.

Self-monitoring

SaCoSone carries out independent self-monitoring functions. Thus, for example the connected sensors are checked constantly for function and wire break. In case of a fault SaCoSone reports the occurred malfunctions in single system components via system alarms.

Control

SaCoSone controls all engine-internal functions as well as external components, for example:

- Start/stop sequences:
  Local and remote start/stop sequence for the GenSet. Activation of start device. Control (auto start/stop signal) regarding prelubrication oil pump. Monitoring and control of the acceleration period.
- Jet system:
  For air fuel ratio control purposes, compressed air is lead to the turbocharger at start and at load steps.
- Control signals for external functions:
  - Nozzle cooling water pump (only engine type MAN L32/40 GenSet)
  - HT cooling water preheating unit
  - Prelubrication oil pump control
  - Variable injection timing
- Redundant shutdown functions:
  - Engine overspeed
  - Low lube oil pressure inlet engine
  - High cooling water temperature outlet engine

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Speed control system

Governor
The engine electronic speed control is realised by the Control Module. As standard, the engine is equipped with an electro-hydraulic actuator. Engine speed indication is carried out by means of redundant pick-ups at the camshaft.

Speed adjustment
Local, manual speed setting is possible at the Control Unit with a turn switch. Remote speed setting is either possible via 4 – 20 mA signal or by using hardwired lower/raise commands.

Speed adjustment range
Between –5 % and +10 % of the nominal speed at idle running.

Droop
Adjustable by parameterisation tool from 0 – 5 % droop.

Load distribution
By droop setting.

Engine stop
Engine stop can be initiated local at the Display Module and remote via a hardware channel or the bus interface.

3.5 Interfaces

Data machinery interface

This interface serves for data exchange to ship alarm systems or integrated automation systems (IAS).

The status messages, alarms and safety actions, which are generated in the system, can be transferred. All measuring values and alarms acquired by SaCoSone GenSet are available for transfer.

The following Modbus protocols are available:

- Modbus RTU (Standard)
- Modbus ASCII

The Modbus RTU protocol is the standard protocol used for the communication from the GenSet. For the integration in older automation system, also Modbus ASCII is available.

Modbus RTU protocol

The Modbus RTU protocol is the standard protocol used for the communication from the GenSet.

The bus interface provides a serial connection. The protocol is implemented according to the following definitions:

- Modbus application protocol specification, Modbus over serial line specification and implementation guide

There are two serial interface standards available:

- RS422 – standard, 4 + 2 wire (cable length <= 100 m), cable type as specified in the circuit diagram, line termination: 150 ohms
- RS485 – standard, 2 + 2 wire (cable length <= 100 m), cable type as specified in the circuit diagram, line termination: 150 ohms

Settings
The communication parameters are set as follows:

Modbus slave	SaCoS
Modbus master	Machinery alarm system
Slave ID (default)	1
Data rate (default)	57,600 baud

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Modbus slave	SaCoS
Data rate (optionally available)	4,800 baud 9,600 baud 19,200 baud 38,400 baud 115,200 baud
Data bits	8
Stop bits	1
Parity	None
Transmission mode	Modbus RTU

Table 57: Settings for Modbus RTU

Function codes

The following function codes are available to gather data from the SaCoSone controllers:

Function code	Function code hexadecimal	Description
1	0x01	read coils
3	0x03	read holding registers
5	0x05	write coil
6	0x06	write single register
15	0x0F	write multiple coils
16	0x10	write multiple registers
22	0x16	mask write register
23	0x17	read multiple registers

Table 58: Functions codes

Message frame separation

Message frames shall be separated by a silent interval of at least 4 character times.

Provided data

Provided data includes measured values and alarm or state information of the engine.

Measured values are digitised analogue values of sensors, which are stored in a fixed register of the Control Module S. Measured values include media values (pressures, temperatures) where, according to the rules of classification, monitoring has to be done by the machinery alarm system. The data type used is signed integer of size 16 bit. Measured values are scaled by a constant factor in order to provide decimals of the measured.

Pre-alarms, shutdowns and state information from the SaCoSone system are available as single bits in fixed registers. The data type used is unsigned of size 16 bit. The corresponding bits of alarm or state information are set to the binary value „1“, if the event is active.

Contents of List of Signals

For detailed information about the transferred data, please refer to the ”List of Signals“ of the engine’s documentation set. This list contains the following information:

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Field	Description
Address	The address (e.g.: MW15488) is the software address used in the Control Module S.
HEX	The hexadecimal value (e.g.: 3C80) of the software address that has to be used by the MODBUS master when collecting the specific data.
Bit	Information of alarms, reduce load, shutdown, etc. are available as single bits. Bits in each register are counted 0 to 15.
Meas. Point	The dedicated denomination of the measuring point or limit value as listed in the „list of measuring and control devices“.
Description	A short description of the measuring point or limit value.
Unit	Information about how the value of the data has to be evaluated by the Modbus master (e.g. „°C/100“ means: Reading a data value of „4156“ corresponds to 41.56 °C)
Origin	Name of the system where the specific sensor is connected to, or the alarm is generated.
Signal	The range of measured value.

Table 59: Content of List of Signals

Live bit

In order to enable the alarm system to check whether the communication with SaCoSone is working, a live bit is provided in the list of signals. This bit is alternated every 4 seconds by SaCoSone.Thus, if it remains unchanged for more than 4 seconds, the communication is down.

Modbus ASCII

General

The communication setup is: 9,600 baud, 8 databits, 1 stopbit, no parity.

The Modbus protocol accepts one command (Function code 03) for reading analogue and digital input values one at a time, or as a block of up to 32 inputs.

The following section describes the commands in the Modbus protocol, which are implemented, and how they work.

Protocol description

The ASCII and RTU version of the Modbus protocol is used, where the CMS/DM works as Modbus slave.

All data bytes will be converted to 2-ASCII characters (hex-values). Thus, when below is referred to “bytes“ or “words“, these will fill out 2 or 4 characters, respectively in the protocol. The general “message frame format“ has the following outlook:

[:] [SLAVE] [FCT] [DATA] [CHECKSUM] [CR] [LF]

- [:]
  1 char. Begin of frame
- [SLAVE]
  2 char. Modbus slave address (Selected on DIP-switch at Display Module)
- [FCT]
  2 char. function code
- [DATA]
  n X 2 char. data
- [CHECKSUM]
  2 char. checksum (LRC)

- [CR]
  1 char. CR
- [LF]
  1 char. LF (end of frame)

The following function codes (FCT) are accepted:

- 03H: Read n words at specific address
- 10H: Write n words at specific address

In response to the message frame, the slave (CMS) must answer with ap-propriate data. If this is not possible, a package with the most important bit in FCT set to 1 will be returned, followed by an exception code, where the following is supported:

- 01: Illegal function
- 02: Illegal data address
- 03: Illegal data value
- 06: BUSY. Message rejected

FCT = 03H: Read words

The master transmits an inquiry to the slave (CMS) to read a number (n) of datawords from a given address. The slave (CMS) replies with the required number (n) of datawords. To read a single register (n) must be set to 1. To read block type register (n) must be in the range 1...32.

Request (master):

[DATA] = [ADR][n]

[ADR]=Word stating the address in HEX.

[n]=Word stating the number of words to be read.

Answer (slave-CMS):

[DATA] = [bb][1. word][2. word]....[n. word]

[bb]=Byte, stating number of subsequent bytes.

[1. word]=1. dataword

[2. word]=2. dataword

[n. word]=No n. dataword

FCT = 10H: Write words

The master sends data to the slave (CMS/DM) starting from a particular address. The slave (CMS/DM) returns the written number of bytes, plus echoes the address.

Write data (master):

[DATA] = [ADR][n] [bb][1. word][2. word]....[n word]

[ADR] = Word that gives the address in HEX.
[n] = Word indicating number of words to be written.
[bb] = Byte that gives the number of bytes to follow (2*n)
Please note that 8bb9 is byte size!
[1. word]=1. dataword
[2. word]=2. dataword
[n. word]=No n. dataword

Answer (slave-CMS/DM):

[DATA] = [ADR][bb*2]

[ADR]= Word HEX that gives the address in HEX
[bb*2]=Number of words written.
[1. word]=1. dataword
[2. word]=2. dataword
[n. word]=No n. dataword

Data format

Example for data format

MW113	71	0	F	Signal fault ZS82 : Emergency stop (pushbutton)	SF=1	CMS	binary
		1	F	Signal fault ZS75 : Turning gear dis-engaged	SF=1	CMS	binary
		2	F	Signal fault SS84 : Remote stop	SF=1	CMS	binary
		3	F	Signal fault SS83 : Remote start	SF=1	CMS	binary
		4	F	Signal fault LAH28 : Lube oil level high	SF=1	CMS	binary
		5	F	Signal fault LAL28 : Lube oil level low	SF=1	CMS	binary
		6	F	Signal fault LAH42 : Fuel oil leakage high	SF=1	CMS	binary
		7	F	Signal fault ZS97 : Remote switch	SF=1	CMS	binary
		8	F	Signal fault LAH92 : OMD alarm	SF=1	CMS	binary
		9	F	Signal fault TAH 29-27 : CCMON alarm	SF=1	CMS	binary
		10	F	Signal fault : Remote reset	SF=1	CMS	binary
		11	F	Signal fault LAH98 : Alternator cool-ing water leakage alarm	SF=1	CMS	binary
		12	F	Signal fault : Emergency alternator mode	SF=1	CMS	binary
		13	F	Signal fault : Speed raise	SF=1	CMS	binary
		14	F	Signal fault : Speed lower	SF=1	CMS	binary
		15	F	Signal fault : Switch isochronous/ droop mode	SF=1	CMS	binary

Table 60: Extract from Modbus ASCII list

For this example we assume that the following alarms have been triggered:

- Signal fault SS83 : Remote start
- Signal fault LAL28 : Lube oil level low
- Signal fault ZS97 : Remote switch
- Signal fault LAH92 : OMD alarm
- Signal fault TAH 29-27 : CCMON alarm
- Signal fault : Emergency alternator mode
- Signal fault : Switch isochronous/droop mode

Bit	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Value	0	0	0	1	0	1	0	1	1	1	0	0	1	0	0	1

Table 61: Bit sample of MW113

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In Modbus ASCII these 16 bits are grouped in 4 groups each containing 4 bits and then translated from binary format to hexadecimal format (0 – 9, A – F)

	Binary	Hex
Bit 0 – 3	0001	1
Bit 4 – 7	0101	5
Bit 8 – 11	1100	C
Bit 12 – 15	1001	9

Table 62: Translation from binary to hexadecimal format

The next step these hexadecimal values are interpreted as ASCII-signs (extract from ASCII table)

Hexadecimal	ASCII
30	0
31	1
32	2
33	3
34	4
35	5
36	6
37	7
38	8
39	9
40	A
41	B
42	C
43	D
44	E
45	F

Table 63: Interpretation of hexadecimal values as ASCII

In this example the letter (ASCII letter) 1 will be translated hexadecimal value 31 and so on:

1 --> 31

5 --> 35

C --> 43

9 --> 39

When the ship alarm system recalls MW113, it receives the following data embedded in the Modbus message: 31 35 43 39

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	Interfaces to external systems
Alternator control	SaCoSone GenSet provides inputs for all temperature signals for the temperatures of the alternator bearings and alternator windings.
Power management	Hardwired interface for remote start/stop, speed setting, alternator circuit breaker trip etc.
Remote control	For remote control several digital inputs are available.
Ethernet interface	The ethernet interface at the Display Module can be used for the connection of SaCoSone EXPERT.
Serial interface	The serial RS485 interface is used for the connection to the CoCoS-EDS.
Multifunction Monitoring System	SaCoSone GenSet provides an interface to a Multifunction Monitoring System. The Multifunction Monitoring System is delivered as extra control cabinet.
External governor	SaCoSone GenSet provides a Power Output signal (release signal) to the actuator of the external mechanical or electronical governor. As long as the signal is closed, the speed governor is not releasing any fuel amount. For the actuator of the electronical mechanical governor an analogue 4 – 20 mA signal (to avoid black smoke during operation, e.g. during load up of the engine, a charge air limiter) and a digital input (healthy output/major alarm, which is closed, as long as there is no failure within the governor) is provided.
Trace heating	Trace heating has to be activated if engine is running with HFO.
Mandatory signals	According DNV-GL the opacity signal must be given. As Genset cannot provide the opacity singal, the customer must purchase the “Schaller OMD-Remote-Indicator”. This system is not provided/sold by MAN Energy Solutions.

3.6 Technical data

Control Unit

Design

- Cabinet mounted on engine
- MAN Energy Solutions standard color light grey (RAL7035)
- Weight: 75 kg
- Dimensions: 380 x 1,000 x 250 mm*
  * width x height x depth (including base)
- Degree of protection: IP54

Extension Unit (only for V-engines)

Design

- Unit mounted on engine
- MAN Energy Solutions standard color light grey (RAL7035)
- Weight: 11 kg
- Dimensions: 380 x 380 x 210 mm*
  * width x height x depth (including base)
- Degree of protection: IP54

Multifunction Monitoring System

Design

- Cabinet mounted off engine
- MAN Energy Solutions standard color light grey (RAL7035)
- Weight: 50 kg

- Dimensions: 380 x 380 x 210 mm*
  * width x height x depth (including base)
- Degree of protection: IP55

Environmental Conditions

Components on engine

- Ambient air temperature: +5 °C to +55 °C
- Relative humidity: < 96 %
- Vibrations: < 0.7 g

Multifunction Monitoring System

- Ambient air temperature: +5 °C to +55 °C
- Relative humidity: < 96 %
- Vibrations: < 0.7 g

3.7 Installation requirements

Location

The Control Unit is mounted on the engine.

Cabling

The cables for the connection of sensors and actuators which are not mounted on the engine are not included in the scope of MAN Energy Solutions supply.

For electrical noise protection, an electric ground connection is made from the modules to engine. The engine itself must have an electric ground connection to the hull of the ship.

All wiring to external systems should be carried out without conductor sleeves.

Installation works

During the installation period the yard has to protect all components against water, dust and fire. It is not allowed to do any welding near the SaCoSone components.

If it is inevitable to do welding near the components, the components and panels have to be protected against heat, electric current and electromagnetic influences. To guarantee protection against current, all of the cabling must be disconnected from the affected components.

The installation of additional components inside is not allowed.

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4 Specification for engine supplies

4.1 Explanatory notes for operating supplies – Diesel engines

Temperatures and pressures stated in section Planning data for emission standard IMO Tier II – Auxiliary GenSet, Page 62 must be considered.

4.1.1 Lube oil

Selection of the lube oil must be in accordance with the relevant sections.

The lube oil must always match the worst fuel oil quality.

A base number (BN) that is too low is critical due to the risk of corrosion.

A base number that is too high, could lead to deposits/sedimentation.

4.1.2 Fuel

The quality of the fuel specified in the relevant sections must be ensured.

Engine operation with DM-grade fuel according to ISO 8217, viscosity ≥ 2 cSt at 40 °C

A) Short-term operation, max. 72 hours

Engines that are normally operated with heavy fuel, can also be operated with DM-grade fuel for short periods.

Boundary conditions:

- DM-grade fuel in accordance with stated specifications and a viscosity of ≥ 2 cSt at 40 °C.
- MGO-operation maximum 72 hours within a two-week period (cumulative with distribution as required).
- Fuel oil cooler switched on and fuel oil temperature before engine ≤ 45 °C. In general, the minimum viscosity before engine of 1.9 cSt must not be undershoot!

B) Long-term (> 72 h) or continuous operation

For long-term (> 72 h) or continuous operation with DM-grade fuel special engine- and plant-related planning prerequisites must be set and special actions are necessary during operation.

Following features are required on engine side:

- Valve seat lubrication with possibility to be turned off and on manually.

Following features are required on plant side:

- Layout of fuel system to be adapted for low-viscosity fuel (capacity and design of fuel supply and booster pump).
- Cooler layout in fuel system for a fuel oil temperature before engine of ≤ 45 °C (min. permissible viscosity before engine 1.9 cSt).
- Nozzle cooling system with possibility to be turned off and on during engine operation.

Boundary conditions for operation:

- Fuel in accordance with MGO (DMA, DFA) and a viscosity of ≥ 2 cSt at 40°C.

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- Fuel oil cooler activated and fuel oil temperature before engine ≤ 45°C. In general the minimum viscosity before engine of 1.9 cSt must not be undershoot!
- Valve seat lubrication turned on.
- Nozzle cooling system switched off.

Continuous operation with MGO (DMA, DFA):

- Lube oil for diesel operation (BN10-BN16) has to be used.

Operation with heavy fuel oil of a sulphur content of < 1.5 %

Previous experience with stationary engines using heavy fuel of a low sulphur content does not show any restriction in the utilisation of these fuels, provided that the combustion properties are not affected negatively.

This may well change if in the future new methods are developed to produce low sulphur-containing heavy fuels.

If it is intended to run continuously with low sulphur-containing heavy fuel, lube oil with a low BN (BN30) has to be used. This is required, in spite of experiences that engines have been proven to be very robust with regard to the continuous usage of the standard lube oil (BN40) for this purpose.

Instruction for minimum admissible fuel temperature

- In general the minimum viscosity before engine of 1.9 cSt must not be undershoot.
- The fuel specific characteristic values “pour point” and “cold filter plugging point” have to be observed to ensure pumpability respectively filterability of the fuel oil.
- Fuel temperatures of approximately minus 10 °C and less have to be avoided, due to temporarily embrittlement of seals used in the engines fuel oil system and as a result their possibly loss of function.

Operation with FAME (Fatty acid methyl ester) additives 7% to 100% or with operation with synthetic fuels (DIN EN 15940)

Note the specification and special remarks in paragraph Synthetic fuels (DIN EN 15940) and paragraphs FAME (fatty acid methyl ester) additive of 0.5 to 7%, FAME (fatty acid methyl ester) additive up to max. 7% and FAME (fatty acid methyl ester) additive up to max. 100%.

4.1.3 Nozzle cooling

The quality of the engine cooling water required in relevant section has to be ensured.

Nozzle cooling system activation	
Kind of fuel	**Activated**
MGO (DMA, DFA)	No, see section Fuel, Page 119
MDO (DMB, DFB)	No
HFO	Yes

Table 64: Nozzle cooling system activation

4.1.4 Intake air

The quality of the intake air as stated in the relevant sections has to be ensured.

4.2 Specification of lubricating oil (SAE 40) for operation with DMA/DMB, DFA, DFB and biofuels

General

The specific output achieved by modern diesel engines combined with the use of fuels that satisfy the quality requirements more and more frequently increase the demands on the performance of the lubricating oil which must therefore be carefully selected.

Doped lubricating oils (HD oils) have a proven track record as lubricants for the drive, cylinder, turbocharger and also for cooling the piston. Doped lubricating oils contain additives that, amongst other things, ensure dirt absorption capability, cleaning of the engine and the neutralisation of acidic combustion products.

Only lubricating oils that have been approved by MAN Energy Solutions may be used. These are listed under https://corporate.man-es.com/lubrication.

Specifications

Doped lube oils (HD oils)

The base oil which has been mixed with additives (doped lube oil) must have the following properties:

Additives

The additives must be dissolved in the oil, and their composition must ensure that as little ash as possible remains after combustion.

The ash must be soft. If this prerequisite is not met, it is likely the rate of deposition in the combustion chamber will be higher, particularly at the outlet valves and at the turbocharger inlet housing. Hard additive ash promotes pitting of the valve seats, and causes valve burn-out, it also increases mechanical wear of the cylinder liners.

Additives must not increase the rate, at which the filter elements in the active or used condition are blocked.

Washing ability

The washing ability must be high enough to prevent the accumulation of tar and coke residue as a result of fuel combustion.

Dispersion capability

The selected dispersibility must be such that commercially-available lubricating oil cleaning systems can remove harmful contaminants from the oil used, i.e. the oil must possess good filtering properties and separability.

Neutralisation capability

The neutralization capacity (DIN ISO 3771) must be high enough to neutralize the acidic products formed during combustion. The reaction time of the additives must be adapted to the process in the combustion chamber.

Evaporation tendency

The evaporation tendency must be as low as possible as otherwise the oil consumption will be adversely affected.

Additional requirements

The lubricating oil must not contain viscosity index improver. Fresh oil must not contain water or other contaminants.

Lubricating oil selection

Engine	SAE class
16/24, 21/31, 27/38, 23/30, 28/32, 32/40, 32/44, 35/44DF, 40/54, 45/60, 48/60, 58/64, 51/60DF	40

Table 65: Viscosity (SAE class) of lubricating oils

Doped oil quality

Exclusively lube oils approved by MAN Energy Solutions must be used. Lube oils according to the military specification O-278 can be used if they are included in the current list of approved lube oils under https://corporate.man-es.com/lubrication.

The operating conditions of the engine and the quality of the fuel determine the additive fractions the lube oil should contain. If marine diesel oil with a high sulfur content of 1.0 up to 1.5 weight % is used, a base number (BN) of approx. 20 should be selected. However, the operating results that ensure the most efficient engine operation ultimately determine the additive content.

Cylinder lubricating oil

In engines with separate cylinder lubrication systems, the pistons and cylinder liners are supplied with lubricating oil via a separate lubricating oil pump. The quantity of lubricating oil is set at the factory according to the quality of the fuel to be used and the anticipated operating conditions.

Use a lubricating oil for the cylinder and lubricating circuit as specified above.

Oil for mechanical/hydraulic speed governors

Multigrade oil 5W40 should ideally be used in mechanical-hydraulic controllers with a separate oil sump, unless the technical documentation for the speed governor specifies otherwise. If this oil is not available when filling, 15W40 oil may be used instead in exceptional cases. In this case, it makes no difference whether synthetic or mineral-based oils are used.

The military specification applied for these oils is NATO O-236.

Experience with the drive engine L27/38 has shown that the operating temperature of the Woodward controller UG10MAS and corresponding actuator for UG723+ can reach temperatures higher than 93 °C. In these cases, we recommend using synthetic oil such as Castrol Alphasyn HG150.

Lube oil additives

It is not permissible to use any other additives in conjunction with the lube oil or to mix oils of different brands (oils from different manufacturers and different brands of the same manufacturer) since this can reduce the effectiveness of already existing additives, which have been carefully matched to one another and the base oil.

Selection of lube oils/warranty

Most oil manufacturers are in close, permanent contact with engine manufacturers and can therefore specify which oil from their own product line is approved by the engine manufacturer for the specific application. Irrespective of

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this information, the lube oil manufacturers are liable for the quality and properties of their products. If you have any questions, we would be more than happy to provide you with additional information.

Oil during operation

There are no prescribed oil change intervals for MAN Energy Solutions medium speed engines. The oil properties must be analysed monthly. The oil must therefore be suitable for the intended purpose and meet the defined limit values as per the table. If this is the case, the oil can continue to be used. See table Limit values for used lube oil.

The quality can only be maintained if it is purified via a separator or an otherwise suitable device.

The list of the currently approved lubricating oils is available at https://corporate.man-es.com/lubrication.

Tests

A monthly analysis of lube oil samples is mandatory for safe engine operation. We can analyse samples for customers in the MAN Energy Solutions PrimeServLab.

Note:
If operating fluids are improperly handled, this can pose a danger to health, safety and the environment. The relevant safety information by the supplier of operating fluids must be observed.

The list of the currently approved lubricating oils is available at https://corporate.man-es.com/lubrication.

Note:
MAN Energy Solutions does not assume liability for problems that occur when using these oils.

	Limit value	Procedure
Viscosity at 40 °C	110 – 220 mm²/s	ASTM D7042, ASTM D445, DIN EN 16896 or ISO 3104
Base number (BN)	at least 50 % of the fresh oil	ISO 3771
Flash point (PM)	min. 185 °C	ISO 2719
Water content	max. 0.20 % (max. 0.5 % for brief periods)	DIN 51777 or ASTM D6304
n-heptane insoluble	max. 1.5 %	DIN 51592 or IP 316
Metal content	dependent on engine type and operating conditions	–
Guide value only Fe Cr Cu Pb Sn Al	. max. 50 ppm max. 10 ppm max. 15 ppm max. 20 ppm max. 10 ppm max. 20 ppm	ASTM D5185 or DIN 51399-1
For operation with bio-fuels: proportion of bio-fuel	max. 12 %	FT-IR

Table 66: Limit values for used lubricating oil

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4.3 Specification of lubricating oil (SAE 40) for residual fuel operation (HFO)

General

The specific output achieved by modern diesel engines combined with the use of fuels that satisfy the quality requirements more and more frequently increase the demands on the performance of the lubricating oil which must therefore be carefully selected.

Medium alkalinity lubricating oils have a proven track record as lubricants for the moving parts and turbocharger cylinder and for cooling the pistons. Lubricating oils of medium alkalinity contain additives that, in addition to other properties, ensure a higher neutralization reserve than with fully compounded engine oils (HD oils).

International specifications do not exist for medium alkalinity lubricating oils. A test operation is therefore necessary for a corresponding long period in accordance with the manufacturer's instructions.

Only lubricating oils that have been approved by MAN Energy Solutions may be used.

The list of the currently approved lubricating oils is available at https://corporate.man-es.com/lubrication.

Specifications

Base oil

The base oil (doped lubricating oil = base oil + additives) must have a narrow distillation range and be refined using modern methods. If it contains paraffins, they must not impair the thermal stability or oxidation stability.

The base oil must comply with the limit values in the table below, particularly in terms of its resistance to ageing:

Properties/Characteristics	Unit	Test method	Limit value
Make-up	–	–	Ideally paraffin based
Low-temperature behaviour, still flowable	°C	ASTM D 2500	–15
Flash point (Cleveland)	°C	ASTM D 92	> 200
Ash content (oxidised ash)	Weight %	ASTM D 482	< 0.02
Coke residue (according to Conradson)	Weight %	ASTM D 189	< 0.50
Insoluble n-heptane	Weight %	ASTM D 4055 or DIN 51592	< 0.2
Evaporation loss	Weight %	-	< 2

Table 67: Target values for base oils

Medium alkalinity lubricating oil

The prepared oil (base oil with additives) must have the following properties:

Additives

The additives must be dissolved in oil and their composition must ensure that as little ash as possible is left over after combustion, even if the engine is provisionally operated with distillate fuel.

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The ash must be soft. If this prerequisite is not met, it is likely the rate of deposition in the combustion chamber will be higher, particularly at the outlet valves and at the turbocharger inlet housing. Hard additive ash promotes pitting of the valve seats, and causes valve burn-out, it also increases mechanical wear of the cylinder liners.

Additives must not increase the rate, at which the filter elements in the active or used condition are blocked.

Washing ability

The washing ability must be high enough to prevent the accumulation of tar and coke residue as a result of fuel combustion. The lubricating oil must not absorb the deposits produced by the fuel.

Dispersion capability

The selected dispersibility must be such that commercially-available lubricating oil cleaning systems can remove harmful contaminants from the oil used, i.e. the oil must possess good filtering properties and separability.

Neutralisation capability

The neutralization capacity (DIN ISO 3771) must be high enough to neutralize the acidic products formed during combustion. The reaction time of the additives must be adapted to the process in the combustion chamber.

For tips on selecting the base number, refer to the table entitled Base number to be used for various operating conditions, Page 125.

Evaporation tendency

The evaporation tendency must be as low as possible as otherwise the oil consumption will be adversely affected.

Additional requirements

The lubricating oil must not contain viscosity index improver. Fresh oil must not contain water or other contaminants.

Lube oil selection

Engine	SAE class
16/24, 21/31, 27/38, 23/30, 28/32, 32/40, 32/44, 35/44DF, 40/54, 45/60, 48/60, 58/64, 51/60DF	40

Table 68: Viscosity (SAE class) of lubricating oils

Neutralisation properties (BN)

Lubricating oils with medium alkalinity and a range of neutralization capabilities (BN) are available on the market. At the present level of knowledge, an interrelation between the expected operating conditions and the BN number can be established. However, the operating results are still the overriding factor in determining which BN number provides the most efficient engine operation.

Table Base number to be used for various operating conditions, Page 125 indicates the relationship between the anticipated operating conditions and the BN number.

Approx. BN of fresh oil (mg KOH/g oil)	Engines/operating conditions
20	Marine diesel oil (MDO) of a lower quality and with a high sulphur content or residual fuel with a sulphur content of less than 0.50%
30	generally 16/24, 21/31, 23/30, 28/32 under normal operating conditions. For engines 27/38, 32/40, 32/44CR, 32/44K, 40/54, 48/60 as well as 58/64 and 51/60DF operating with 100% HFO with a sulphur content < 1.5% only.
40	Under unfavourable operating conditions and where the corresponding requirements for the oil service life and cleaning capacity exist, 16/24, 21/31, 23/30 and 28/32. In general 27/38, 32/40, 32/44CR, 32/44K, 40/54, 48/60 as well as 58/64 and 51/60DF for operation with residual fuel, provided the sulphur content is over 1.5%.

Approx. BN of fresh oil (mg KOH/g oil)	Engines/operating conditions
50	32/40, 32/44CR, 32/44K, 40/54, 48/60 and 58/64, if the oil service life or engine cleanliness is insufficient with a BN number of 40 (high sulphur content of fuel, extremely low lubricating oil consumption).

Table 69: Base number to be used for various operating conditions

Operation with low-sulphur fuel

To comply with the emissions regulations, the sulphur content of fuels used nowadays varies. Fuels with low-sulphur content must be used in environmentally-sensitive areas (e.g. SECA). Fuels with higher sulphur content may be used outside SECA zones. In this case, the BN number of the lube oil selected must satisfy the requirements for operation using fuel with high-sulphur content. A lube oil with low BN number may only be selected if fuel with a low sulphur content is used exclusively during operation.
However, the practical results demonstrate that the most efficient engine operation is the factor ultimately determining the permitted additive content.

Cylinder lubricating oil

In engines with separate cylinder lubrication systems, the pistons and cylinder liners are supplied with lubricating oil via a separate lubricating oil pump. The quantity of lubricating oil is set at the factory according to the quality of the fuel to be used and the anticipated operating conditions.

Use a lubricating oil for the cylinder and lubricating circuit as specified above.

Oil for mechanical/hydraulic speed governors

Multigrade oil 5W40 should ideally be used in mechanical-hydraulic controllers with a separate oil sump, unless the technical documentation for the speed governor specifies otherwise. If this oil is not available when filling, 15W40 oil may be used instead in exceptional cases. In this case, it makes no difference whether synthetic or mineral-based oils are used.

The military specification applied for these oils is NATO O-236.

Experience with the drive engine L27/38 has shown that the operating temperature of the Woodward controller UG10MAS and corresponding actuator for UG723+ can reach temperatures higher than 93 °C. In these cases, we recommend using synthetic oil such as Castrol Alphasyn HG150.

Hydraulic oil for engines with VVT controller

Hydraulic oil HLP 46 (DIN 51502) or ISO VG 46 (DIN 51519) must be used according to the specification DIN 51524-2. Mixing hydraulic oils from different manufacturers is not permitted.

Lube oil additives

It is not permissible to use any other additives in conjunction with the lube oil or to mix oils of different brands (oils from different manufacturers and different brands of the same manufacturer) since this can reduce the effectiveness of already existing additives, which have been carefully matched to one another and the base oil.

Oil during operation

There are no prescribed oil change intervals for MAN Energy Solutions medium speed engines. The oil properties must be analysed monthly. The oil must therefore be suitable for the intended purpose and meet the defined limit values as per the table. If this is the case, the oil can continue to be used. See table Limit values for used lube oil.

The quality can only be maintained if it is purified via a separator or an otherwise suitable device.

Temporary operation with distillate fuel

Due to current and future emissions regulations, the use of residual fuel in designated areas is not possible. Instead of this, a low-sulphur diesel fuel must be used in these areas.

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If the duration of the operation with low-sulphur diesel fuel is limited to less than 1,000 h, a lubricating oil that is intended for residual fuel operation (BN 30–55 mg KOH/g) can continue to be used during this time.

If the temporary operation with low-sulphur diesel fuel lasts longer than 1,000 h and is then operated with residual fuel again after that, a lubricating oil with a BN of 20 must be used. If the BN 20 lubricating oil is from the same manufacturer as the lubricating oil used in the HFO operation with high BN (40 or 50), no oil change is required for the switch. It is sufficient to use BN 20 oil to top up the used lubricating oil.

If you want to use residual fuel again, you must switch back in good time to a lubricating oil with a higher BN (30–55). If the lubricating oil with the higher BN is from the same manufacturer as the BN 20, the switch can also be made without changing oil. To do this, approx. 2 weeks before operating again with residual fuel, use the lubricating oil with the higher BN (30–55) to top up the consumed lubricating oil.

	Limit value	**Procedure**
Viscosity at 40 °C	110–220 mm²/s	ASTM D7042, ASTM D445, DIN EN 16896 or ISO 3104
Base number (BN)	at least 50 % of fresh oil	ISO 3771
Flash point (PM)	at least 185 °C	ISO 2719
Water content	max. 0.2 % (max. 0.5 % for brief periods)	DIN 51777 or ASTM D6304
n-heptane insoluble	max. 1.5 %	DIN 51592 or IP 316
Metal content	dependent on engine type and operating conditions	–
Guide value only Fe Cr Cu Pb Sn Al	 max. 50 ppm max. 10 ppm max. 15 ppm max. 20 ppm max. 10 ppm max. 20 ppm	ASTM D5185 or DIN 51399-1

Table 70: Limit values for used lube oil

Tests

A monthly analysis of lube oil samples is mandatory for safe engine operation. We can analyse samples for customers in the MAN Energy Solutions PrimeServLab.

Note:
MAN Energy Solutions does not assume liability for problems that occur when using these oils.

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4.4 Diesel fuel (DMA, DFA) specification

General information

Diesel fuel is a middle distillate refined from crude oil. It is also referred to as: gas oil, marine gas oil (MGO), DMA, DFA, diesel oil. It should not contain any residue from crude oil refining.

Selection of suitable fuel

Unsuitable or adulterated fuel generally results in a shortening of the service life of engine parts/components, damage to these and to catastrophic engine failure. It is therefore important to select the fuel with care in terms of its suitability for the engine and the intended application. Through its combustion, the fuel influences the emissions behaviour of the engine.

Specifications and approvals (DMA)

The fuel quality varies regionally and depends on climatic conditions. All requirements from ISO 8217:2024 apply

The following values must be maintained at the engine inlet:

Property	Unit		Limit value[1]	Standard[2]
Appearance	-	-	Clear, bright and free from visible contamination	visually
Kinematic viscosity at 40° C[3]	mm^2/s	Max. Min.	6.0 2.0	ISO 3104, ASTM D7042, ASTM D445, DIN EN 16896
Density at 15°C	kg/m^3	Max. Min.	890.0 820.0	ISO 3675, ISO 12185
Water content	% (m/m)	Max.	0.02	DIN 51777, DIN EN 12937, ASTM D6304
Cetane number		Min.	40	EN ISO 5165, IP541, EN 15195, EN 16715, EN 17155
Sulphur content[4]	% (m/m)	Max.	1.0	ISO 8754, ISO 14596, ASTM D4294, DIN 51400-10
Flashpoint[5]	°C	Min.	60.0	ISO 2719
Acid number	mg KOH/g	Max.	0.5	ASTM D664
Carbon residue[6]	% (m/m)	Max.	0.30	ISO 10370
Ash content	% (m/m)	Max.	0.010	ISO 6245
Lubricity (WSD)	µm	Max.	520	ISO 12156-1, ASTM D6079
Corrosion effect on copper	Class	Max.	1	EN ISO 2160
Hydrogen sulphide	mg/kg	Max.	2.0	IP 570
FAME[7]-content	% (V/V)	Max.	0.5	ASTM D7963, IP 579, DIN EN 14078
Oxidation stability	g/m^3	Min.	25	EN ISO 12205
Sediment content[8]	% (m/m)	Max.	0.01	ISO 10307-1
CFPP	°C		10°C below the lowest temperature in the fuel system	DIN EN 116, IP 309, IP 612
Pour Point[9] winter grade	°C	Max.	-6	ISO 3016
Pour Point[9] summer grade	°C	Max.	0	ISO 3016

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Property	Unit		Limit value[1)]	Standard[2)]
Na, K, Ca, P, Cu, Zn, Si	mg/kg	Max.	free from	DIN EN 16476

Table 71: Requirements for diesel fuel (DMA)

Remarks:

1) The fuel must be suitable for the intended application. It must not contain any substance in a concentration that causes additional air pollution, is harmful for personnel, jeopardises ship safety and/or has an adverse effect on machine performance. The fuel must be free from non-ferrous metals according to DIN EN 16476. The fuel must not contain any waste oil.

2) Always refer to the currently applicable edition.

3) Specific requirements of the injection system must be taken into account

4) Independent of the maximum permissible sulphur content, local laws and regulations must be adhered to

5) Additional requirements (e.g. SOLAS) must be observed. Applicable laws must be adhered to.

6) Determined at 10 % distillation residue

7) The FAME must either be in accordance with EN 14214 or with ASTM D6751 as well as with increased oxidation stability of at least 8 hours (EN 15751). For information on using a fuel with more than 0.5 % FAME, see paragraph Diesel fuel (DMA, DFA) specification, Page 130

8) If the sample is not clear and bright, complete sedimentation through hot filtration and the determination of water content is required

9) 10°C below the lowest temperature in the fuel system

The following fuels are approved for use if the fuel complies with table Requirements for diesel fuel (DMA), Page 128:

- Classes ISO F-DMA & DMZ according to ISO 8217:2024
- Diesel fuel as per EN 590:2022 with additional requirement regarding flashpoint > 60 °C in SOLAS regulated areas
- Diesel fuel no. 2-D as per ASTM D975-21 with additional requirement regarding flashpoint > 60 °C in SOLAS regulated areas

Please submit enquiries to MAN Energy Solutions for all fuels which do not meet the abovementioned standards.

Viscosity

In order to ensure sufficient lubrication, a minimum level of viscosity must be ensured at the fuel injection pump. The specified maximum temperature required to maintain a viscosity of more than 1.9 mm^2/s upstream of the fuel injection pump depends on the fuel viscosity. The temperature of the fuel upstream of the fuel injection pump must not exceed 45 °C in any case. The lubricity requirement for the fuel upstream of the engine is a maximum of 520 µm WSD in each case according to ISO 12156-1.

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Military fuel specification

The fuels of type F-75 or F-76 as per NATO STANAG 1385 can be used if they fully comply with the standards or limit values listed in the table Requirements of the diesel fuel (DMA) pursuant to ISO 8217:2024 and the minimum permissible viscosity upstream of the injection pump with the corresponding temperature is adhered to.

Synthetic fuels (DIN EN 15940)

When using synthetic fuels according to DIN EN 15940 with a density of less than 820 kg/m^2 at 15 °C, prior consultation with MAN Energy Solutions is required.

Synthetic fuels such as HVO, BTL, CTL, GTL according to DIN EN 15940, can be produced from renewable electrical energy and CO_2 or from the same basic material such as FAME fuels (vegetable oil, cooking oil, animal fat) but in a completely different procedure. Synthetic fuels are produced by means of hydrogen treatment, with a fuel being generated which has a very similar chemical structure to high-performance diesel fuel and consists of paraffinic hydrocarbons. In contrast to fossil diesel fuel, synthetic fuel barely contains any aromatic components, which causes very good combustion properties.

Although the energy content (per mass unit) is higher in comparison with fossil diesel fuel, the volumetric energy content is lower due to the lower density (typically approx. 780 kg/m^3 at 15°C). This may lead to deviations in the specified engine output, operating behaviour, load application and emissions as well as deviations in the specific fuel consumption.

The lubricity of synthetic fuels is relatively low. In order to meet fuel specifications (requirements on diesel fuel) and guarantee sufficient lubricity of the fuel, the fuel supplier needs to add a lubricity additive or FAME.

The lower flashpoint limit is too low at a minimum of 55°C. The additional requirement relating to flashpoint min. 60 °C in SOLAS regulated areas must be observed.

We strongly advise against using a mixture of HFO and synthetic fuel (in accordance with EN 15940). The reason is that the HFO contains asphaltenes, which are held in solution by the aromatics contained in HFO. Synthetic fuel is purely paraffinic (does not contain any aromatics) and therefore cannot hold asphaltenes in solution. This means that when synthetic fuel is added to HFO, these asphaltenes precipitate, deposits form or fuel filters become clogged or, in the worst case scenario, the injection system fails.

FAME (fatty acid methyl ester) additive of 0.5 to 100% (DFA)

The following values must be maintained at the engine inlet:

Property	Unit		Limit value[1)]	Standard[2)]
Appearance	-	-	Clear, bright and free from visible contamination	visually
Kinematic viscosity at 40° C[3)]	mm^2/s	Max. Min.	6.0 2.0	ISO 3104, ASTM D7042, ASTM D445, DIN EN 16896
Density at 15°C	kg/m^3	Max. Min.	890.0 820.0	ISO 3675, ISO 12185

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Property	Unit		Limit value[1]	Standard[2]
Water content	% (m/m)	Max.	0.02	DIN 51777, DIN EN 12937, ASTM D6304
Cetane number		Min.	40	EN ISO 5165, IP541, EN 15195, EN 16715, EN 17155
Sulphur content[4]	% (m/m)	Max.	1.0	ISO 8754, ISO 14596, ASTM D4294, DIN 51400-10
Flashpoint[5]	°C	Min.	60.0	ISO 2719
Acid number	mg KOH/g	Max.	0.5	ASTM D664
Carbon residue[6]	% (m/m)	Max.	0.30	ISO 10370
Ash content	% (m/m)	Max.	0.010	ISO 6245
Lubricity (WSD)	µm	Max.	520	ISO 12156-1, ASTM D6079
Corrosion effect on copper	Class	Max.	1	EN ISO 2160
Hydrogen sulphide	mg/kg	Max.	2.0	IP 570
FAME[7]-content	% (V/V)	Min.	0.5	ASTM D7963, IP 579, DIN EN 14078
Oxidation stability	h	Min.	8	EN 15751
Sediment content[8]	% (m/m)	Max.	0.01	ISO 10307-1
CFPP	°C		10°C below the lowest temperature in the fuel system	DIN EN 116, IP 309, IP 612)
Pour Point[9] winter grade	°C	Max.	-6	ISO 3016
Pour Point[9] summer grade	°C	Max.	0	ISO 3016
Na, K, Ca, P, Cu, Zn, Si	mg/kg	Max.	free from	DIN EN 16476

Table 72: Requirements for diesel fuel (DMA)

Remarks:

[1] The fuel must be suitable for the intended application. It must not contain any substance in a concentration that causes additional air pollution, is harmful for personnel, jeopardises ship safety and/or has an adverse effect on machine performance. The fuel must be free from non-ferrous metals according to DIN EN 16476. The fuel must not contain any waste oil.

[2] Always refer to the currently applicable edition.

[3] Specific requirements of the injection system must be taken into account

[4] Independent of the maximum permissible sulphur content, local laws and regulations must be adhered to

[5] Additional requirements (e.g. SOLAS) must be observed. Applicable laws must be adhered to.

[6] Determined at 10% distillation residue

[7] The FAME must either be in accordance with EN 14214 or with ASTM D6751 as well as with increased oxidation stability of at least 8 hours (EN 15751).

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8) If the sample is not clear and bright, complete sedimentation through hot filtration and the determination of water content is required

9) 10°C below the lowest temperature in the fuel system

When using DFA (FAME according to EN 14214 or ASTM D6751* or their mixtures with DMA), prior consultation with MAN Energy Solutions is required. In addition, the following should be observed:

- Due to the typically lower calorific value or energy content of FAME fuels and their mixtures with DMA (DFA), it may result in deviations to the specified engine output, operating behaviour, load application, specific fuel consumption and emissions.
- The sealing materials used must be suitable for DFA. NBR seals are not suitable and must not be used.
- DFA tends to attract water. The risk of microbial growth is therefore increased. For this reason, the water content needs to be kept as low as possible. The maximum water content must not be exceeded. MAN Energy Solutions recommends draining water from the fuel tank every day.
- Long standstill periods (e.g. emergency power units) must be avoided due to microbial growth. To prevent damage, it is recommendable to only operate applications with fuel which is free of FAME (DMA).
- The fuel reacts to air and this may lead to microbial growth. Ensure that the atmospheric oxygen ventilation is kept to a minimum. A nitrogen buffer is ideally installed in the fuel tank.
- The entire fuel system must be purged with fuel which is free of FAME (DMA) prior to longer standstill periods.
- If DFA is to be used with other fuels and mixing cannot be avoided, contact your fuel supplier to ensure the compatibility of these fuels.
- It is recommended that wherever possible a heat tracing system is installed in the fuel supply system, in order to prevent deposits or blockage of the lines.
- As DFA have a higher evaporation temperature than standard DMA qualities, these are enriched in lubricating oil. Regular analysis of all the lubricating oil is highly recommended. The lubricating oil needs to be replaced if a FAME content of 12% is reached.
- DFA may cause a layer to form, such a phenomenon leads to increased consumption of lubricating oil. If such an increase in lubricating oil consumption values is detected, please contact your MAN PrimeServ department.
- Fuels may cause harmful reactions with metals such as zinc or copper. We highly recommend getting in contact with your tank and heating oil system supplier.
- After switching to DFA, pay attention to the delta pressure indicators/alarms of the filters, as the residues dissolved by DFA can clog the filters.
- In any case, it is the responsibility of the operating company to adhere to the legal requirements (e.g. SOLAS) and agree on these with the relevant authorities.

* as well as with increased oxidation stability of at least 8 hours (EN 15751)

Cold suitability

The cold suitability of the fuel is determined by the climatic requirements at the place of installation. It is the responsibility of the operating company to choose a fuel with sufficient cold suitability.

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The cold suitability of a fuel may be determined and assessed using the following standards:

- Limit of filterability (CFPP) as per EN 116
- Pour point as per ISO 3016
- Cloud point as per EN 23015

To be able to draw a reliable conclusion, it is recommended to perform all three stated procedures.

Analyses

Analysis of fuel samples is of great importance for safe engine operation. We can analyse fuel for customers at the MAN Energy Solutions PrimeServLab laboratory.

To guarantee the safety of the crew and to obtain a representative sample, sampling must take place in accordance with valid MAN Energy Solutions operating instructions.

4.5 Marine diesel oil (DMB, DFB) specification

General information

Marine diesel oil as a heavy distillate is available for marine applications only. Another name is: Marine diesel oil (MDO) It is made from crude oil and may contain synthetic components (e.g. BtL, CtL, GtL and HVO). The fuel is treated the same as residual fuel in the supply chain. This means that it is possible for the fuel to be blended with high-viscosity residual fuel residue, e.g. in a bunker vessel, and it might therefore contain residue from crude oil processing. This can affect the properties of the fuel.

Selection of suitable fuel

Unsuitable or adulterated fuel generally results in a shortening of the service life of engine parts/components, damage to these and to catastrophic engine failure. It is therefore important to select the fuel with care in terms of its suitability for the engine and the intended application. Through its combustion, the fuel influences the emissions behaviour of the engine.

Specifications and approvals

The fuel quality varies regionally and depends on climatic conditions. All requirements from ISO 8217:2024 apply.

The following values must be maintained at the engine inlet:

Property	Unit		Limit value[1]	Standard[2]
Appearance[3]	–	–	Free from contamination	visually
Kinematic viscosity at 40 °C[4]	mm^2/s	Max. Min.	11.0 2.0	ISO 3104, ASTM D7042, ASTM D445, DIN EN 16896
Density at 15°C	kg/m^3	Max. Min.	900.0 820.0	ISO 3675, ISO 12185
Water content	% (m/m)	Max.	0.02	DIN 51777, DIN EN 12937, ASTM D6304

Property	Unit		Limit value[1]	Standard[2]
Cetane number		Min.	35	EN ISO 5165, IP541, EN 15195, EN 16715, EN 17155
Sulphur content[5]	% (m/m)	Max.	1.50	EN ISO 8754, EN ISO 14596, ASTM D4294, DIN 51400-10
Flashpoint[6]	°C	Min.	60.0	ISO 2719
Acid number	mg KOH/g	Max.	0.5	ASTM D664
Carbon residue	% (m/m)	Max.	0.30	ISO 10370
Ash content	% (m/m)	Max.	0.010	ISO 6245
Lubricity (WSD)	µm	Max.	520	ISO 12156-1, ASTM D6079
Corrosion effect on copper	Class	Max.	1	ISO 2160
Hydrogen sulphide	mg/kg	Max.	2.0	IP 570
FAME[7]-content DMB	% (V/V)	Max.	0.5	ASTM D7963, IP 579, DIN EN 14078
FAME[7]-content DFB	% (V/V)	Max.	7.0	ASTM D7963, IP 579, DIN EN 14078
Oxidation stability DMB	g/m^3	Min.	25	ISO 10307-1
Oxidation stability[8] DFB	h	Min.	8.0	ISO 10370
Na, K, Ca, P, Cu, Zn, Si	mg/kg	Max.	free from	DIN EN 16476

Table 73: Requirements for diesel fuel (DMB/DFB)

Remarks:

[1] The fuel must be suitable for the intended application. It must not contain any substance in a concentration that causes additional air pollution, is harmful for personnel, jeopardises ship safety and/or has an adverse effect on machine performance. The fuel must be free from non-ferrous metals according to DIN EN 16476. The fuel must not contain any waste oil.

[2] Always in relation to the currently applicable edition.

[3] Only possible with clear samples. If the sample is not clear or contains visible contamination, the check must be completed mandatorily for the entire sediment.

[4] Specific requirements of the injection system must be taken into account

[5] Local laws and regulations must be observed independently of the maximum possible sulphur content.

[6] Additional requirements (e.g. SOLAS) must be observed. Applicable laws must be adhered to.

[7] The FAME must either be in accordance with EN 14214 or with ASTM D6751 as well as with increased oxidation stability of at least 8 hours (EN 15751).

[8] If there is more than 2% (V/V) FAME, an analysis as per EN15751 must additionally be carried out.

Approved fuels

The following fuels are approved for use if the fuel complies with table Requirements for diesel fuel (DMB/DFB), Page 133:

- Class ISO F-DMB according to ISO 8217:2024

- Class ISO F-DFB according to ISO 8217:2024 with additional requirement regarding oxidation stability

Please submit enquiries to MAN Energy Solutions for all fuels which do not meet the abovementioned standards.

Viscosity

In order to ensure sufficient lubrication, a minimum level of viscosity must be ensured at the fuel injection pump. The specified maximum temperature required to maintain a viscosity of more than 1.9 mm^2/s upstream of the fuel injection pump depends on the fuel viscosity. The temperature of the fuel upstream of the fuel injection pump must not exceed 45 °C in any case. The lubricity requirement for the fuel upstream of the engine is a maximum of 520 µm WSD in each case according to ISO 12156-1.

Contamination

We recommend installing a separator upstream of the fuel filter. Separation temperature 40–50°C. Most solid particles (sand, corrosion and catalytic converter fragments) and water can thus be removed and the cleaning intervals for the filter elements can be significantly extended.

FAME (Fatty acid methyl ester) additive up to max. 7 %

Using fuels with biofuel admixture based on fatty acid methyl ester (FAME) of max. 7 vol. % is possible.
The FAME must comply with the requirements stipulated in EN 14214 or ASTM D6751.*

It is the responsibility of the operating company that the fuel always complies with all requirements in table Requirements for diesel fuel (DMB/DFB), Page 133.

Applications with longer standstill periods (e.g. emergency power units) can be affected by fuel ageing. To prevent damage, it is recommendable to only operate these applications with fuel which is free of FAME or to purge the entire fuel system with fuel which is free of biodiesel prior to longer standstill periods.

FAME blends typically contain a higher water content. This higher water content must be reduced by appropriate means in order to adhere to the maximum permissible water content at the engine inlet.

In any case, it is the responsibility of the operating company to adhere to the legal requirements (e.g. SOLAS).

MAN Energy Solutions is not liable for damage caused to the engine or subsequent damage resulting from this caused by FAME fuel blends.

* as well as with increased oxidation stability of at least 8 hours (EN 15751)

Cold suitability

The cold suitability of the fuel is determined by the climatic requirements at the place of installation. It is the responsibility of the operating company to choose a fuel with sufficient cold suitability.

The cold suitability of a fuel may be determined and assessed using the following standards:

- Limit of filterability (CFPP) as per EN 116
- Pour point as per ISO 3016

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- Cloud point as per EN 23015

To be able to draw a reliable conclusion, it is recommended to perform all three stated procedures.

Analyses

Analysis of fuel samples is of great importance for safe engine operation. We can analyse fuel for customers at the MAN Energy Solutions PrimeServLab laboratory.

To guarantee the safety of the crew and to obtain a representative sample, sampling must take place in accordance with valid MAN Energy Solutions operating instructions.

4.6 Residual fuel (HFO) specification

General information

Four-stroke diesel engines from MAN Energy Solutions can be powered with any residual fuel recovered from crude oil that fulfils the requirements specified in the table Heavy fuel oil requirements, Page 136, provided that the engine and the fuel management system are designed accordingly. It is also referred to as: Residual fuels (RM), FAME Residual fuels (RF). In order to ensure a favourable ratio between fuel costs, spare parts and also repair and servicing expenditure, we recommend observing the following points.

Selection of suitable fuel

Unsuitable or adulterated fuel generally results in a shortening of the service life of engine parts/components, damage to these and to catastrophic engine failure. It is therefore important to select the fuel with care in terms of its suitability for the engine and the intended application. Through its combustion, the fuel influences the emissions behaviour of the engine.

Specifications and approvals

The fuel quality varies regionally and depends on climatic conditions. All requirements from ISO 8217:2024 apply

The following values must be maintained at the engine inlet:

Property	Unit		Limit value[1]	Standard[2]
Kin. Viscosity at 50 °C[3]	mm/s	Max. Min.	700 1.9	EN ISO 3104, ASTM D7042, ASTM D445, DIN EN 16896
Kin. Viscosity at 100 °C[3]	mm/s	Max.	55	EN ISO 3104, ASTM D7042, ASTM D445, DIN EN 16896
Density at 15 °C	kg/m^3	Max.	1010	ISO 3675, ISO 12185
Water content[4]	% (m/m)	Max.	0.20	DIN 51777, ASTM D6304, DIN ISO 3733
Sulphur content[5]	% (m/m)	Max.	5.0	ISO 8754, ISO 14596, ASTM D4294
Flashpoint[6]	°C	Min.	60.0	ISO 2719
Acid number	mg KOH/g	Max.	2.5	ASTM D664
Carbon residue (CCR)	% (m/m)	Max.	20.0	EN ISO 10370

Property	Unit		Limit value[1]	Standard[2]
Ash content	% (m/m)	Max.	0.150	ISO 6245
Hydrogen sulphide	mg/kg	Max.	2.0	IP 570
Total sediment (aged)	% (m/m)	Max.	0.10	ISO 10307-2
Asphaltene content	% (m/m)	Max.	2/3 x CCR	Factory standard, DIN 51595
Fatty acid methyl ester content[7]	% (m/m)		Report	ASTM D7963, IP 631, DIN EN 14078, DIN EN 14103
Pour point[8]	°C	Max.	30	ISO 3016
Vanadium	mg/kg	Max.	450	IP 501, IP 470, ISO 14597, DIN EN 15944 DIN 51790-6
Sodium	mg/kg	Max.	100 and 1/3 x vanadium	IP 501, IP 470
Aluminium and silicone[9]	mg/kg	Max.	15	IP 501, IP 470, DIN ISO 10478
Calcium Zinc	mg/kg mg/kg	Max. Max.	30 15	IP 501, IP 470
Calcium Phosphorus	mg/kg mg/kg	Max. Max.	30 15	IP 501, IP 470, IP 500
CCAI[10]		Max.	870	

Table 74: Heavy fuel oil requirements

Remarks:

[1] Engine inlet requirement: Additional parameters defined for ISO 8217. The entire ISO 8217:2024 document is mandatory. The fuel mixture at the engine inlet must be homogeneous. The fuel mixture is homogeneous if the p-value according to ASTM D7060 is at min. 1.20. Other processes (e.g. ASTM D7112 or ASTM D7157) can also be used to check the homogeneity of the fuel mixture. Furthermore, the fuel must be fit for use and must not contain substances in a concentration that contributes to further contamination of the air and/or may impair the safety of personnel or the performance of the machine.

[2] Always reference the latest edition.

[3] If FAME is present in the HFO (RF), the max. viscosity is limited to 500 mm^2/s at 50 °C.
Specific requirements of the injection system must be taken into account.

[4] According to ISO 8217:2024, the bunker product (before purification) may contain max. 0.50 % water.

[5] Local laws and regulations must be observed independently of the maximum possible sulphur content.

[6] Additional requirements (e.g. SOLAS) must be observed. Applicable laws must be adhered to.

[7] When using RF (FAME according to EN 14214 or ASTM D6751* or their mixtures with HFO), prior consultation with MAN Energy Solutions is required.
The FAME must either be in accordance with EN 14214 or with ASTM D6751 as well as with increased oxidation stability of at least 8 hours (EN 15751). For additional information, see FAME mixtures, Page 144.

[8] The pour point must be suitably selected by the operator in accordance with the design of the fuel system and on the basis of the requirements at the place of use.

[9] The bunker product (prior to purification) may contain max. 60 mg/kg Al and Si.

[10] This method is only applicable to 'straight run' residual oils. The increasing complexity of refinery processes means that the CCAI method does not correctly reproduce the ignition behaviour for all residual oils. A test device (fuel combustion analyser; FCA) based on the constant volume combustion method measures the ignition delay to determine the ignition quality of a fuel and this measurement is converted into the cetane number (ECN: Estimated Cetane Number). It was discovered that residual fuels with a low ECN number cause malfunctions and can even lead to engine damage. An ECN > 20 can be considered acceptable.

Please submit enquiries to MAN Energy Solutions for all fuels which do not meet the abovementioned standards.

Residual fuel (HFO)

Origin/refinery process

The quality of the residual fuel depends to a large extent on the quality of the crude oil and the refining process used. For this reason, residual fuels of the same viscosity can have significantly different properties depending on the bunker spaces. Residual fuel can consist of a mixture of residual oil, distillates and FAME. Residual oils and distillates generally originate from modern refining processes, such as CatCracker or Visbreaker. These processes can have an adverse affect on the stability of the fuel and on the ignition and combustion properties. These factors also have a considerable effect on the preparation of the residual fuel and the operating results of the engine.

The engine operator is responsible for selecting the corresponding residual fuels.

Important

The fuel properties in the Residue Fuel Requirements table Heavy fuel oil requirements, Page 136, even if they meet the requirements mentioned there, may not be sufficient to determine the ignition and combustion properties and stability of the fuel. This means that the operational performance of the engine may depend on properties that are not defined in the specification. This particularly applies to the oil property that causes formation of deposits in the combustion chamber, injection system, gas pipes and exhaust system. A number of fuels have a tendency towards incompatibility with lubricating oil which leads to deposits being formed in the fuel injection pump that can cause a blockage of the pumps. It may therefore be necessary to exclude specific fuels that could cause problems.

Blends

The addition of engine oils (old lubricating oil, ULO – used lubricating oil) and additives that are not manufactured from mineral oils, (coal-tar oil, for example), and residual products of chemical or other processes such as solvents (polymers or chemical waste) is not permitted. Some of the reasons for this are as follows: abrasive and corrosive effects, unfavourable combustion characteristics, poor compatibility with mineral oils and, last but not least, adverse effects on the environment. The order for the fuel must expressly state what is not permitted as the fuel specifications that generally apply do not include this limitation.

If engine oils (old lubricating oil, ULO – used lubricating oil) are added to fuel, this poses a particular danger as the additives in the lubricating oil act as emulsifiers that cause dirt, water and catfines to be transported as fine suspension. They therefore prevent the necessary cleaning of the fuel. In our experience (and this has also been the experience of other manufacturers), this can severely damage the engine and turbocharger components.

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The addition of chemical waste products (solvents, for example) to the fuel is prohibited for environmental protection reasons according to the resolution of the IMO Marine Environment Protection Committee passed on 1st January 1992.

Leak oil collector

Leak oil collectors that act as receptacles for leak oil, and also return and overflow pipes in the lube oil system, must not be connected to the fuel tank. Leak oil lines should be emptied into sludge tanks.

Please submit enquiries to MAN Energy Solutions for all fuels which do not meet the abovementioned standards.

Additional information

The following information will clarify the correlation between the quality of the residual fuel, fuel preparation, engine operation and the operating results.

Viscosity/injection viscosity

Residual fuels with higher viscosity can be of lower quality. The maximum permissible viscosity depends on the available pre-heating equipment and the capacity (flow rate) of the separator.

The prescribed injection viscosity of 12-14 mm^2/s and the corresponding fuel temperature upstream of the engine must be complied with. Only in this way can a suitable atomisation and mixture formation be ensured and therefore low-residue combustion. This also prevents mechanical overload of the injection system at the same time. The prescribed injection viscosity and/or the required fuel oil temperature upstream of the engine can be found in the viscosity temperature diagram.

Heavy fuel oil preparation

Fault-free engine operation depends to a considerable extent on the care with which the heavy fuel oil was prepared. Particular attention should be paid to ensuring that inorganic foreign matter with a strongly abrasive effect (catalyst particles, rust, sand) are effectively separated. It has been shown in practice that wear as a result of abrasion in the engine increases considerably if the aluminium and silicon content is higher than 15 mg/kg.

Viscosity and density have an influence on the cleaning effect. This must be taken into account when designing and installing the cleaning system.

Vanadium/Sodium

If the vanadium/sodium ratio is unfavourable, the melting point of the ash may fall in the operating area of the exhaust valve which can lead to high-temperature corrosion. Most of the water and water-soluble sodium compounds it contains can be removed by pre-treating the heavy fuel oil in the settling tank and in the separators.

The risk of high-temperature corrosion is low if the sodium content is one third of the vanadium content or less. It must also be ensured that sodium does not enter the engine in the form of seawater in the intake air.

If the sodium content is higher than 100 mg/kg, this is likely to result in a higher quantity of salt deposits in the combustion chamber and exhaust-gas system. This will impair the function of the engine (including the suction function of the turbocharger).

Under certain conditions, high-temperature corrosion can be prevented using a fuel additive that increases the melting point of heavy fuel oil ash (see also Residual fuel (HFO) specification, Page 143).

Ash

Fuel ash consists for the greater part of vanadium oxide and nickel sulphate (see above chapter for more information). Heavy fuel oil containing a high proportion of ash in the form of foreign matter, e.g. sand, corrosion compounds and catalyst particles, accelerates the mechanical wear in the engine. Catalyst particles produced as a result of the catalytic cracking process may be present in the heavy fuel oil. In most cases, these catalyst particles are aluminium silicates causing a high degree of wear in the injection system and the engine.

Flashpoint

National and international regulations for transport and storage involving the use of fuel must be considered in regard to the flashpoint. In general, a flashpoint of above 60 °C is specified for fuels of diesel engines.

Low-temperature performance

The pour point is the temperature at which the fuel can no longer flow (but can be pumped). Since many residual fuels with low viscosity have a pour point above 0°C, the bunker facility must also be pre-heated. The entire fuel system must be designed in such a way that the residual fuel can be preheated to around 10°C above the pour point.

Pump properties

If the viscosity of the fuel is higher than 700 mm²/s (cSt), or the temperature is not at least 10°C above the pour point, pump problems will occur. For more information, also refer to section Low-temperature behaviour.

Combustion properties

If the proportion of asphaltene is more than two thirds of the coke residue (Conradson), combustion may be delayed which in turn may increase the formation of combustion residues, leading to such as deposits on and in the injection nozzles, large amounts of smoke, low output, increased fuel consumption and a rapid rise in ignition pressure as well as combustion close to the cylinder wall (thermal overloading of lubricating oil film). If the ratio of asphaltene to coke residues reaches the limit 0.66, and if the asphaltene content exceeds 8%, the risk of deposits forming in the combustion chamber and injection system is higher. These problems can also occur when using unstable heavy fuel oil, or if incompatible heavy fuel oil are blended. This would lead to an increased separation of asphalt (see section Compatibility, Page 143).

Ignition quality

Nowadays, to achieve the prescribed reference viscosity, cracking-process products are used as the low viscosity ingredients of residual fuels although the ignition characteristics of these may also be poor. The cetane number of these compounds should be > 35. If the proportion of aromatic hydrocarbons is high (more than 35%), this also adversely affects the ignition quality.

The ignition delay in residual fuels with poor ignition characteristics is longer, the combustion is also delayed which can lead to thermal overloading of the oil film at the cylinder liner and also high cylinder pressures. The ignition delay and accompanying increase in pressure in the cylinder are also influenced by the end temperature and compression pressure, i.e. by the compression ratio, the charge-air pressure and charge-air temperature.

The disadvantages of using fuels with poor ignition characteristics can be limited by pre-heating the charge air in partial load operation and reducing the output for a limited period. However, a more effective solution is a high compression ratio and operational adjustment of the injection system to the ignition characteristics of the fuel used, as is the case with MAN Energy Solutions.

The ignition quality is one of the most important properties of the fuel. This value appears as CCAI in ISO 8217. This method is only applicable to ‘straight run’ residual oils. The increasing complexity of refinery processes has the effect that the CCAI method does not correctly reflect the ignition behaviour for all residual oils.

A test instrument based on the Fuel Combustion Analyser (FCA) method has been developed, which is used in some fuel testing laboratories (FCA according to IP 541).
The ignition quality of a fuel is determined as the ignition delay in the instru-

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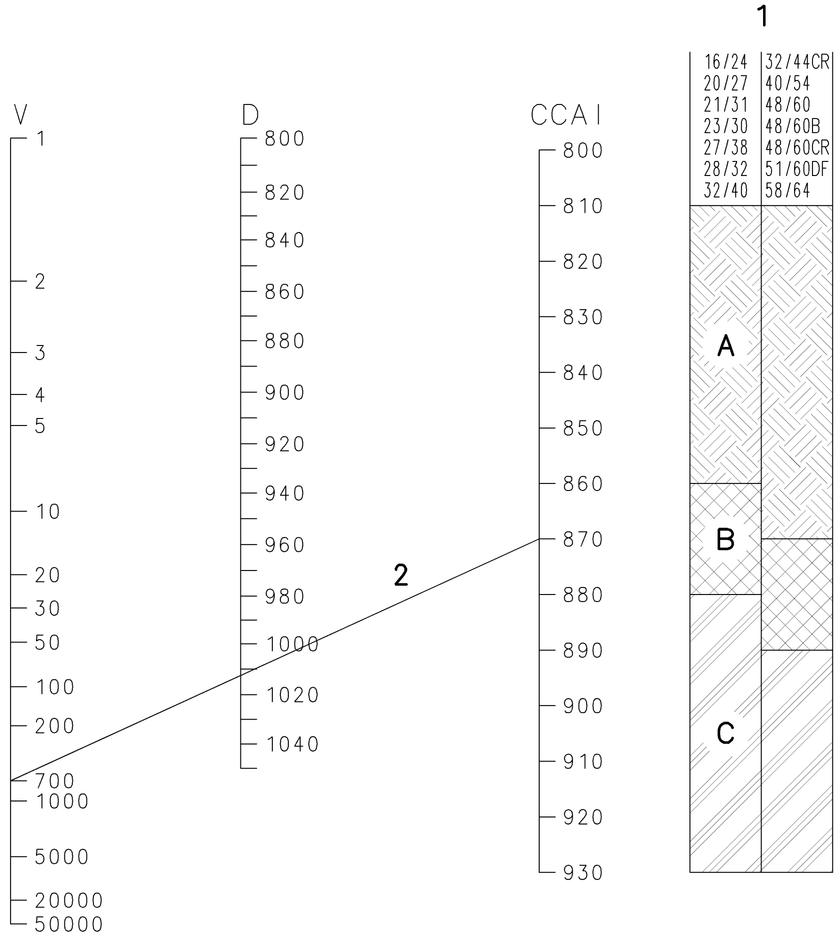
ment and converted into an instrument-dependent cetane number (ECN: Estimated Cetane Number). It has been determined that residual fuels with a low ECN number cause operating problems and may even lead to damage to the engine. An ECN > 20 can be considered acceptable.

As the liquid components of the residual fuel have a decisive influence on the ignition quality, and flow properties determine the combustion quality, the system operator is responsible for obtaining a fuel that is suitable for the diesel engine. Also see illustration entitled Nomogram for determining the CCAI – assigning the CCAI ranges to engine types, Page 142.



V	Viscosity in mm²/s (cSt) at 50°C	A	Normal operating conditions
D	Density [in kg/m³] at 15°C	B	The ignition characteristics can be poor and require an adjustment to the engine or the operating conditions.
CCAI	Calculated Carbon Aromaticity Index	C	Any problems identified can even lead to engine damage after a short operating period.
1	Engine type	2	The CCAI is calculated from the density and viscosity of the heavy fuel oil.

The CCAI can be calculated with the help of the following formula:

$$CCAI = D - 141 \log\log (V+0.85) - 81$$

Figure 46: Nomogram for determining the CCAI and assigning the CCAI ranges to engine types

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Sulphuric acid corrosion

The engine should be operated at the coolant temperatures prescribed in the operating handbook for the relevant load. If the temperature of the components that are exposed to acidic combustion products is below the acid dew point, acid corrosion can no longer be effectively prevented, even if alkaline lube oil is used.

Stability

The fuel must be a homogeneous mixture when entering the engine. Precipitation of any fuel components is not permissible! Experience has shown that stability decreases with continued storage and the given conditions. It is hence of great interest to the operator that the fuel has the maximum possible stability reserve so that it can provide a homogeneous fuel mixture at all times when entering the engine (see table Heavy fuel oil requirements).

Compatibility

The supplier must guarantee that the heavy fuel oil is homogeneous and remains stable even after the usual storage time. If different bunker oils are mixed, this may lead to separation that is connected with sludge build-up in the fuel system and where large quantities of sludge can be deposited in the separator, clog up the filter, prevent atomisation and lead to residue-rich combustion.

Cases like this can be traced back to incompatibility or instability. The fuel storage tanks should therefore be drained as much as possible before they can be bunkered again, in order to avoid incompatibilities.

Contamination

The fuel must not contain any substances that can lead to instability or deposits, otherwise engine operation may be impaired or engine damage may occur. With the help of an analysis according to ASTM D7845 (GC-MS), such substances can be partially detected and analysed. The fuel should be free of all substances listed in ASTM D7845, or their concentration should be below the limit of quantification noted therein. Proportions above the limit of quantification of all substances listed in ASTM D7845 can cause problems in engine operation. The combination of different substances could also cause problems with the engine even in a small amount.

Mixing residue fuels

If residual fuel for the main engine is blended with distillate fuel (e.g. DMA, FAME) or other residual fuels, to obtain the required quality, it is essential that the components are compatible (see section Compatibility, Page 143). The compatibility of the resulting mixture must be tested over the entire mixing range. Reduced long-term stability due to consumption of the stability reserve can be a result. If a mixture of different fuels is planned or unavoidable, the stability reserve of the fuel must be sufficient to ensure that non-homogeneous fuels are not produced when blending.

Mixture with synthetic fuel

We strongly advise against using a mixture of HFO and synthetic fuel (in accordance with EN 15940). The reason is that the HFO contains asphaltenes, which are held in solution by the aromatics contained in HFO. Synthetic fuel is purely paraffinic (does not contain any aromatics) and therefore cannot hold asphaltenes in solution. This means that when synthetic fuel is added to HFO, these aromatics precipitate, deposits form or fuel filters become clogged or, in the worst case scenario, the injection system fails.

Additives for heavy fuel oil

MAN Energy Solutions- Engines can also be economically operated without additives. It is up to the customer to decide whether or not the use of additives is beneficial. The supplier of the additive must guarantee that the engine operation will not be impaired by using the product.

As a rule, the use of fuel additives during the warranty period must be avoided.

If the lubrication oil quality and the engine cooling system fulfil the specified requirements, the BN values stated in section 010.005 Engine – Operating Instructions 010.000.023-11 are sufficient.

heavy fuel oil with low sulphur content

From the perspective of an engine manufacturer, there is no lower threshold for the sulphur content of heavy fuel oil. We have not identified any issues that can be traced to the sulphur content with the low-sulphur heavy fuel oils that are currently commercially available.

If the engine is not constantly operated with low-sulphur heavy fuel oil, the lubricating oil must be selected accordingly for the highest sulphur content of the utilised fuels.

FAME mixtures

FAME admixtures (RF20 to RF500)

When using RF (FAME according to EN 14214 or ASTM D6751* and their mixtures with HFO), prior consultation with MAN Energy Solutions is required. In addition, the following should be observed:

- The fuel mixture at the engine inlet must be homogeneous. The fuel mixture is homogeneous if the p-value according to ASTM D7060 is at least 1.20. Other processes (e.g. ASTM D7112 or ASTM D7157) can also be used to check the homogeneity of the fuel mixture. Furthermore, the fuel must be fit for use and must not contain substances in a concentration that contribute to further contamination of the air and/or may impair the safety of personnel or the performance of the machine.
- If RF is to be used with other fuels and blending cannot be avoided, contact your fuel supplier to ensure the compatibility of these fuels.
- After switching to RF, pay attention to the delta pressure indicators/alarms of the filters, as they can become clogged by residues dissolved by RF.
- Heating is installed and active in the fuel supply system to prevent deposits or blockages to the pipes.
- The temperature resistance of the fuel must be guaranteed up to 150°C.
- Storage and leakage handling of FAME fuels, FAME mixtures with residual fuels and distillate fuels must be separated from each other in order to avoid incompatibility reactions due to the mixing of larger amounts of different fuels.
- Due to the typically lower calorific value or energy content of RF, it may result in deviations to the specified engine output, operating behaviour, load application, specific fuel consumption and emissions.
- Fuels may cause harmful reactions with metals such as zinc or copper. We highly recommend getting in contact with your tank and heating oil system supplier.
- The sealing materials used must be suitable for RF. NBR seals are not suitable and must not be used.
- RF reacts to air and this may lead to microbial growth. Ensure that the atmospheric oxygen ventilation is kept to a minimum. A nitrogen buffer is ideally installed in the fuel tank.
- RF tends to attract water. This increases the risk of microbial growth. Correctly adjust the separator to the new fuel type.
- If free water appears in the fuel tanks, it is important to drain this water immediately.
- Long standstill periods (e.g. emergency power units) must be avoided due to microbial growth. To prevent damage, it is recommendable to only operate applications with fuel which is free of FAME.

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- The entire fuel system must be purged with fuel which is free of FAME prior to longer standstill periods.
- Since FAME has a higher evaporation temperature, it accumulates in the lubricating oil. Regular analysis of all the lubricating oil is highly recommended. The lubricating oil needs to be replaced if a FAME content of 12% is reached.
- RF may cause a layer to form, such a phenomenon leads to increased consumption of lubricating oil. If such an increase in lubricating oil consumption values is detected, please contact your MAN PrimeServ department.

In any case, it is the responsibility of the operating company to adhere to the legal requirements (e.g. SOLAS) and agree on these with the relevant authorities.

* as well as with increased oxidation stability of at least 8 hours (EN 15751).

Cold suitability

The cold suitability of the fuel is determined by the climatic requirements at the place of installation. It is the responsibility of the operating company to choose a fuel with sufficient cold suitability.

The cold suitability of a fuel may be determined and assessed using the following standard:

- Pour point as per ISO 3016

Analyses

To ensure sufficient cleaning of the fuel via the separator, perform regular functional check by sampling up- and downstream of the separator.

Analysis of fuel samples is of great importance for safe engine operation. We can analyse fuel for customers at the MAN Energy Solutions PrimeServLab laboratory.

To guarantee the safety of the crew and to obtain a representative sample, sampling must take place in accordance with valid MAN Energy Solutions operating instructions.

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4.7 Viscosity-temperature diagram (VT diagram)

Explanations of viscosity-temperature diagram

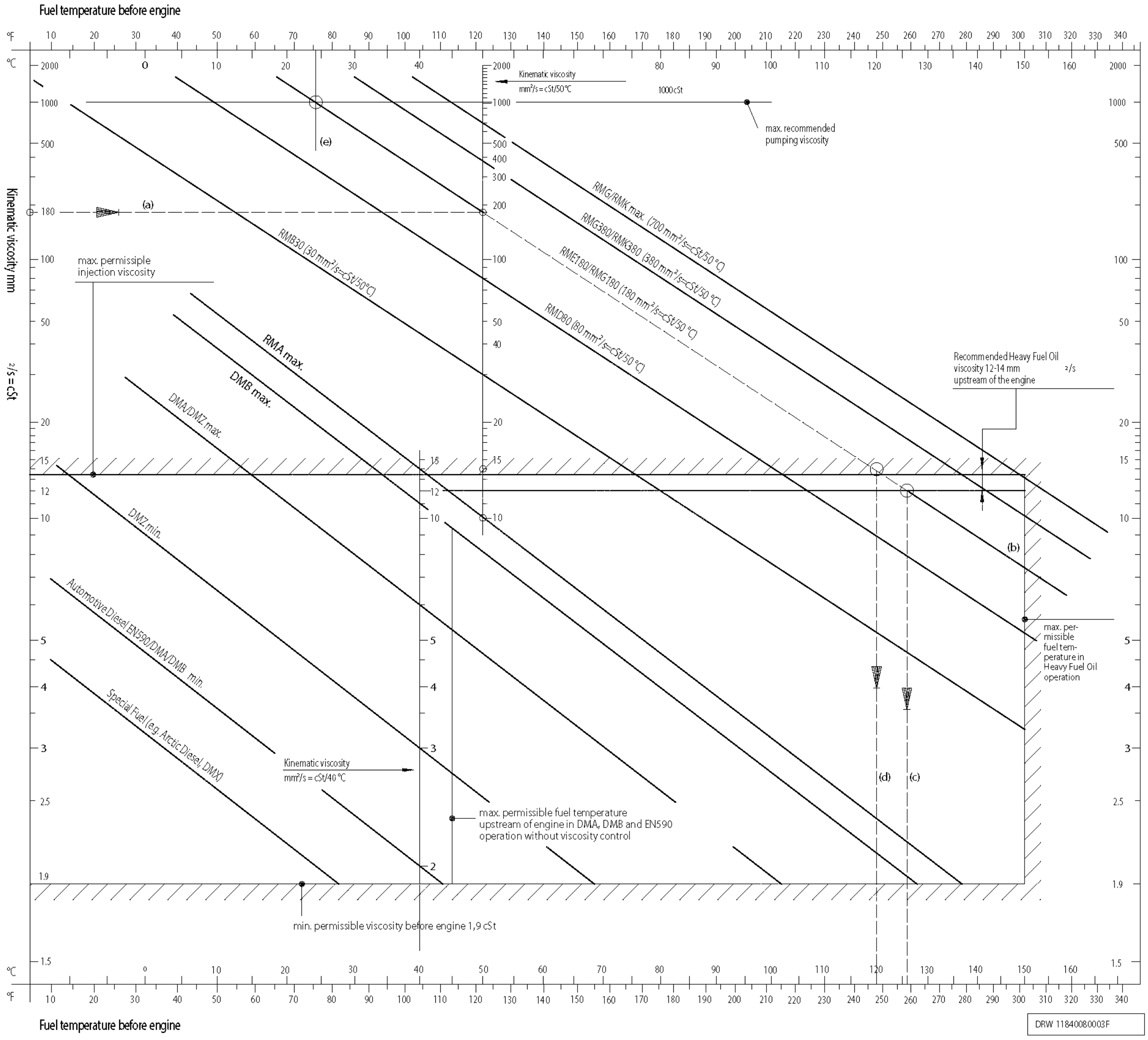

Figure 47: Viscosity-temperature diagram (VT diagram)

In the diagram, the fuel temperatures are shown on the horizontal axis and the viscosity is shown on the vertical axis.

The diagonal lines correspond to viscosity-temperature curves of fuels with different reference viscosities. The vertical viscosity axis in mm²/s (cSt) applies for 40, 50 or 100 °C.

Determining the viscosity-temperature curve and the required preheating temperature

Example: Heavy fuel oil with 180 mm²/s at 50 °C

Prescribed injection viscosity in mm²/s	Required fuel temperature at the engine inlet[1)] in °C
≥ 12	126 (line c)
≤ 14	119 (line d)

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Prescribed injection viscosity in mm²/s	Required fuel temperature at the engine inlet[1] in °C
[1] For these figures, the temperature drop from the last pre-heating device to the fuel injection pump is not taken into account.	

Table 75: Determining the viscosity temperature trend and the required pre-heating temperature

A heavy fuel oil with a viscosity of 180 mm^2/s at 50 °C can reach a viscosity of 1,000 mm^2/s at 24 °C (line e) – this is the maximum permissible viscosity of fuel that the pump can deliver.

A heavy fuel oil discharge temperature of 152 °C is reached when using a recent state-of-the-art preheating device with 8 bar saturated steam. At higher temperatures there is a risk of residues forming in the preheating system – this leads to a reduction in heating output and thermal overloading of the heavy fuel oil. Asphalt is also formed in this case, i.e. quality deterioration.

The heavy fuel oil lines between the outlet of the last preheating system and the injection valve must be suitably insulated to limit the maximum drop in temperature to 4 °C. This is the only way to achieve the necessary injection viscosity of 14 mm^2/s for heavy fuel oils with a reference viscosity of 700 mm^2/s at 50 °C (the maximum viscosity as defined in the international specifications such as ISO CIMAC or British Standard). If heavy fuel oil with a low reference viscosity is used, the injection viscosity should ideally be 12 mm^2/s in order to achieve more effective atomisation to reduce the combustion residue.

The delivery pump must be designed for heavy fuel oil with a viscosity of up to 1,000 mm^2/s. The pour point also determines whether the pump is capable of transporting the heavy fuel oil. The bunker facility must be designed so as to allow the heavy fuel oil to be heated to roughly 10 °C above the pour point.

Note:

The viscosity of gas oil or diesel oil (marine diesel oil) upstream of the engine must be at least 1.9 mm^2/s. If the viscosity is too low, this may cause seizing of the pump plunger or nozzle needle valves as a result of insufficient lubrication.

This can be avoided by monitoring the temperature of the fuel. Although the maximum permissible temperature depends on the viscosity of the fuel, it must never exceed the following values:

- 45 °C at the most with MGO (DMA) and MDO (DMB)

A fuel cooler must therefore be installed.

If the viscosity of the fuel is < 2 cSt at 40 °C, consult the technical service of MAN Energy Solutions in Augsburg.

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4.8 Specification of engine coolant

Preliminary remarks

An engine coolant is composed as follows: water for heat removal and coolant additive for corrosion protection.

Like the fuel and lubricating oil, the engine coolant must be carefully selected, handled and checked. If this is not the case, corrosion, erosion and cavitation may occur at the walls of the cooling system in contact with water and deposits may form. Deposits obstruct the transfer of heat and can cause thermal overloading of the cooled parts. The system must be treated with an anticorrosive agent before bringing it into operation for the first time. The concentrations prescribed by the engine manufacturer must always be observed during subsequent operation. The above especially applies if a chemical additive is added.

Requirements

Limit values

The properties of untreated coolant must correspond to the following limit values:

Properties/Characteristic	Properties	Unit
Water type	Distillate or fresh water, free of foreign matter.	–
Total hardness	max. 10	dGH[1]
pH value	6.5 – 8	–
Chloride ion content	max. 50	mg/l[2]

Table 76: Properties of coolant that must be complied with

[1] 1 dGH (German hardness) ≙ 10 mg CaO in 1 litre of water ≙ 17.8 mg $CaCO_3$/l

≙ 0.357 mval/l ≙ 0.178 mmol/l

[2] 1 mg/l ≙ 1 ppm

Testing equipment

The MAN Energy Solutions water testing equipment incorporates devices that determine the water properties directly related to the above. The manufacturers of anticorrosive agents also supply user-friendly testing equipment.

For information on monitoring cooling water, see section Coolant inspecting, Page 152.

Additional information

Distillate

If distilled water (from a fresh water generator, for example) or fully desalinated water (from ion exchange or reverse osmosis) is available, this should ideally be used as the engine coolant. These waters are free of lime and salts, which means that deposits that could interfere with the transfer of heat to the coolant, and therefore also reduce the cooling effect, cannot form. However, these waters are more corrosive than normal hard water as the thin film of lime scale that would otherwise provide temporary corrosion protection does not form on the walls. This is why distilled water must be handled particularly carefully and the concentration of the additive must be regularly checked.

Hardness

The total hardness of the water is the combined effect of the temporary and permanent hardness. The proportion of calcium and magnesium salts is of overriding importance. The temporary hardness is determined by the carbonate content of the calcium and magnesium salts. The permanent hardness is determined by the amount of remaining calcium and magnesium salts (sulphates). The temporary (carbonate) hardness is the critical factor that determines the extent of limescale deposit in the cooling system.

Water with a total hardness of > 10°dGH must be mixed with distilled water or softened. Subsequent hardening of extremely soft water is only necessary to prevent foaming if emulsifiable slushing oils are used.

Damage to the cooling water system

Corrosion

Corrosion is an electrochemical process that can widely be avoided by selecting the correct water quality and by carefully handling the water in the engine cooling system.

Flow cavitation

Flow cavitation can occur in areas in which high flow velocities and high turbulence is present. If the steam pressure is reached, steam bubbles form and subsequently collapse in high pressure zones which causes the destruction of materials in constricted areas.

Erosion

Erosion is a mechanical process accompanied by material abrasion and the destruction of protective films by solids that have been drawn in, particularly in areas with high flow velocities or strong turbulence.

Stress corrosion cracking

Stress corrosion cracking is a failure mechanism that occurs as a result of simultaneous dynamic and corrosive stress. This may lead to cracking and rapid crack propagation in water-cooled, mechanically-loaded components if the coolant has not been treated correctly.

Treatment of engine coolant

Formation of a protective film

The purpose of treating the engine coolant using anticorrosive agents is to produce a continuous protective film on the walls of cooling surfaces and therefore prevent the damage referred to above. In order for an anticorrosive agent to be 100 % effective, it is extremely important that untreated water satisfies the requirements in the paragraph Requirements, Page 148.

Additives for coolants

Only the additives approved by MAN Energy Solutions and listed in the tables under the paragraph entitled Permissible cooling water additives may be used.

In closed circuits only

Additives may only be used in closed circuits where no significant consumption occurs, apart from leaks or evaporation losses. Observe the applicable environmental protection regulations when disposing of coolant containing additives. For more information, consult the additive supplier.

Chemical additives

Sodium nitrite and sodium borate based additives etc. have a proven track record. Galvanised iron pipes or zinc sacrificial anodes must not be used in cooling systems. This corrosion protection is not required due to the prescribed coolant treatment and electrochemical potential reversal that may occur due to the coolant temperatures which are usual in engines nowadays. If necessary, the pipes must be deplated.

Slushing oil

For MAN Energy Solutions engines, it is not permissible to use corrosion protection oils in the cooling water circuit.

Antifreeze agents

If temperatures below the freezing point of water in the engine cannot be excluded, an antifreeze agent that also prevents corrosion must be added to the cooling system or corresponding parts. Otherwise, the entire system must be heated.

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Sufficient corrosion protection can be provided by adding the products listed in the table entitled Antifreeze agent with slushing properties (Military specification: Federal Armed Forces Sy-7025), while observing the prescribed minimum concentration. This concentration prevents freezing at temperatures down to –22 °C and provides sufficient corrosion protection. However, the quantity of antifreeze agent actually required always depends on the lowest temperatures that are to be expected at the place of use.

Antifreeze agents are generally based on ethylene glycol. A suitable chemical anticorrosive agent must be added if the concentration of the antifreeze agent prescribed by the user for a specific application does not provide an appropriate level of corrosion protection, or if the concentration of antifreeze agent used is lower due to less stringent frost protection requirements and does not provide an appropriate level of corrosion protection. Considering that the antifreeze agents listed in the table Antifreeze agents with slushing properties also contain corrosion inhibitors and their compatibility with other anticorrosive agents is generally not given, only pure glycol may be used as antifreeze agent in such cases.

Simultaneous use of anticorrosive agent from the table Nitrite-free chemical additives together with glycol is not permitted, because monitoring the anticorrosive agent concentration in this mixture is no more possible.

Antifreeze agents reduce the capacity of the coolant to absorb heat. In some cases the cooling effect of the coolant may not be sufficient for certain operation conditions. The MAN Energy Solutions standard design is not based on using antifreeze agents. In case it is intended to use anti-freeze agent, consult MAN Energy Solutions beforehand.

Before an antifreeze agent is used, the cooling system must be thoroughly cleaned.

If the coolant contains emulsifiable slushing oil, antifreeze agent may not be added as otherwise the emulsion would break up and oil sludge would form in the cooling system.

Biocides

If you cannot avoid using a biocide because the coolant has been contaminated by bacteria, observe the following steps:

- You must ensure that the biocide to be used is suitable for the specific application.
- The biocide must be compatible with the sealing materials used in the coolant system and must not react with these.
- The biocide and its decomposition products must not contain corrosion-promoting components. Biocides whose decomposition products contain chloride or sulphate ions are not permitted.
- Biocides that cause foaming of coolant are not permitted.

Prerequisite for effective use of an anticorrosive agent

Clean cooling system

As contamination significantly reduces the effectiveness of the additive, the tanks, pipes, coolers and other parts outside the engine must be free of rust and other deposits before the engine is started up for the first time and after repairs of the pipe system.

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The entire system must therefore be cleaned with the engine switched off using a suitable cleaning agent (see section Cooling water system cleaning, Page 154).

Loose solid matter in particular must be removed by flushing the system thoroughly as otherwise erosion may occur in locations where the flow velocity is high.

The cleaning agents must not corrode the seals and materials of the cooling system. In most cases, the supplier of the coolant additive will be able to carry out this work and, if this is not possible, will at least be able to provide suitable products to do this. If this work is carried out by the engine operator, he should use the services of a specialist supplier of cleaning agents. The cooling system must be flushed thoroughly after cleaning. Once this has been done, the engine coolant must be immediately treated with anticorrosive agent. Once the engine has been brought back into operation, the cleaned system must be checked for leaks.

Regular checks of the coolant condition and coolant system

Treated coolant may become contaminated when the engine is in operation, which causes the additive to loose some of its effectiveness. It is therefore advisable to regularly check the cooling system and the coolant condition. To determine leakages in the lube oil system, it is advisable to carry out regular checks of water in the expansion tank. Indications of oil content in water are, e.g. discoloration or a visible oil film on the surface of the water sample.

The additive concentration must be checked at least once a week using the test kits specified by the manufacturer. The results must be documented.

Note:

The chemical additive concentrations shall not be less than the minimum concentrations indicated in the table Nitrite-containing chemical additives.

Excessively low concentrations lead to corrosion and must be avoided. Concentrations that are somewhat higher do not cause damage. Concentrations that are more than twice as high as recommended should be avoided.

Every 2 to 6 months, a coolant sample must be sent to an independent laboratory or to the engine manufacturer for an integrated analysis.

If chemical additives or antifreeze agents are used, coolant should be replaced after 3 years at the latest.

If there is a high concentration of solids (rust) in the system, the water must be completely replaced and entire system carefully cleaned.

Deposits in the cooling system may be caused by fluids that enter the coolant or by emulsion break-up, corrosion in the system, and limescale deposits if the water is very hard. If the concentration of chloride ions has increased, this generally indicates that seawater has entered the system. The maximum specified concentration of 50 mg chloride ions per kg must not be exceeded as otherwise the risk of corrosion is too high. If exhaust gas enters the coolant, this can lead to a sudden drop in the pH value or to an increase in the sulphate content.

Water losses must be compensated by filling with untreated water that meets the quality requirements specified in the paragraph Requirements, Page 148. The concentration of anticorrosive agent must subsequently be checked and adjusted if necessary.

Subsequent checks of the coolant are especially required if the coolant had to be drained off in order to carry out repairs or maintenance.

Protective measures

Anticorrosive agents contain chemical compounds that can pose a risk to health or the environment if incorrectly used. Comply with the directions in the manufacturer's material safety data sheets.

Avoid prolonged direct contact with the skin. Wash hands thoroughly after use. If larger quantities spray and/or soak into clothing, remove and wash clothing before wearing it again.

If chemicals come into contact with your eyes, rinse them immediately with plenty of water and seek medical advice.

Anticorrosive agents are generally harmful to the water cycle. Observe the relevant statutory requirements for disposal.

Auxiliary engines

If the same cooling water system used in a MAN Energy Solutions two-stroke main engine is used in a marine engine of type 16/24, 21/ 31, 23/30H, 27/38 or 28/32H, the cooling water recommendations for the main engine must be observed.

Analyses

MAN Energy Solutions can analyse antifreeze agent for their customers in the chemical laboratory PrimeServLab. A 0.25 l sample is required for the test.

Permitted coolant additives

A list of currently approved coolant additives and their concentration can be found at https://corporate.man-es.com/lubrication.

4.9 Coolant inspecting

Summary

Acquire and check typical values of the operating media to prevent or limit damage.

The freshwater used to fill the cooling water circuits must satisfy the specifications. The cooling water in the system must be checked regularly in accordance with the maintenance schedule.

The following work/steps is/are necessary:

Acquisition of typical values for the operating fluid, evaluation of the operating fluid and checking the concentration of the anticorrosive agent.

Tools/equipment required

Equipment for checking the fresh water quality

The following equipment can be used:

- The MAN Energy Solutions water testing kit, or similar testing kit, with all necessary instruments and chemicals that determine the water hardness, pH value and chloride content (obtainable from MAN Energy Solutions or Mar-Tec Marine, Hamburg).

Equipment for testing the concentration of additives

When using chemical additives:

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- Testing equipment in accordance with the supplier's recommendations. Testing kits from the supplier also include equipment that can be used to determine the fresh water quality.

Testing the typical values of water

Short specification

Typical value/property	Water for filling and refilling (without additive)	Circulating water (with additive)
Water type	Fresh water, free of foreign matter	Treated coolant
Total hardness	≤ 10 dGH[1)]	≤ 10 dGH[1)]
pH value	6.5 – 8 at 20 °C	≥ 7.5 at 20 °C
Chloride ion content	≤ 50 mg/l	≤ 50 mg/l[2)]

Table 77: Quality specifications for coolants (short version)

[1)] dGH	German hardness
1 dGH	= 10 mg/l CaO = 17.8 mg/l $CaCO_3$ = 0.178 mmol/L
[2)] 1 mg/l	= 1 ppm

Testing the concentration of rust inhibitors

Short specification

Anticorrosive agent	Concentration
Chemical additives	According to the quality specification, see section Specification of engine coolant, Page 147.
Anti-freeze agents	

Table 78: Concentration of coolant additives

Testing the concentration of chemical additives

The concentration should be tested every week, and/or according to the maintenance schedule, using the testing instruments, reagents and instructions of the relevant supplier.

Chemical anti-corrosion agents can only provide effective protection if the concentration is precisely maintained. Respectively, the concentrations recommended by MAN Energy Solutions (quality specifications in section Specification of engine coolant, Page 147) must be maintained under all circumstances. These recommended concentrations may deviate from those specified by the manufacturer.

Testing the concentration of anti-freeze agents

The concentration must be checked in accordance with the manufacturer's instructions or the test can be outsourced to a suitable laboratory. If in doubt, consult MAN Energy Solutions.

Regular water samplings

Small quantities of lube oil in coolant can be found by visual check during regular water sampling from the expansion tank.

Testing

Regular analysis of coolant is very important for safe engine operation. We can analyse fuel for customers at MAN Energy Solutions laboratory PrimeServLab.

4.10 Cooling water system cleaning

Summary

Remove contamination/residue from operating fluid systems, ensure/re-establish operating reliability.

Cooling water systems containing deposits or contamination prevent effective cooling of parts. Contamination and deposits must be regularly eliminated.

This comprises the following:

Cleaning the system and, if required removal of limescale deposits, flushing the system.

Cleaning

The coolant system must be checked for contamination at regular intervals. Cleaning is required if the degree of contamination is high. This work should ideally be carried out by a specialist who can provide the right cleaning agents for the type of deposits and materials in the cooling circuit. The cleaning should only be carried out by the engine operator if this cannot be done by a specialist.

Oil sludge

Oil sludge from lubricating oil that has entered the cooling system or a high concentration of anticorrosive agents can be removed by flushing the system with fresh water to which some cleaning agent has been added. Suitable cleaning agents are listed alphabetically in the table entitled Cleaning agents for removing oil sludge., Page 154 Products by other manufacturers can be used providing they have similar properties. The manufacturer's instructions for use must be strictly observed.

Manufacturer	Product	Concentration	Duration of cleaning procedure/temperature
Drew	HDE - 777	4 – 5%	4 h at 50 – 60 °C
Nalfleet	MaxiClean 2	2 – 5%	4 h at 60 °C
Unitor	Aquabreak	0.05 – 0.5%	4 h at ambient temperature
Vecom	Ultrasonic Multi Cleaner	4%	12 h at 50 – 60 °C

Table 79: Cleaning agents for removing oil sludge

Lime and rust deposits

Lime and rust deposits can form if the water is especially hard or if the concentration of the anticorrosive agent is too low. A thin lime scale layer can be left on the surface as experience has shown that this protects against corrosion. However, limescale deposits with a thickness of more than 0.5 mm obstruct the transfer of heat and cause thermal overloading of the components being cooled.

Rust that has been flushed out may have an abrasive effect on other parts of the system, such as the sealing elements of the water pumps. Together with the elements that are responsible for water hardness, this forms what is known as ferrous sludge which tends to gather in areas where the flow velocity is low.

Products that remove limescale deposits are generally suitable for removing rust. Suitable cleaning agents are listed alphabetically in the table entitled Cleaning agents for removing limescale and rust deposits., Page 155 Products by other manufacturers can be used providing they have similar

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properties. The manufacturer's instructions for use must be strictly observed. Prior to cleaning, check whether the cleaning agent is suitable for the materials to be cleaned. The products listed in the table entitled Cleaning agents for removing limescale and rust deposits, Page 155 are also suitable for stainless steel.

Manufacturer	Product	Concentration	Duration of cleaning procedure/temperature
Drew	SAF-Acid Descale-IT Ferroclean	5 – 10 % 5 – 10 % 10 %	4 h at 60 – 70 °C 4 h at 60 – 70 °C 4 – 24 h at 60 – 70 °C
Nalfleet	Nalfleet 9 - 068	5 %	4 h at 60 – 75 °C
Unitor	Descalex	5 – 10 %	4 – 6 h at approx. 60 °C
Vecom	Descalant F	3 – 10 %	ca. 4 h at 50 – 60 °C

Table 80: Cleaning agents for removing lime scale and rust deposits

In emergencies only

Hydrochloric acid diluted in water or aminosulphonic acid may only be used in exceptional cases if a special cleaning agent that removes limescale deposits without causing problems is not available. Observe the following during application:

- Stainless steel heat exchangers must never be treated using diluted hydrochloric acid.
- Cooling systems containing non-ferrous metals (aluminium, red bronze, brass, etc.) must be treated with deactivated aminosulphonic acid. This acid should be added to water in a concentration of 3 – 5 %. The temperature of the solution should be 40 – 50 °C.
- Diluted hydrochloric acid may only be used to clean steel pipes. If hydrochloric acid is used as the cleaning agent, there is always a danger that acid will remain in the system, even when the system has been neutralised and flushed. This residual acid promotes pitting. We therefore recommend you have the cleaning carried out by a specialist.

The carbon dioxide bubbles that form when limescale deposits are dissolved can prevent the cleaning agent from reaching boiler scale. It is therefore absolutely necessary to circulate the water with the cleaning agent to flush away the gas bubbles and allow them to escape. The length of the cleaning process depends on the thickness and composition of the deposits. Values are provided for orientation in the table entitled Cleaning agents for removing limescale and rust deposits, Page 155.

Following cleaning

The cooling system must be flushed several times once it has been cleaned using cleaning agents. Replace the water during this process. If acids are used to carry out the cleaning, neutralise the cooling system afterwards with suitable chemicals then flush. The system can then be refilled with water that has been prepared accordingly.

Note:

Start the cleaning operation only when the engine has cooled down. Hot engine components must not come into contact with cold water. Open the venting pipes before refilling the cooling water system. Blocked venting pipes prevent air from escaping which can lead to thermal overloading of the engine.

Note:

The products to be used can endanger health and may be harmful to the environment. Follow the manufacturer's handling instructions without fail.

The applicable regulations governing the disposal of cleaning agents or acids must be observed.

4.11 Specification of intake air (combustion air)

General

The quality and condition of intake air (combustion air) have a significant effect on the engine output, wear and emissions of the engine. In this regard, not only are the atmospheric conditions extremely important, but also contamination by solid and gaseous foreign matter.

Mineral dust in the intake air increases wear. Chemicals and gases promote corrosion.

This is why effective cleaning of intake air (combustion air) and regular maintenance of the air filter are required.

When designing the intake air system, the maximum permissible overall pressure drop (filter, silencer, pipe line) of 20 mbar must be taken into consideration.

Exhaust turbochargers for marine engines are equipped with silencers and air filters as a standard.

Requirements

Liquid fuel engines: As minimum, inlet air (combustion air) must be cleaned by an ISO Coarse 45% class filter as per DIN EN ISO 16890, if the combustion air is drawn in from inside (e.g. from the machine room/engine room). If the combustion air is drawn in from outside, in the environment with a risk of higher inlet air contamination (e.g. due to sand storms, due to loading and unloading grain cargo vessels or in the surroundings of cement plants), additional measures must be taken. This includes the use of pre-separators, pulse filter systems and a higher grade of filter efficiency class at least up to ISO ePM10 50% according to DIN EN ISO 16890.

Gas engines and dual-fuel engines: As minimum, inlet air (combustion air) must be cleaned by an ISO COARSE 45% class filter as per DIN EN ISO 16890, if the combustion air is drawn in from inside (e.g. from machine room/ engine room). Gas engines or dual-fuel engines must be equipped with a dry filter. Oil bath filters are not permitted because they enrich the inlet air with oil mist. This is not permissible for gas operated engines because this may result in engine knocking. If the combustion air is drawn in from outside, in the environment with a risk of higher inlet air contamination (e.g. due to sand storms, due to loading and unloading grain cargo vessels or in the surroundings of cement plants) additional measures must be taken. This includes the use of pre-separators, pulse filter systems and a higher grade of filter efficiency class at least up to ISO ePM10 50% according to DIN EN ISO 16890.

In general, the following applies:

The inlet air path from air filter to engine shall be designed and implemented airtight so that no false air may be drawn in from the outdoor.

The concentration downstream of the air filter and/or upstream of the turbocharger inlet must not exceed the following limit values.

The air must not contain organic or inorganic silicon compounds.

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Properties	Limit	Unit [1)]
Dust (sand, cement, CaO, Al_2O_3 etc.)	max. 5	mg/Nm^3
Chlorine	max. 1.5	
Sulphur dioxide (SO_2)	max. 1.25	
Hydrogen sulphide (H_2S)	max. 5	
Salt (NaCl)	max. 1	
[1)] One Nm^3 corresponds to one cubic meter of gas at 0 °C and 101.32 kPa.		

Table 81: Typical values for intake air (combustion air) that must be complied with

Note:

Intake air shall not contain any flammable gases. Make sure that the combustion air is not explosive and is not drawn in from the ATEX Zone.

4.12 Specification of compressed air

General

For compressed air quality observe the ISO 8573-1. Compressed air must be free of solid particles and oil (acc. to the specification).

Requirements

Compressed air quality of starting air system

The starting air must fulfil at least the following quality requirements according to ISO 8573-1.

Purity regarding solid particles	Quality class 6
Particle size > 40µm	max. concentration < 5 mg/m^3
Purity regarding moisture	Quality class 7
Residual water content	< 0.5 g/m^3
Purity regarding oil	Quality class X

Additional requirements are:

- The air must not contain organic or inorganic silicon compounds.
- The layout of the starting air system must ensure that no corrosion may occur.
- The starting air system and the starting air receiver must be equipped with condensate drain devices.
- By means of devices provided in the starting air system and via maintenance of the system components, it must be ensured that any hazardous formation of an explosive compressed air/lube oil mixture is prevented in a safe manner.

Compressed air quality in the control air system

Please note that control air will be used for the activation of some safety functions on the engine – therefore, the compressed air quality in this system is very important.

Control air must meet at least the following quality requirements according to ISO 8573-1.

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▪ Purity regarding solid particles	Quality class 5
▪ Purity regarding moisture	Quality class 4
▪ Purity regarding oil	Quality class 3

For catalysts

The following specifications are valid unless otherwise defined by any other relevant sources:

Compressed air quality for soot blowing

Compressed air for soot blowing must meet at least the following quality requirements according to ISO 8573-1.

▪ Purity regarding solid particles	Quality class 3
▪ Purity regarding moisture	Quality class 4
▪ Purity regarding oil	Quality class 2

Compressed air quality for reducing agent atomisation

Compressed air for atomisation of the reducing agent must fulfil at least the following quality requirements according to ISO 8573-1.

▪ Purity regarding solid particles	Quality class 3
▪ Purity regarding moisture	Quality class 4
▪ Purity regarding oil	Quality class 2

Note:

To prevent clogging of catalyst and catalyst lifetime shortening, the compressed air specification must always be observed.

5 Engine supply systems

5.1 Basic principles for pipe selection

5.1.1 External pipe dimensioning

The external piping systems are to be dimensioned, designed, installed and connected to the engine by the shipyard. The pipe systems should to be designed in such a way that the pressure losses are kept within reasonable limits. To achieve this at justifiable cost, it is recommended to maintain the flow rates as indicated below. Nevertheless, depending on specific conditions of piping systems, it may be necessary in some cases to adopt even lower flow rates. Generally, it is not recommended to use higher flow rates.

For small pipes a low flow speed has to calculated, for bigger pipes (> DN 125) the higher values may be chosen.

	Recommended flow rates (m/s)	
	Suction side	**Delivery side**
Fresh water (cooling water)	1.0 – 2.0	1.5 – 3.0
Lube oil	0.5 – 1.0	1.5 – 2.5
Seawater	1.0 – 1.5	1.5 – 2.5
Diesel fuel	0.5 – 1.0	1.5 – 2.0
Heavy fuel oil	0.3 – 0.8	1.0 – 1.8
Compressed air for control air system	-	2 – 10
Compressed air for starting air system	-	25 – 30 [1)]
Intake air	20 – 25	
Exhaust gas	40	
[1)] During engine start higher velocities acceptable, depends on total pressure loss of supply system.		

Table 82: Recommended flow rates

In addition to obtaining certain flow rates it is recommended to achieve an uniform inflow towards pumps. If disturbances in front of the pump cannot be avoided on the system side, the inflow musts be made uniform to a permissible level. This can be achieved, amongst other things, by a sufficiently long straight pipe section (approx. 5 to 8 times the nominal diameter DN between the pump and the point of interference), bends with a large radius of curvature, as well as other measures.

Bends have to be carried out using radius 1.5 x DN or higher. Sharp angles or other installations that may cause cavitation are to be avoided.

5.1.2 Specification of materials for piping

General

- The properties of the piping shall conform to international standards, e.g. DIN EN 10208, DIN EN 10216, DIN EN 10217 or DIN EN 10305, DIN EN 13480-3.

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- For piping, carbon steel pipe should be used; stainless steel shall be used where necessary.
- Outer surface of carbon steel pipes needs to be primed and painted according to shipyard`s specification.
- The pipes are to be sound, clean and free from all imperfections. The internal surfaces must be thoroughly cleaned and all scale, grit, dirt and sand used in casting or bending has to be removed. No sand is to be used as packing during bending operations.
- In case of pipes with forged bends, care must be taken to ensure that inner surfaces are smooth and that no stray weld metal remains after joining.
- Advices in MAN Energy Solutions work instruction 010.000.001-03. Pipelines cleaning, pickling and preservation. Carry out the pressure test for cleaning of steel pipes before fitting them together should be observed.
- Certain material combinations are sensitive to electro-chemical corrosion, therefore special attention must be paid to the arrangement within a pipe system including all connected components.
- All information given is to be regarded as indication only; the sole responsibility for the functionality and durability of the external piping system lies with the shipyard.

LT-, HT- and nozzle cooling water pipes

Galvanised steel pipe must not be used for the piping of the system as all additives contained in the engine cooling water attack zinc. Moreover, there is the risk of the formation of local electrolytic element couples where the zinc layer has been worn off, and the risk of aeration corrosion where the zinc layer is not properly bonded to the substrate.

Proposed material (EN)

P235GH, E235, X5CrNiMoTi17-12-2

Fuel oil pipes, lube oil pipes

Galvanised steel pipe must not be used for the piping of the system as acid components of the fuel may attack zinc.

Proposed material (EN)

E235, P235GH, X6CrNiMoTi17-12-2

Urea pipes (for SCR only)

Galvanised steel pipe, brass and copper components must not be used for the piping of the system.

Proposed material (EN)

X6CrNiMoTi17-12-2

Compressed air pipes

Galvanised steel pipe must not be used for the piping of the system.

Proposed material (EN)

E235, P235GH, X6CrNiMoTi17-12-2

Seawater pipes

Material depending on required flow speed and mechanical stress.

Proposed material

CuNiFe, glass fiber reinforced plastic, rubber lined steel

5.1.3 Installation of flexible pipe connections

Arrangement of hoses on resiliently mounted engine

Flexible pipe connections become necessary to connect GenSet with external piping systems. They are used to compensate the dynamic movements of the GenSet in relation to the external piping system.

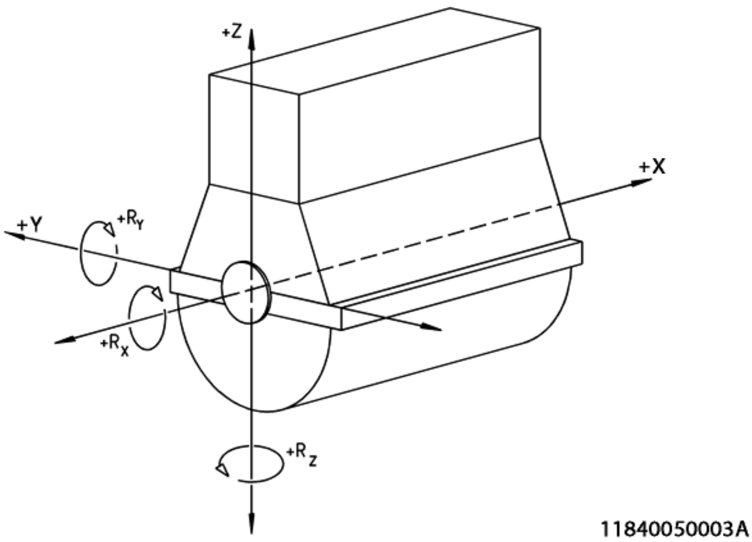

Figure 48: Coordinate system

Generally flexible pipes (rubber hoses with steel inlet, metal hoses, PTFE-corrugated hose-lines, rubber bellows with steel inlet, steel bellows, steel compensators) are nearly unable to compensate twisting movements. Therefore the installation direction of flexible pipes must be vertically (in Z-direction) if ever possible. Torsion on flexible pipe connections must be avoided. Flexible pipe connections which are installed in X-direction are particularly at risk. Therefore the installation of flexible pipe connections in this direction should be avoided. Where the installation of flexible pipe connections in X-direction is nevertheless unavoidable, the continuing pipeline on the plant side must be designed in such a way that the torsional forces can be safely absorbed. An installation in horizontal-lateral (Y-direction) is not recommended.

The media connections (compensators) to and from the engine must be highly flexible whereas the fixations of the compensators on the one hand with the engine and on the other hand with the environment must be realised as stiff as possible.

Flange and screw connections

Flexible pipes delivered loose by MAN Energy Solutions are fitted with flange connections from DN32 upwards. Smaller sizes are fitted with screw connections. Each flexible pipe is delivered complete with counter flanges or, those smaller than DN32, with weld-on sockets.

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Arrangement of the external piping system

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

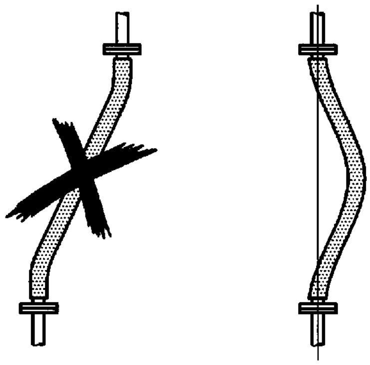

Figure 49: Arrangement of pipes in system

Installation of hoses

In the case of straight-line-vertical installation, a suitable distance between the hose connections has to be chosen, so that the hose is installed with a sag. To satisfy a correct sag in a straight-line-vertically installed hose, the distance between the hose connections (hose installed, engine stopped) has to be approximately 5% shorter than the same distance of the unconnected hose (without sag). Flexible hoses must not be installed with tensile stress, compression or torsional tension.

In case it is unavoidable (this is not recommended) to connect the hose in lateral-horizontal direction (Y-direction) the hose must preferably be installed with a 90° arc. The minimum bending radii, specified in provided drawings, are to be observed.

Hoses must not be twisted during installation. Turnable lapped flanges on the hoses avoid this.

Where bolted connections are used, hold the hexagon on the hose with a wrench while fitting the nut.

All installation instructions of the hose manufacturer have to be complied with.

Depending on the required application rubber hoses with steel inlet, metal hoses or PTFE-corrugated hose lines are used.

Installation of steel compensators

Steel compensators are used for hot media, e.g. exhaust gas. They can compensate movements in line and transversal to their centre line, but they are absolutely unable to compensate twisting movements. Compensators are very stiff against torsion. For this reason all kind of steel compensators installed on resilient mounted engines are to be installed in vertical direction.

Note:
Exhaust gas compensators are also used to compensate for thermal expansion. Exhaust gas compensators are therefore required for all type of engine mountings, also for semi-resilient or rigid mounted engines. But in these cases

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the compensators can be shorter, as they are designed only to compensate the thermal expansions and vibrations, but not other dynamic engine movements.

Supports of pipes

Flexible pipes must be installed as close as possible to the engine connection.

On the shipside, directly after the flexible pipe, the pipe is to be fixed with a sturdy pipe anchor of higher than normal quality. This anchor must be capable to absorb the reaction forces of the flexible pipe, the hydraulic force of the fluid and the dynamic force.

Example of the axial force of a compensator to be absorbed by the pipe anchor:

- Hydraulic force
  = (cross section area of the compensator) x (pressure of the fluid inside)
- Reaction force
  = (spring rate of the compensator) x (displacement of the comp.)
- Axial force
  = (hydraulic force) + (reaction force)

Additionally a sufficient margin has to be included to account for pressure peaks and vibrations.

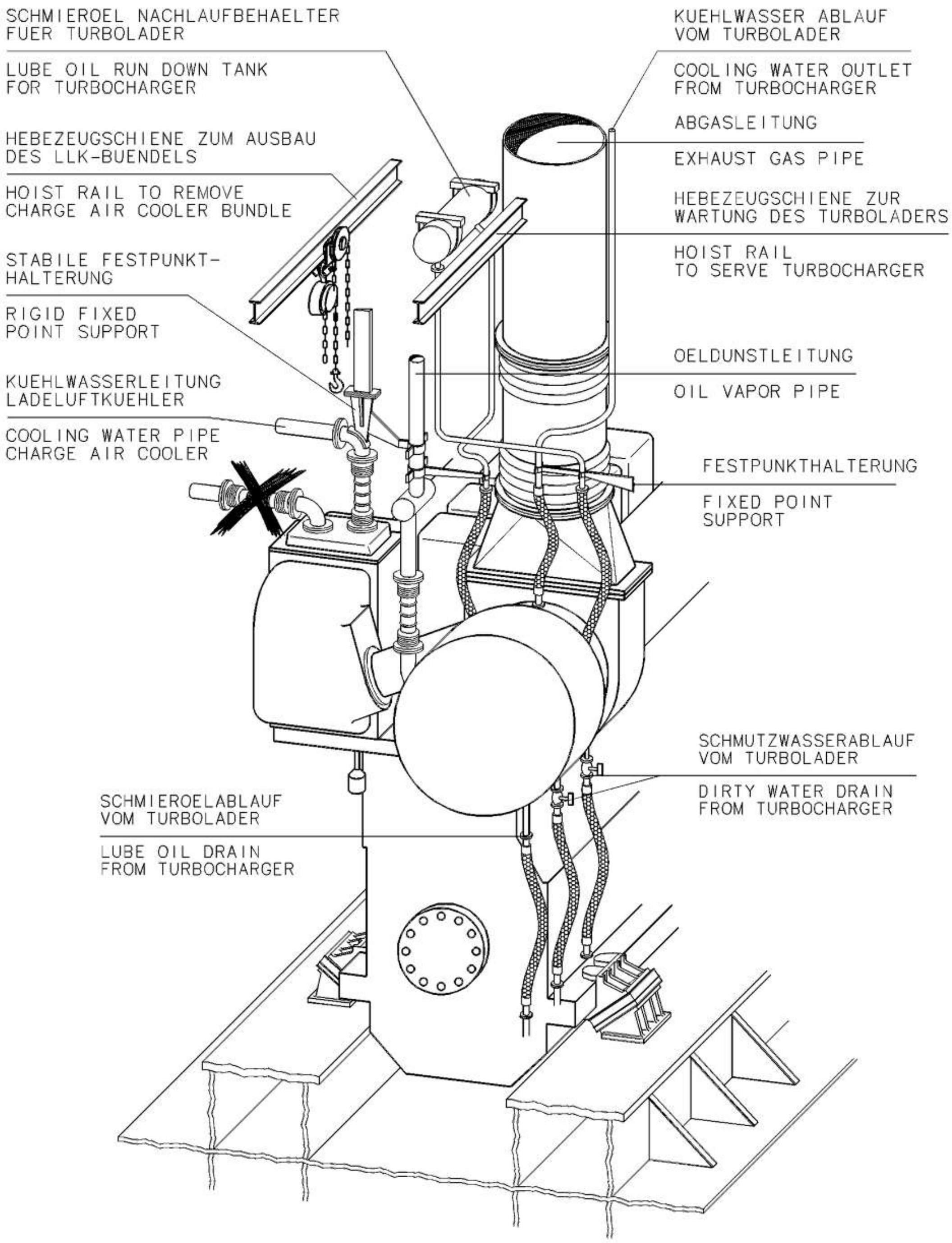

Figure 50: Installation of hoses

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5.1.4 Condensate amount in charge air pipes and air vessels

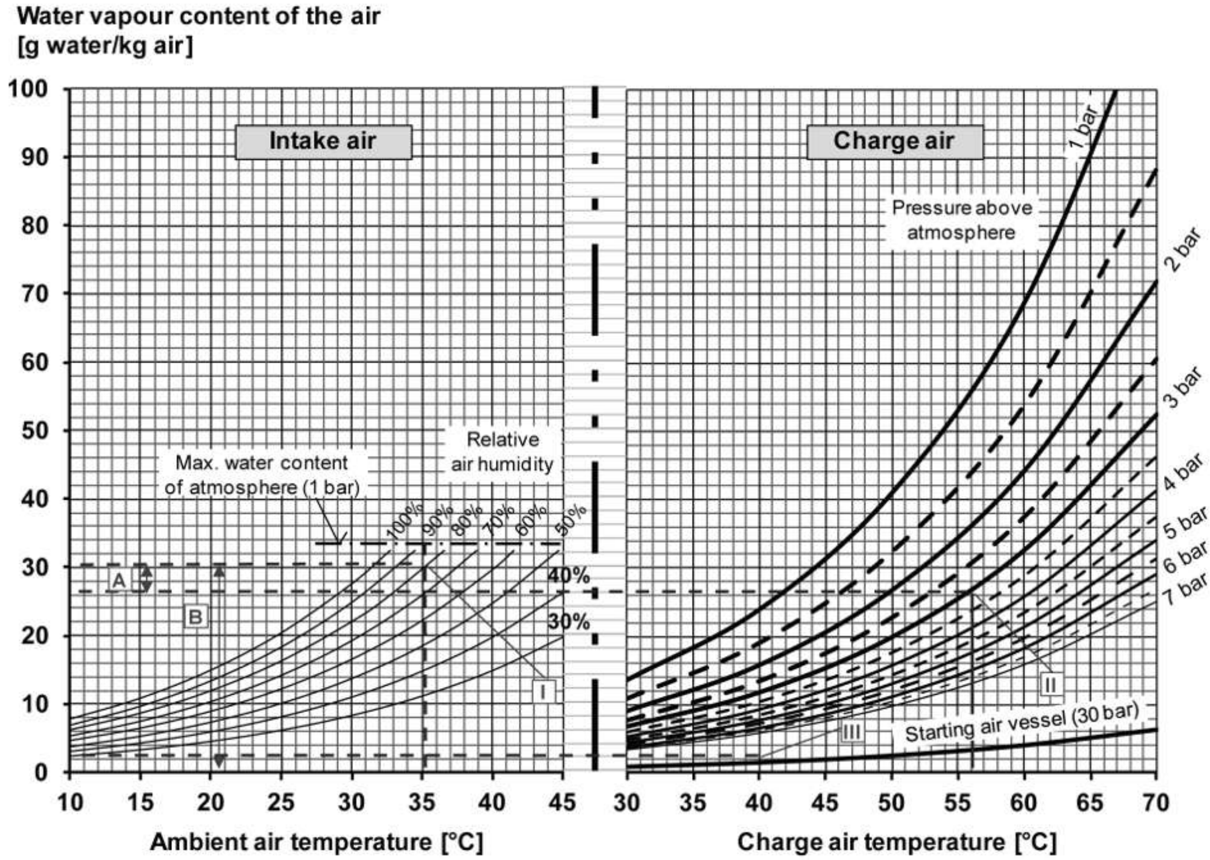

Figure 51: Diagram condensate amount

The amount of condensate precipitated from the air can be considerablly high, particularly in the tropics. It depends on the condition of the intake air (temperature, relative air humidity) in comparison to the charge air after charge air cooler (pressure, temperature).

It is important, that no condensed water of the intake air/charge air will be led to the compressor of the turbocharger, as this may cause damages.

In addition the condensed water quantity in the engine needs to be minimised. This is achieved by controlling the charge air temperature.

How to determine the amount of condensate:

First determine the point I of intersection in the left side of the diagram (intake air), see figure Diagram condensate amount, Page 165 between the corresponding relative air humidity curve and the ambient air temperature.

Secondly determine the point II of intersection in the right side of the diagram (charge air) between the corresponding charge air pressure curve and the charge air temperature. Note that charge air pressure as mentioned in section Planning data, Page 62 is shown as absolute pressure.

At both points of intersection read out the values [g water/kg air] on the vertically axis.

The intake air water content I minus the charge air water content II is the condensate amount A which will precipitate. If the calculations result is negative no condensate will occur.

For an example see figure Diagram condensate amount, Page 165. Intake air water content 30 g/kg minus 26 g/kg = 4 g of water/kg of air will precipitate.

To calculate the condensate amount during filling of the starting air receiver just use the 30 bar curve (see figure Diagram condensate amount, Page 165) in a similar procedure.

Example how to determine the amount of water accumulating in the charge air pipe

Parameter	Unit	Value
Engine output (P)	kW	9,000
Specific air flow (le)	kg/kWh	6.9
Ambient air condition (I):		
Ambient air temperature	°C	35
Relative air humidity	%	80
Charge air condition (II):		
Charge air temperature after cooler[1)]	°C	56
Charge air pressure (over pressure)[1)]	bar	3.0
Solution according to above diagram		
Water content of air according to point of intersection (I)	kg of water/kg of air	0.030
Maximum water content of air according to point of intersection (II)	kg of water/kg of air	0.026
The difference between (I) and (II) is the condensed water amount (A)		
A = I – II = 0.030 – 0.026 = 0.004 kg of water/kg of air		
Total amount of condensate Q_A:		
Q_A = A x le x P		
Q_A = 0.004 x 6.9 x 9,000 = 248 kg/h		
[1)] In case of two-stage turbocharging choose the values of the high-pressure TC and cooler (second stage of turbocharging system) accordingly.		

Table 83: Example how to determine the amount of water accumulating in the charge air pipe

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Example how to determine the condensate amount in the starting air receiver

Parameter	Unit	Value
Volumetric capacity of tank (V)	litre m^3	3,500 3.5
Temperature of air in starting air receiver (T)	°C K	40 313
Air pressure in starting air receiver ($p_{above\ atmosphere}$) Air pressure in starting air receiver ($p_{absolute}$)	bar bar abs $\frac{N}{m^2}$	30 31 31×10^5
Gas constant for air (R)	$\frac{Nm}{kg \times K}$	287
Ambient air temperature	°C	35
Relative air humidity	%	80
Weight of air in the starting air receiver is calculated as follows: $m = \frac{p \times V}{R \times T} = \frac{31 \times 10^5 \times 3.5}{287 \times 313} = 121 kg$		
Solution according to above diagram		
Water content of air according to point of intersection (I)	kg of water/kg of air	0.030
Maximum water content of air according to point of intersection (III)	kg of water/kg of air	0.002
The difference between (I) and (III) is the condensed water amount (B) B = I – III B = 0.030 – 0.002 = 0.028 kg of water/kg of air		
Total amount of condensate in the vessel (Q_B) Q_B = m x B Q_B = 121 x 0.028 = 3.39 kg		

Table 84: Example how to determine the condensate amount in the starting air receiver

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5.2 Lube oil system

5.2.1 Lube oil system description

The diagrams represent standard design of the external lube oil service system. All moving parts of the engine are pressurised with oil circulating in the build-on system, based on wet sump lubrication.

The lubrication of the cylinder liners is designed as a separate system, attached to the engine but served by the inner lubrication system.

System flow

The lube oil service pump draws oil from the oil sump. Then pumps it through the lube oil cooler and the lube oil automatic filter, to the main lube oil pipe. From there, it is distributed to the lubricating points of engine and turbocharger. Then returns by gravity to the oil sump inside the lube oil service tank.

Treatment systems, which are cleaning the lube oil continuously in a by-pass stream, are installed on the GenSet and in the plant.

Lube oil consumption

During the running-in period, the lube oil consumption may exceed the values stated.

The total lube oil consumption will be increased by the following processes and influences:

- Desludging interval of the lube oil separator/automatic filter and lube oil content of the discharged sludge (approximately 30 %)
- Lube oil evaporation
- Leakage
- Losses at lube oil filter exchange

Requirements before commissioning of engine

The flushing of the lube oil system in accordance to the MAN Energy Solutions specification (see the relevant working instructions) demands before commissioning of the engine, that all installations within the system are in proper operation. Be aware that special installations for commissioning are required and the lube oil separator must be in operation from the very first phase of commissioning.

Contact MAN Energy Solutions or licensee if any uncertainties occur.

T-001/Lube oil service tank

The engine frame tank has the function of the lube oil service tank. The main purpose is to separate air and particles from the lube oil, before being pumped back to the engine. Even a low oil level should still permit the lube oil to be drawn in free of air if the ship is pitching. The approximate quantities of oil necessary for new engine, before starting up are given in the table Cooling water and oil volume of engine, Page 75. Concerning the required lube oil quality, see table Main fuel/lube oil type.

It is recommended to use the separator suction pipe for draining of the lube oil service tank. For all used reserve connections a siphon in the plant is recommended.

H-002/Lube oil preheater

To fulfill the starting conditions (see section Starting conditions, Page 33) preheating of the lube oil in the lube oil frame tank is necessary. Therefore the preheater of the separator is often used. The preheater must be enlarged in size if necessary, so that it can heat up the content of the frame tank to ≥ 40 °C, within 4 hours. If engines have to be kept in stand-by mode, the lube oil of the corresponding engines always has to be in the temperature range of starting conditions. Means that also the maximum lube oil temperature limit should not be exceeded during engine start.

For arctic operation conditions the heater capacity has to be increased.

FIL-004/Lube oil suction strainer

The lube oil suction strainer protects the attached lube oil pumps against larger dirt particles that may have accumulated in the tank.

P-001/Lube oil service pump

The main lube oil service pump is mounted on the free end of the engine and is driven by means of the crankshaft through a gear. The pump gear is lubricated by the engines oil flow. The oil pressure at engine inlet is controlled by an adjustable spring loaded pressure relief valve (PCV-007). For the capacity of the attached lube oil service pump, see table Nominal values for cooler specification – Auxiliary GenSet, Page 62. If additional lube oil consumers (e.g. alternator bearing or backflush filter) will be installed, which are supplied by the service pump, please contact MAN Energy Solutions to check if the lube oil capacity of the pump is still sufficient.

FIL-027/Lube oil fine filter

The lube oil is intensively cleaned by fine filtration in the by-pass thus relieving the main filters and allowing an economical design.

The lube oil fine filter is not of self-cleaning type, therefore the filter elements need to be replaced. The design is to be based on a lube oil quantity of 1.0 l/kW. This lube oil quantity should be cleaned within 24 hours at:

- Liquid fuels of DM- and DF-class operation 4 – 5 times
- Dual fuel engines operating on gas (+MDO/MGO for ignition only) 4 – 5 times

The formula for determining the fine filter flow rate (Q) is:

$$Q = \frac{1.0 \times P \times n}{24}$$

Q [l/h]	Fine filter flow rate
P [kW]	Total engine output
n	MDO/MGO = 5 Gas (+ MDO/MGO for ignition only) = 5

With the evaluated flow rate and the lube oil volume of the engine, the number of filter elements of the fine filter has to be selected according to the evaluation table of the maker. The table per maker is based on a fixed filter life time stated in the table (filter lifetime in engine operating hours). This has to be considered carefully. For a longer filter exchange interval, the number of filter elements has to be increased.

The information regarding released manufacturers and filter types for lube oil fine filters can be found here: https://www.man-es.com/documentation/lube-oil-treatment.

Fine filter equipment

Depending on the size of the fine filter, a lifting possibility above the filter housing can be necessary for filter exchange.

The supply pump shall be of freestanding type, that is not mounted on the same frame as the fine filter. It is to be installed in the immediate vicinity of the lube oil service tank.

This arrangement has three advantages:

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- Suction of lube oil without causing cavitation.
- The lube oil fine filter does not need to be installed near of the service tank. It can be mounted in one room together with the fuel oil filters or separators.
- Better accessibility of lube oil fine filter for filter exchange.

As a reserve for the lube oil fine filter, the use of the diesel fuel oil separator is admissible. For reserve operation, the diesel fuel oil separator must be converted accordingly. This includes the pipe connection to the lube oil system which must not be implemented with valves or spectacle flanges. The connection is to be executed by removable changeover joints that will definitely prevent MDO from getting into the lube oil circuit. See also rules and regulations of classification societies.

PCV-007/Pressure relief valve

By use of the pressure relief valve, a constant lube oil pressure before the engine is adjusted.

The pressure relief valve is installed upstream of the lube oil cooler. The return pipe (spilling pipe) from the pressure relief valve returns into the lube oil service tank.

The control line of the pressure relief valve has to be connected to the engine inlet. In this way the pressure losses of filters, pipes and cooler are compensated automatically.

P-007/Prelubrication pump

The GenSet is as standard equipped with an electrically driven pump for prelubrication before starting and also for postlubrication when the engine is stopped. The prelubrication pump, which is of the gear pump type, is self priming and installed in parallel to the lube oil service pump. Its operation is requested by the GenSet automation system, as long as required. The voltage for automatic control must be supplied from the emergency switchboard in order to secure post- and prelubrication in case of a critical situation.

In case of unintended engine stop (e.g. blackout) the postlubrication must be started as soon as possible (latest within 20 min) after the engine has stopped and must persist for minimum 15 min. This is required to cool down the bearings of the turbocharger and hot inner components (see also section External lube oil system – Prelubrication/postlubrication).

For installed pump capacities see the following table.

No. of cylinders, config.			6L	8L	9L	10L
Delivery rate	50 Hz	m^3/h	27	27	43	43
	60 Hz		33	33	52	52
Differential pressure	-	bar	3.5	3.5	3.5	3.5
E-motor capacity	50 Hz	kW	8.0	8.0	17.3	17.3
	60 Hz		10.4	10.4	15.0	15.0

Table 85: Technical data of the installed prelubrication/postlubrication pump

HE-002/Lube oil cooler

The lube oil cooler is of the plate type with LT cooling water as cooling medium and is mounted at the front end of the base frame.

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Heat data, flow rates and tolerances are indicated in section Planning data for emission standard IMO Tier II – Auxiliary GenSet, Page 62 and the following.

On the lube oil side the pressure drop shall not exceed 1.1 bar.

No. of cylinders, config.		6L	8L	9L	10L
Rated heat capacity	kW	433	552	631	710
Max. pressure drop (LO)	bar	Max. 1.1			
Max. pressure drop (LT CW)	bar	Approx. 0.25 – 0.30			

Table 86: Technical data of the installed lube oil cooler

TCV-001/Lube oil temperature control valve

The three-way valve regulates the lube oil temperature at engine inlet by directing the lube oil flow through the lube oil cooler or in by-pass to it. Wax-type thermostatic elements ensure a constant temperature regulation.

No. of cylinders, config.		L engines
Type[1]		Wax-type thermostat
Set point	°C	63
Pressure drop	bar	0.4
[1] Full open temperature of wax elements: Set point.		
Control range of lube oil inlet temperature: Set point minus 10 K.		

Table 87: Technical data of the lube oil temperature control valve

Lube oil treatment

The treatment of the circulating lube oil can be divided into two major functions:

- Removal of contaminations to keep up the lube oil performance.
- Retention of dirt to protect the engine.

The removal of combustion residues, water and other mechanical contaminations is the major task of separators/centrifuges (CF-001) installed in by-pass to the main lube oil service system of the engine. The installation of a lube oil separator per engine is recommended to ensure a continuous separation during engine operation.

The lube oil filters integrated in the system protect the diesel engine in the main circuit retaining all residues which may cause a harm to the engine.

Depending on the filter design, the collected residues are to be removed from the filter mesh by automatic back flushing, manual cleaning or changing the filter cartridge. The retention capacity of the installed filter should be as high as possible.

When selecting an appropriate filter arrangement, the customer request for operation and maintenance, as well as the class requirements, have to be taken in consideration.

Instead of a separator an adequate filtration system (FIL-027) can be used for lube oil treatment. This is only valid for engines which operate with liquid fuels of DM- or DF-class (acc. ISO 8217) exclusively (gas also for dual fuel engines, no heavy fuel oil). By using a filtration system, the used lube oil must be suitable for filtration. A separate heater to preheat the lube oil before engine start has to be foreseen. The filtration system must be approved by MAN Energy Solutions.

FIL-002/Lube oil duplex filter

The lube oil duplex filter has the function of both, main filter and indicator filter. It is designed as duplex filter and the cartridges are of a paper filter type. Each filter consists of a primary and a secondary filter stage. If one of the filters is clogged, switch-over to the second filter and cleaning must be carried out manually. The pipe section between filter and engine inlet must be closely inspected before installation.

Parameter	Unit	Value
Type	-	Duplex filter
Capacity	m^3/h	2 x 132
Cartridge type	-	Two stage paper cartridge
Filter mesh width (sphere passing mesh)	µm	1st stage: 15 2nd stage: 60

Table 88: Technical data of lube oil duplex filter

CF-008/Lube oil centrifugal filter

The built-on by-pass filter is of a centrifugal type. It removes small impurities and herewith serves as inspection device for checking the pureness of the lube oil system.

Only a small part of the oil main stream is routed through the centrifuge. Its flow pressure is operating the centrifuge itself. The centrifuge shall be installed as close as possible to the pressure side of the lube oil pump for improved centrifuge effect.

Parameter	Unit	Value
Type	-	Centrifugal filter with paper insert
Min. flow (at 3 bar)	m^3/h	3.1
Max. flow (at 7 bar)	m^3/h	4.5

Table 89: Technical data of lube oil centrifugal filter

External automatic filter (optional, not shown in lube oil diagram)

Automatic filtration offers long filter service intervals. An external free-standing lube oil automatic filter can optionally be integrated in the lube oil supply line. The back washing/flushing of the filter elements has to be arranged in a way that the lube oil flow and pressure will not be affected. If an external backflush filter without own supply pump is foreseen, please contact MAN Energy Solutions to check, if the capacity of the lube oil service pump P-001 is sufficient to serve the lube oil automatic filter additionally. The flushing discharge is led into the lube oil service tank T-001.

TR-001/Condensate trap

See section Crankcase vent and lube oil tank vent, Page 180.

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CF-001/Lube oil separator

The lube oil is intensively cleaned by separation in the by-pass thus relieving the filters and allowing an economical design.

The lube oil separator should be of the self-cleaning type. The design is to be based on a lube oil quantity of 1.0 l/kW. This lube oil quantity should be cleaned in times within 24 hours.

The formula for determining the separator flow rate (Q) is:

$$Q = \frac{1.0 \times P \times n}{24}$$

Q [l/h]	Separator flow rate
P [kW]	Total engine output
n	HFO = 7 MDO/MGO = 5 Gas (+ MDO/MGO for ignition only) = 5

With the evaluated flow rate the size of separator has to be selected according to the evaluation table of the manufacturer. The separator rating stated by the manufacturer should be higher than the flow rate (Q) calculated according to the formula above.

Separator equipment

The lube oil preheater H-002 must always be able to heat the oil to 95 – 98 °C and the size is to be selected accordingly. In addition to a PI-temperature control, which avoids a thermal overloading of the oil, silting of the preheater must be prevented by high turbulence of the oil in the preheater.

Control accuracy ±1 °C.

Cruise ships operating in arctic waters require larger lube oil preheaters. In this case the size of the preheater must be calculated with a Δt of 60 K.

The freshwater supplied must be treated as specified by the separator supplier.

The supply pumps shall be of the free-standing type, i.e. not mounted on the separator and are to be installed in the immediate vicinity of the lube oil service tank.

This arrangement has three advantages:

- Suction of lube oil without causing cavitation.
- The lube oil separator does not need to be installed in the vicinity of the service tank but can be mounted in the separator room together with the fuel oil separators.
- Better matching of the capacity to the required separator throughput.

As a reserve for the lube oil separator, the use of the diesel fuel oil separator is admissible. For reserve operation the diesel fuel oil separator must be converted accordingly. This includes the pipe connection to the lube oil system which must not be implemented with valves or spectacle flanges. The connection is to be executed by removable change-over joints that will definitely prevent MDO from getting into the lube oil circuit. See also rules and regulations of classification societies.

Multi-engine plants

In principle one lube oil separator unit per engine in operation is recommended. But the experienced load profile for the majority of merchant vessels is in average around 43 – 50 % of the installed auxiliary GenSet power. Regarding this, it might be an economic solution to install one common separator for multi-engine plants. Requirement: One separator unit must not be dedicated to more than 3 engines and there must always be one separator unit in reserve. With three identical engines the time-related average power demand corresponds to 1.3 – 1.5 times the power of one engine.

$$Q = f \times 1.0 \times P \times \frac{n}{24}$$

- Bulk carrier and tanker: f ~ 1.3
- Container vessel: f ~ 1.5

If the average load profile is well above 50 %, factor f or the number of separators must be increased.

It must be ensured that during the switch-over from one to another GenSet, the valves of the upstream and the downstream line (to and from the lube oil service tank) are always switched simultaneously. Generally there is the risk, that wear and dirt particles being transferred from one engine to another.

The switch-over times, respectively the time how long the lube oil separator is connected to each engine, must be determined depending on the proportional power generation. If there is no heater available to keep the lube oil of stand-by engines at the right temperature, a periodical switch-over to these engines must be considered as well. On the other hand, the heat input from the cleaned lube oil into the service tank of the running engines must be limited to meet the right lube oil temperature at engine inlet.

Separator efficiency

Various operating parameters affect the separation efficiency. These include temperature (which controls both, fuel oil viscosity and density), flow rate and separator maintenance. Figure Separation efficiency dependence on particle size, density difference, viscosity and flow rate, Page 174 shows, how the operating parameters affect the separator efficiency.

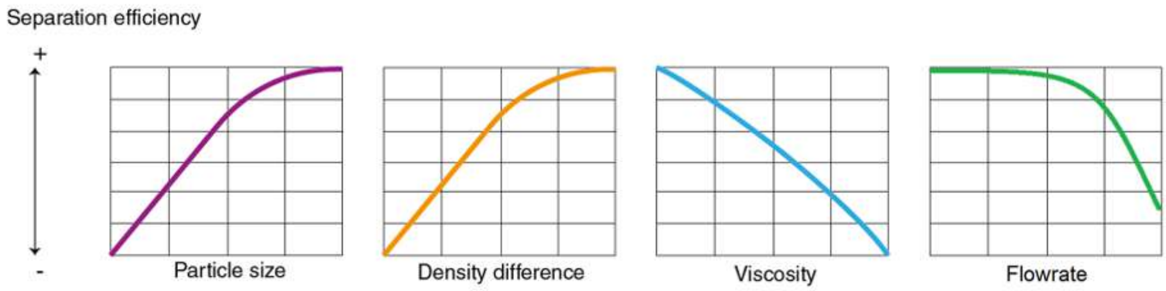

Figure 52: Separation efficiency dependence on particle size, density difference, viscosity and flow rate (reference: Diagram 1 – 3: "CIMAC Paper No. 51 – Onboard Fuel Oil Cleaning", CIMAC Congress, 2013)

Due to the fact that auxiliary generating sets often are operated with the worst fuels available and in an unfavourable part load range, the lube oil can pollute much earlier than this of comparable main propulsion engines. Therefore it is recommended to run the lube oil separators within no more than 25 % of its nominal capacity. Separator manufacturers already may have considered a similar factor for choosing the optimum separator capacity.

T-006/Leakage oil collecting tank

Leaked fuel and lube oil is collected in this tank. The content must not be added to the fuel, but led into the sludge tank.

T-021/Sludge tank

Separated impurities from the lube oil separator module and the content of the leakage oil collecting tank T-006 are disposed into the sludge tank. The sludge tank is also part of the fuel oil leakage system. See description in paragraph T-021/Sludge tank, Page 210.

Withdrawal points for samples

Points for drawing lube oil samples are to be provided upstream and downstream of the filters and the separator, to verify the effectiveness of these system components.

Piping system

It is recommended to use pipes according to the pressure class PN16.

In agreement with MAN Energy Solutions optional branches can be foreseen for:

- External lube oil automatic filter.
- Pressure lubrication of alternator bearings.

P-012/Lube oil transfer pump

The lube oil transfer pump supplies fresh oil from the lube oil storage tank to the operating tank. Starting and stopping of the lube oil transfer pump should preferably be done automatically by float switches fitted in the tank.

Lube oil system diagrams

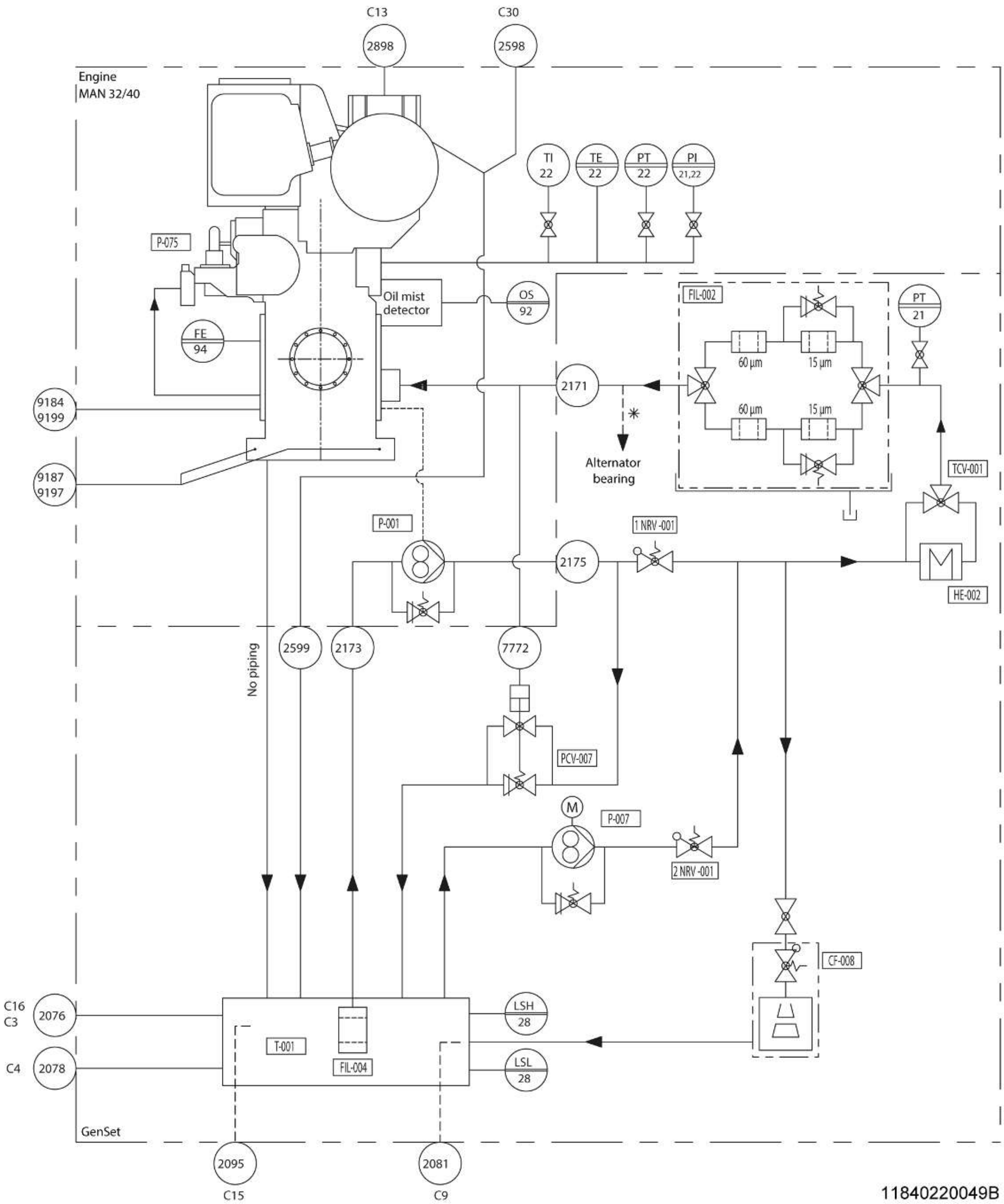

Figure 53: Lube oil system diagram, GenSet – Internal

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Engine components			
P-001	Lube oil service pump (engine driven)	P-075	Cylinder lube oil pump
GenSet components			
CF-008	Centrifuge (by-pass filter)	P-007	Prelubrication pump
FIL-002	Lube oil duplex filter	PCV-007	Pressure relief valve
FIL-004	Lube oil suction strainer	T-001	Lube oil service tank
HE-002	Lube oil cooler	TCV-001	Lube oil temperature control valve
1, 2 NRV-001	Non return valve		
Engine pipe connections			
2171	Engine inlet	7772	Control line to pressure relief valve
2173	Oil pump inlet	9184	Dirty oil drain from crankcase
2175	Oil pump outlet	9187	Dirty oil drain from crankcase
C30/2598	Vent turbocharger	9197	Dirty oil drain from crankcase
2599	Drain from turbocharger	9199	Dirty oil drain from crankcase
C13/2898	Vent crankcase		
GenSet pipe connections			
C3/2076	From separator	C9/2081	Flushing from automatic filter
C16/2076	Supply	C15/2095	Overflow, optional
C4/2078	To separator		

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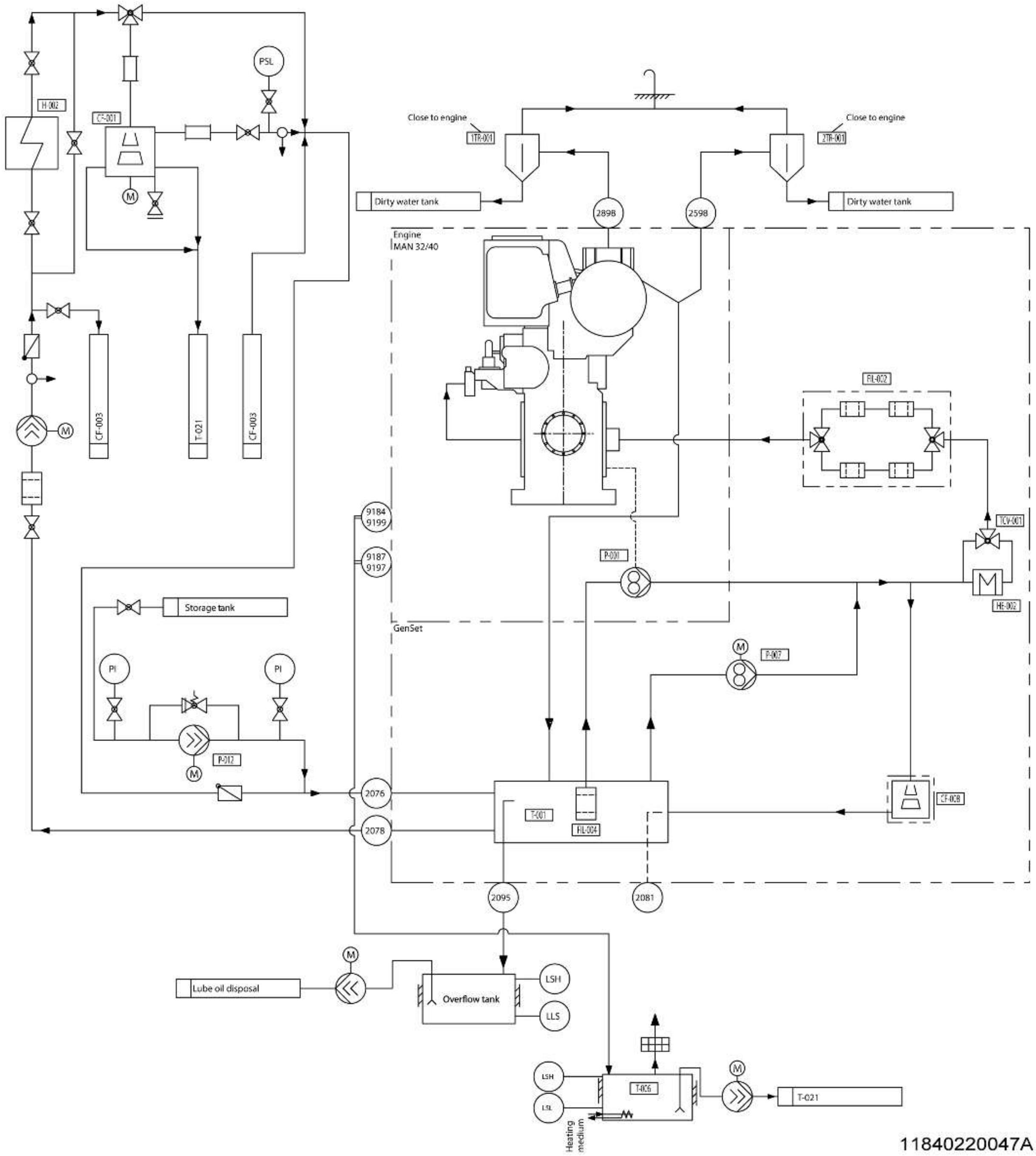

Figure 54: Lube oil system diagram, GenSet – External

Engine pipe connections			
C30/2598	Vent turbocharger	9187	Dirty oil drain from crankcase
2599	Drain from turbocharger	9197	Dirty oil drain from crankcase
C13/2898	Vent crankcase	9199	Dirty oil drain from crankcase
9184	Dirty oil drain from crankcase		
GenSet pipe connections			
C3/2076	From separator	C9/2081	Inlet (optional)
C16/2076	Supply	C15/2095	Overflow
C4/2078	To separator		
Engine components			
P-001	Lube oil service pump (engine driven)		
GenSet components			
CF-008	Filter centrifuge	P-007	Prelubrication pump
FIL-002	Lube oil duplex filter	T-001	Lube oil service tank
FIL-004	Lube oil suction strainer	TCV-001	Lube oil temperature control valve
HE-002	Lube oil cooler		
Engine room components			
CF-001	Lube oil separator	T-006	Leakage oil collecting tank
CF-003	Diesel fuel oil separator	T-021	Sludge tank
H-002	Lube oil preheater	1, 2 TR-001	Condensate trap
P-012	Lube oil transfer pump		

5.2.2 External lube oil system – Prelubrication/postlubrication

Prelubrication

The prelubrication pump must be switched on at least 5 minutes before engine start. The prelubrication pump serves to assist the engine attached main lube oil pump, until this can provide a sufficient flow rate.

For design data of the prelubrication pump see section Planning data for emission standard IMO Tier II – Auxiliary GenSet, Page 62 and paragraph Lube oil, Page 70.

During the starting process, the maximal temperature mentioned in section Starting conditions, Page 33 must not be exceeded at engine inlet. Therefore, a small LT cooling waterpump can be necessary if the lube oil cooler is served only by an attached LT pump.

Postlubrication

The prelubrication pump is also to be used for postlubrication after the engine is turned off.

Postlubrication is effected for a period of 15 minutes.

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5.3 Crankcase vent and lube oil tank vent

Condensate traps

The condensate traps (TR-001) required for the vent pipes of the turbocharger, the engine crankcase and the service tank must be installed as close as possible to the vent connections. This will prevent condensate water, which has formed on the cold venting pipes, to enter the engine or service tank.

Vent pipes

The vent pipes from engine crankcase and turbocharger are to be arranged according to the sketch. The frame tank is vented through the vent pipes of the engine. The pipe design must ensure a sufficient lube oil ventilation and avoid a reduction of the cross section, caused from condensed water. The required nominal diameters ND are stated in the chart following the diagram.

Note:

- The venting pipework must be kept separately for each engine.
- Condensate trap overflows are to be connected via siphone to drain pipe and back to sludge tank.
- Specific requirements of the classification societies are to be strictly observed.
- The pipe connection between engine and ventilation line must be flexible.
- The ventilation pipe must be made with continuous upward slope min. 5°, even when the ship heel or trim (static inclination).

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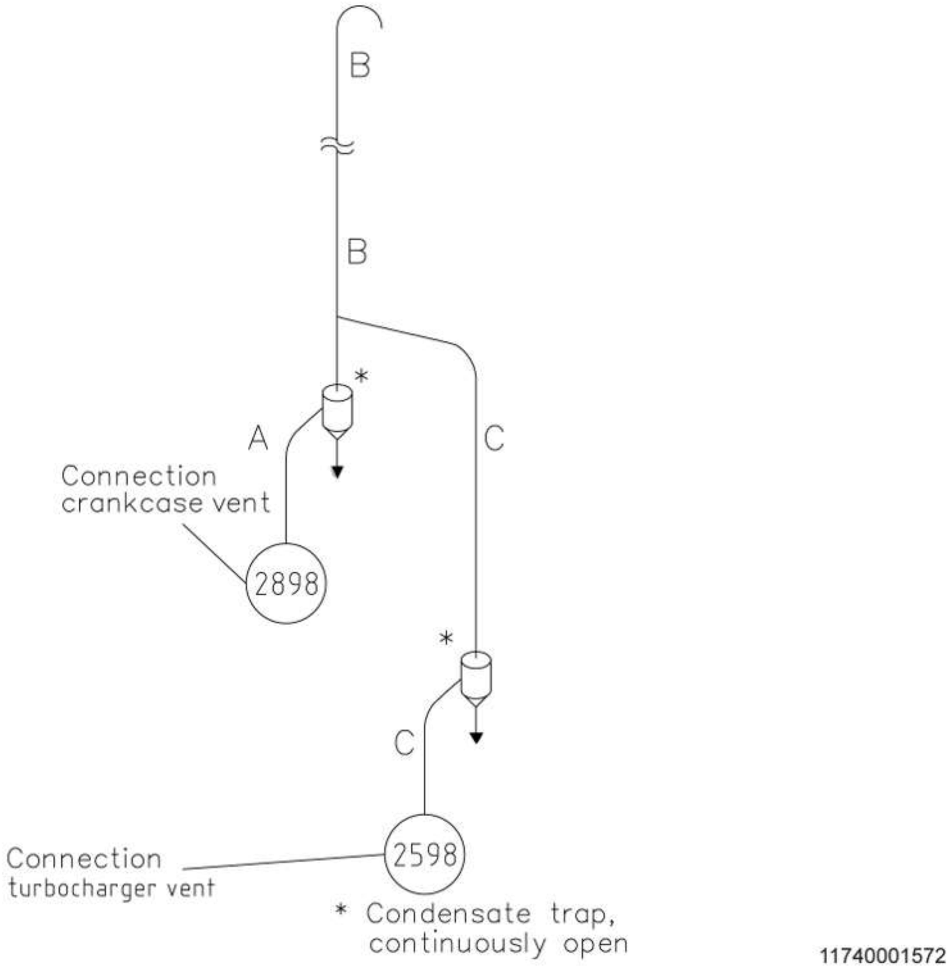

Figure 55: Crankcase vent and turbocharger vent

Engine type	Nominal diameter ND (mm)		
L engine	A	B	C
	125	125	50

5.4 Water systems

5.4.1 General

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During the combustion process in diesel and gas engines the fuels energy is converted into heat. While one part is furthermore converted into mechanical power, the other part remains as waste heat and must be dissipated. The engines exhaust gas contains a large amount of heat, which is partly recovered by the exhaust gas turbo charger and is led back into the power generating process. Another large heat quantity must be removed by cooling the cylinder jackets, fuel injection valves, charge air and lube oil with circulating water. Off the engine there are also heat loads to be dissipated, such from cooling the alternator or diesel fuel. An additional but smaller amount of heat is radiated by hot surfaces of engine, piping and other components.

Dissipating all the heat out of the system is the purpose of the cooling water system.

The engine's cooling water system

The engine's cooling water system comprises a low temperature (LT) circuit and a high temperature (HT) circuit. The systems are designed only for treated fresh water, which meets all requirements specified by MAN Energy Solutions, see section Specification of engine coolant, Page 147.

The LT cooling water system includes heat exchangers for charge air cooling (stage 2), lubricating oil cooling, fuel injection nozzle cooling and alternator cooling if the latter is water-cooled. It is designed for freshwater as cooling medium. The LT cooling water temperature for the auxiliary GenSets is regulated by the plant control system to 32 °C and must not drop below.

The HT cooling water system removes heat from charged air (stage 1), cylinder liners and cylinder heads. An engine outlet temperature of nearly 90 °C ensures a perfect combustion in the entire load area. This temperature limits thermal loads in the high-load area and avoids hot-corrosion in the combustion area. In the low-load area, the temperature is sufficiently high to avoid cold corrosion.

Piping

Coolant additives may attack a zinc layer. It is therefore imperative to avoid using galvanised steel pipes. Treatment of cooling water as specified by MAN Energy Solutions will safely protect the inner pipe walls against corrosion.

Moreover, there is the risk of the formation of local electrolytic element couples where the zinc layer has been worn off, and the risk of aeration corrosion where the zinc layer is not properly bonded to the substrate.

See the working instructions 6682 000.16-01E for cleaning of steel pipes before fitting.

Pipes shall be manufactured and assembled in a way that ensures a proper draining of all segments. Venting is to be provided at each high point of the pipe system and drain openings at each low point. Make sure to use lockable ball valves or locking caps to prevent hot water leaving the system in case the valves are opened by mistake.

Cooling water pipes are to be designed according to pressure values and flow rates stated in section Planning data for emission standard IMO Tier II – Auxiliary GenSet, Page 62 and the following sections. The engine cooling water connections have to be designed according to PN10/PN16.

5.4.2 GenSet design and components – Water systems

The HT regulation and LT cooling water by-pass valve as well as the lube oil cooler are already installed at the engine frame. If the alternator is water cooled, this additional heat load and piping must be considered for the design of the system. Piping and several instruments are installed on the GenSet to minimise the installation costs and time at the shipyard. As standard the GenSet is equipped with 2-string piping. The following options can be chosen additionally:

- Internal piping for 1-string cooling water system

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The standard for the internal cooling water system is shown in figure Cooling water system diagram, Page 185. This system has been constructed with a view to full integration into the external system.

Low temperature cooling water system

MOV-003/Charge air temperature control valve (CHATCO)

Only available at electric propulsion (and at stationary application). The charge air temperature control valve (CHATCO) is of a 3-way, electrically driven type and serves two purposes.

1. In engine part load operation, depending on the ambient temperature the second stage of the charge air cooler (HE-008) is partially or completely by-passed, to maintain a higher charge air temperature.
2. The valve reduces the accumulation of condensed water after the charge air cooler by regulating the charge air temperature as a function of the dew point temperature of the intake air.

HE-002/Lube oil cooler

For the description of the lube oil cooler see section Lube oil system description, Page 167.

Parameter	Unit	Value
Type	-	Plate type heat exchanger
Material	-	Stainless steel
Pressure drop (water side)	bar	0.20 – 0.35

Table 90: Technical data of lube oil cooler

For heat data, flow rates and tolerances see section Planning data for emission standard IMO Tier II – Auxiliary GenSet, Page 62 and the following. For the description of the principal design criteria see paragraph Cooler dimensioning, general, Page 191.

During postlubrication the cooler should be flown through by LT cooling water and not be shut off immediately after engine shut-off.

HE-008/Charge air cooler (stage 2)

The charged combustion air is further cooled by the LT cooling water, passing stage 2 of the charge air cooler. For permitted pressure, heat data and flow rates see section Planning data for emission standard IMO Tier II – Auxiliary GenSet, Page 62 and the following.

A-001/Alternator

Depending on the manufacturer's design, the alternator may need to be cooled with cooling water. If the alternator and/or the lubricating oil for the alternator bearings are water cooled, the pipes for this can be integrated on the GenSet. The additional LT cooling water flow rate must be considered for the dimensioning of the LT cooling water pump P-076.

High temperature cooling water system

P-002/HT cooling water service pump, attached

The HT cooling water service pump (attached) is of the centrifugal type and mounted at the front cover of the engine. It is driven by the engine's crankshaft through a resilient gear transmission.

Depending on the piping arrangement (1-string or 2-string) the discharge head of the pump must carefully be chosen to avoid excessive pressure upstream the engine. Generally a lower discharge pressure is required, if a 1-string cooling water system is installed. For the auxiliary GenSet two pumps are preset as standard, which must be selected according to the type of cooling water system. It must be strictly ensured, that the chosen pump matches to the executed cooling water system.

Parameter	Unit	Value	
Type of cooling water system	-	1-string	2-string
Discharge head	bar	3.5	4.5
Volume flow	m^3/h	53	70

Table 91: Technical data of attached HT cooling water pump

The optimal operating point of the pump must be adjusted in any case by installing orifices or throttle valves. For permitted pressure, heat data and flow rates see section Planning data for emission standard IMO Tier II – Auxiliary GenSet, Page 62 and the following. The different types of cooling water systems are described in section Cooling water system diagrams, Page 186. Depending on the system design, it may be necessary to use a pump with reduced delivery head. For further information or in case of uncertainty please contact MAN Energy Solutions.

TCV-007/HT cooling water temperature control valve

The HT cooling water control valve serves to maintain the cylinder cooling water temperature constantly at 90 °C at the engine outlet, even in case of frequent load changes and to protect the engine against excessive thermal load. In order to fulfill these requirements a thermostatic valve with a suitable nominal temperature must be installed. By default a wax type thermostatic valve with a nominal temperature of 85 °C is used. Depending on the plant design and its characteristic, a control valve with another nominal temperature may satisfy the requirements.

Parameter	Unit	Value
Type	-	Three-way, thermostatic wax elements
Nominal temperature	°C	85
Working range	°C	82 – 91
Pressure drop	bar	0.15 – 0.20

Table 92: Technical data of HT temperature control valve

The auxiliary GenSets are less suitable for heat recovery due to the low HT cooling water temperature regulation.

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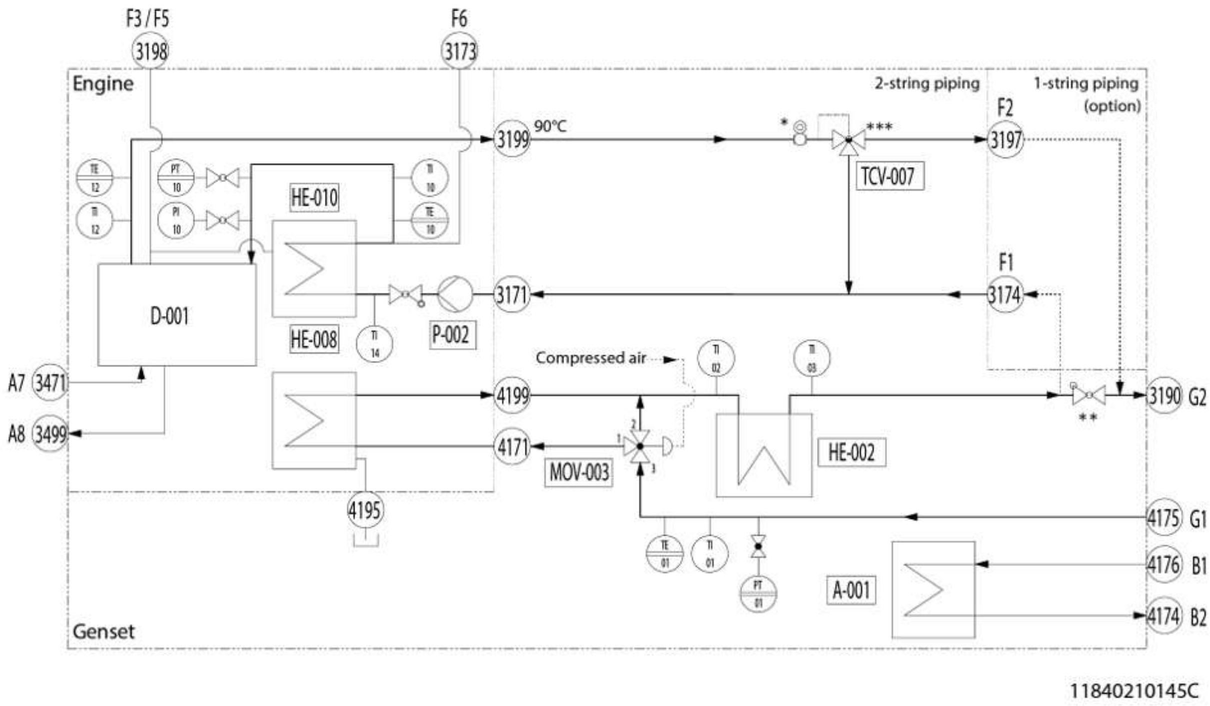

Figure 56: Cooling water system diagram

Instrumentation engine/GenSet			
PT01 (1PT 4170)	Pressure transmitter, inlet engine	PT10 (1PT 3170)	Pressure transmitter, inlet engine
TE10 (1TE 3170)	Temperature element, inlet engine	TE12 (1TE 3180)	Temperature element, outlet engine
GenSet pipe connections			
F1/3173	HT cooling water inlet	A7/3471	Nozzle cooling water inlet
F2/3190	HT cooling water outlet	A8/3499	Nozzle cooling water outlet
F3/3198	Vent (+F5 inlet from external preheater option)	F6/3673	Outlet to external preheater (option)
B1/3263	Alternator inlet	G1/4173	LT cooling water inlet
B2/3273	Alternator outlet	G2/4190	LT cooling water outlet
Engine components			
HE-008	Charge air cooler stage II (LT)	D-001	Diesel engine (cylinder)
HE-010	Charge air cooler stage I (HT)	P-002	HT cooling water service pump, attached
GenSet components			
P-047	Preheating cooling water pump (optional)	HE-002	Lube oil cooler
H-027	Preheater (optional)	TCV-007	HT cooling water control valve
A-001	Alternator	MOV-003	LT cooling water by-pass valve

Engine pipe connections			
3171	HT cooling water inlet	4171	LT cooling water inlet
3183	To preheater	4195	Drain charging air cooler
3199	HT cooling water outlet	4199	LT cooling water outlet

5.4.3 Cooling water system diagrams

Auxiliary GenSet plants

Auxiliary GenSet plants are installed together with main propulsion engines (e.g. on container vessels) to support them and to ensure the electrical power supply on board. A common LT cooling water system allows substantial savings in operating costs. This is why LT central coolers and LT cooling water supply pumps are often used by both, main and auxiliary engines, if they have the same temperature and quality requirements.

1-string system

A further possibility to lower installation and operating costs is to interconnect the HT and the LT cooling system. In this cooling water system, called 1-string cooling water system, there is no HT water cooler installed. The attached HT cooling water pump draws the HT water feed flow directly out of the LT water backflow. After absorbing the heat of charge air cooler and engine, the HT water is pumped back into the LT circuit and the heat load will be dissipated by the central LT cooler. The HT cooling water temperature is adjusted by the thermostatic valve TCV-007.

2-string system

Arrangements with separate LT and HT circuits are called 2-string cooling water systems. Both circuits do not get directly in contact. This may have advantages in case of damage and contamination of the cooling water with lube oil or fuel oil. Leakages can be detected more quickly. The 2-string system also may have less pressure fluctuations, because there are no pumps installed in series. However additional heat exchangers for the HT circuit are necessary. Pumps and heat exchangers can be common for propulsion and GenSet engines, but a separate HT regulation for the GenSet engines is highly recommended.

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Cooling water system diagrams

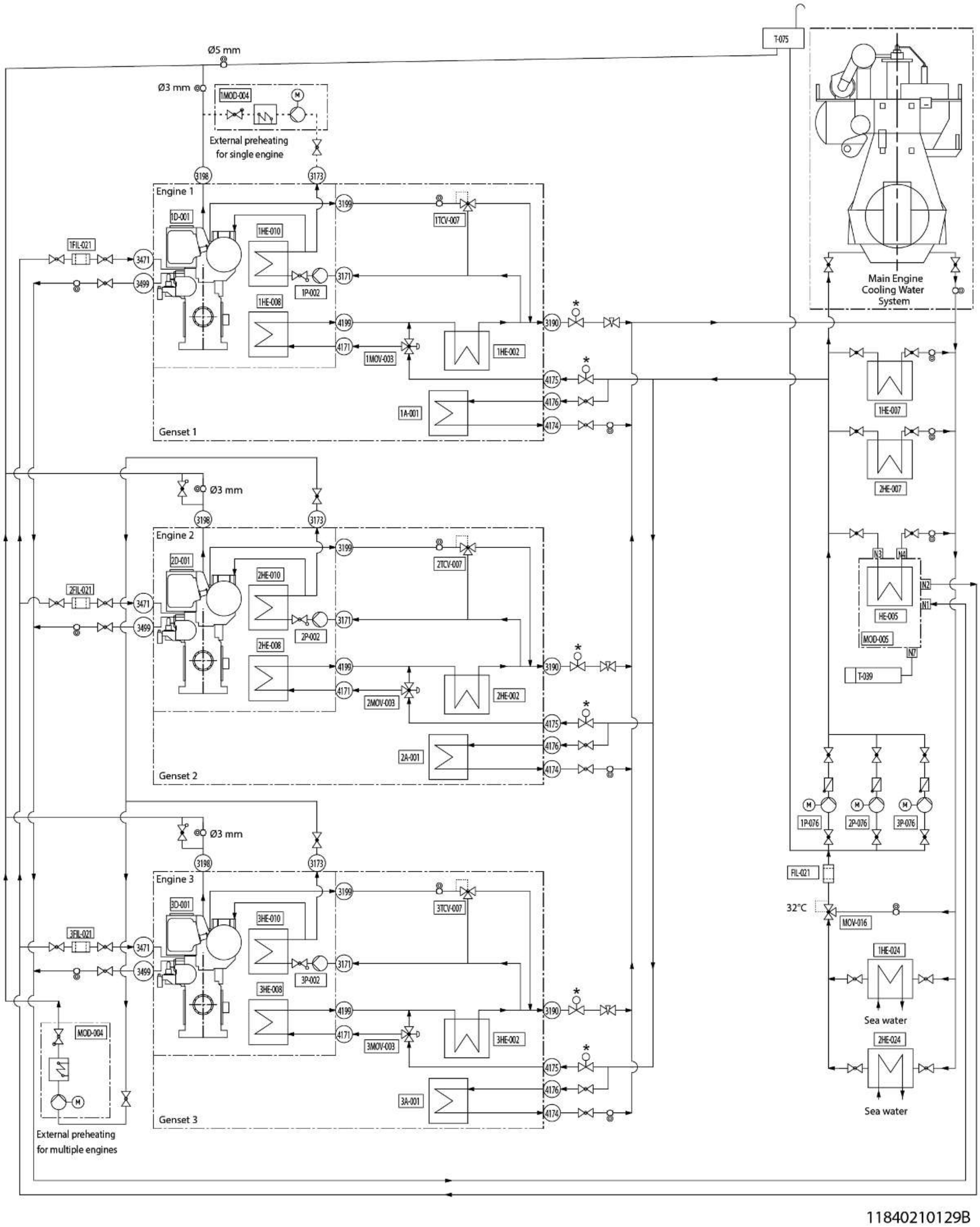

Figure 57: Cooling water system diagram 1-string

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Engine components			
D-001	Diesel engine	HE-010	HT charge air cooler (stage I)
HE-008	LT charge air cooler (stage II)	P-002	HT cooling water service pump, attached
GenSet components			
A-001	Alternator	MOV-003	LT cooling water by-pass valve
HE-002	Lube oil cooler	TCV-007	HT cooling water control valve
Engine room components			
FIL-021	Strainer for commissioning	MOV-016	LT cooling water temperature control valve
HE-005	Nozzle cooling water cooler	1,2 P-076	LT cooling water service pump set, free-standing
HE-007	Fuel oil cooler	3 P-076	LT cooling water port service pump, free-standing
1,2 HE-024	LT cooler	T-039	Cooling water storage tank
MOD-004	HT cooling water preheating module	T-075	LT cooling water expansion tank
MOD-005	Nozzle cooling water module		
Engine pipe connections			
3171	HT cooling water inlet	3471	Nozzle cooling water inlet
3173	HT cooling water outlet (to preheater)	3499	Nozzle cooling water outlet
3198	Engine cooling water ventilation/ preheating	4171	LT cooling water inlet
3199	HT cooling water outlet	4199	LT cooling water outlet
GenSet pipe connections			
3190	LT cooling water inlet	4175	LT cooling water outlet
4174	Alternator outlet	4176	Alternator inlet
Nozzle cooling water module pipe connections			
N1	Nozzle cooling water inlet	N4	LT cooling water outlet
N2	Nozzle cooling water outlet	N7	Discharge
N3	LT cooling water inlet		

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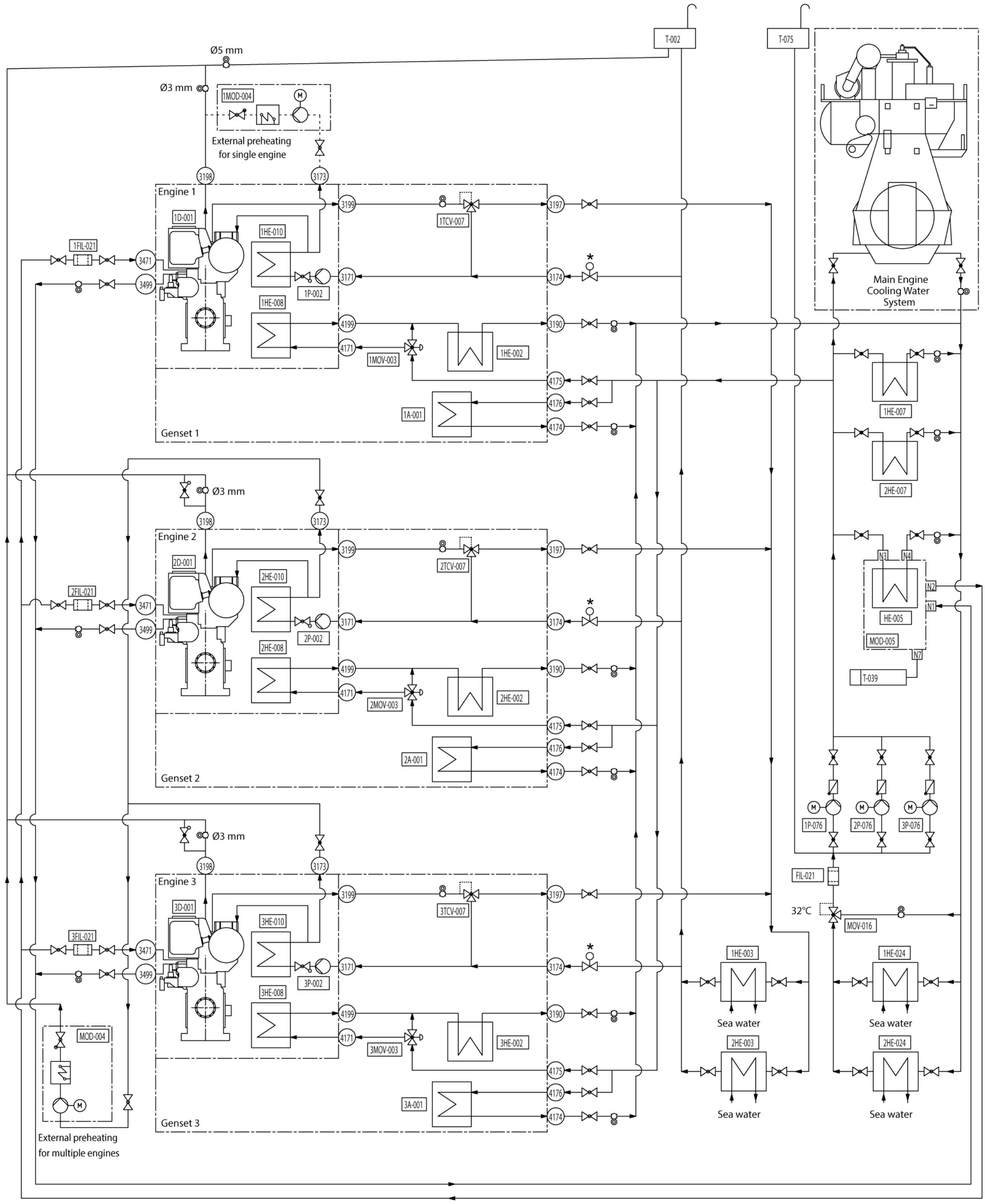

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Figure 58: Cooling water system diagram 2-string

Engine components			
D-001	Diesel engine	HE-010	HT charge air cooler (stage I)
HE-008	LT charge air cooler (stage II)	P-002	HT cooling water service pump, attached
GenSet components			
A-001	Alternator	MOV-003	LT cooling water by-pass valve
HE-002	Lube oil cooler	TCV-007	HT cooling water control valve
Engine room components			
FIL-021	Strainer for commissioning	MOV-016	LT cooling water temperature control valve
1,2 HE-003	Cooler für HT cooling water	1,2 P-076	LT cooling water service pump set, free-standing
HE-005	Nozzle cooling water cooler	3 P-076	LT cooling water port service pump, free-standing
HE-007	Fuel oil cooler	T-002	HT cooling water expansion tank
1,2 HE-024	LT cooler	T-039	Cooling water storage tank
MOD-004	HT cooling water preheating module	T-075	LT cooling water expansion tank
MOD-005	Nozzle cooling water module		
Engine pipe connections			
3171	HT cooling water inlet	3471	Nozzle cooling water inlet
3173	HT cooling water outlet (to preheater)	3499	Nozzle cooling water outlet
3198	Engine cooling water ventilation/ preheating	4171	LT cooling water inlet
3199	HT cooling water outlet	4199	LT cooling water outlet
GenSet pipe connections			
3174	HT cooling water inlet	4174	Alternator outlet
3190	LT cooling water outlet	4175	LT cooling water outlet
3197	HT cooling water outlet	4176	Alternator inlet
Nozzle cooling water module pipe connections			
N1	Nozzle cooling water inlet	N4	LT cooling water outlet
N2	Nozzle cooling water outlet	N7	Discharge
N3	LT cooling water inlet		

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5.4.4 Cooling water system description

The diagrams show the external cooling water systems for auxiliary generating sets (GenSets), which are integrated in the cooling water system of a main propulsion engine. They comprise two different ways of installing the cooling water circuits (1-string or 2-string) and several possible arrangements of the cooling water preheating equipment.

Note:
The arrangement of the cooling water system shown here is only one of many possible solutions. It is recommended to inform MAN Energy Solutions in advance in case other arrangements should be desired.

For the design data of the system components shown in the diagram see section Planning data for emission standard IMO Tier II – Auxiliary GenSet, Page 62 and following sections.

The cooling water is to be conditioned using a corrosion inhibitor, see section Specification of engine coolant, Page 147.

Cooler dimensioning, general

For coolers operated by seawater (not treated water), lube oil or MDO/MGO on the primary side and treated freshwater on the secondary side, an additional safety margin of 10% related to the heat transfer coefficient is to be considered. If treated water is applied on both sides, MAN Energy Solutions does not insist on this margin.

In case antifreeze is added to the cooling water, the corresponding lower heat transfer is to be taken into consideration.

The cooler piping arrangement should include venting and draining facilities for the cooler. In case coolers for lube oil, fuel oil or other environmental hazardous fluids are operated by seawater, we strongly recommend to use double wall plate type coolers. These coolers allow to detect leakage and prevent the seawater from pollution by hazardous fluids.

Open/closed system

Open system

Characterised by "atmospheric pressure" in the expansion tank. Pre-pressure in the system, at the suction side of the cooling water pump is given by the geodetic height of the expansion tank (standard value 6–9 m above crankshaft of engine).

Closed system

In a closed system, the expansion tank is pressurised and has no venting connection to open atmosphere. This system is recommended in case the engine will be operated at cooling water temperatures above 100°C or an open expansion tank may not be placed at the required geodetic height. Use air separators to ensure proper venting of the system.

Venting

Note:
Insufficient venting of the cooling water system prevents air from escaping which can lead to thermal overloading of the engine. Make sure that a minimum flow rate of 1% of the HT-cooling water flow given in section 2 is led from the engine HT-venting connection to the expansion tank at maximum engine speed.

The cooling water system needs to be vented at the highest point in the cooling system. Additional points with venting lines to be installed in the cooling system according to layout and necessity. In case engines may be operated on gas, all venting pipes have to be routed to open atmosphere.

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If LT and HT string are separated, make sure that the venting lines are always routed only to the associated expansion tank. The venting pipe must be connected to the expansion tank below the minimum water level, this prevents oxydation of the cooling water caused by "splashing" from the venting pipe. We recommend to connect the venting pipes at the tank bottom. The expansion tank should be equipped with venting pipe and flange for filling of water and inhibitors.

Additional notes regarding venting pipe routing:

- The ventilation pipe should be continuously inclined (min. 5 degrees).
- At the interface to the system (engine connection terminal), the line must be continued directly with an elastic pipe connection (e.g. hose line).
- No additional masses such as shut-off valves, reducers, extensions, etc. may be attached to the engine-side connection terminal, since they represent an additional oscillating mass that can cause the line to break during operation.
- Venting pipes from several engine circuits may only be connected together if there are no longer any pressure differences between the individual pipes.
- It is to be avoided to merge venting pipes from low-temperature (LT) and high-temperature (HT) circuits, as a separate fault detection (e.g. lubricating oil or fuel in the cooling water) is no longer possible.
- No restrictions, no kinks in the ventilation pipes.
- Merging of ventilation pipes only permitted with appropriate cross-sectional enlargement.
- In case a mixing cooling water system is applied, a throttle valve has to be installed in the HT venting pipe to adjust the flow towards the expansion tank.

Draining

At the lowest point of the cooling system, a drain has to be provided. Additional points for draining to be provided in the cooling system according to layout and necessity, e.g. for components in the system that will be removed for maintenance.

We recommend using lockable valves or locking caps for sample and draining points to avoid opening by mistake.

LT cooling water system

General

In general the LT cooling water passes through the following components:

- Stage 2 of the two-stage charge air cooler (HE-008)
- Lube oil cooler (HE-002)
- Nozzle cooling water cooler (HE-005)
- Fuel oil cooler (HE-007)
- Alternator cooler (if water cooled) (A-001)
- LT cooling water cooler (HE-024)
- Other components such as, e.g., main engine for propulsion

The system components of the LT cooling water circuit are designed for a maximum LT cooling water temperature of 38 °C with a corresponding seawater temperature of 32 °C (tropical conditions).

However, the capacity of the LT cooler (HE-024) is determined by the temperature difference between seawater and LT cooling water. Due to this correlation an LT freshwater temperature of 32 °C can be ensured at a seawater temperature of 25 °C.

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To meet the IMO Tier I/IMO Tier II regulations the set point of the LT cooling water temperature control valve (MOV-016) is to be adjusted to 32 °C. However this temperature will fluctuate and reach at most 38 °C with a seawater temperature of 32 °C (tropical conditions).

The charge air cooler stage 2 (HE-008) and the lube oil cooler (HE-002) are installed in series to obtain a low delivery rate of the LT cooling water pump (P-076).

P-076/LT cooling water pump

Due to operational safety a set of at least two cooling water pumps, one for service and one in stand-by, must be installed for sea operation. These pumps are common for all engines, if they have the same requirements for fresh water quality and temperature. In order to minimise the power consumption, a smaller pump should be installed for port operation and thus only for operating the auxiliary GenSets.

The delivery rates of the pumps are mainly determined by the cooling water, required for the charge air cooler (stage 2) and the other coolers. For the system's flowrates and heat loads see section Planning data for emission standard IMO Tier II – Auxiliary GenSet , Page 62.

MOV-003/LT cooling water by-pass valve

For details of the LT cooling water by-pass valve see section GenSet design and components – Water systems, Page 182.

HE-002/Lube oil cooler, free-standing

For the description see section Lube oil system description, Page 167. For heat data, flow rates and tolerances see section Planning data for emission standard IMO Tier II – Auxiliary GenSet , Page 62 and the following. For the description of the principal design criteria see paragraph Cooler dimensioning, general, Page 191.

HE-024/Cooler for LT cooling water

For heat data, flow rates and tolerances of the heat sources see section Planning data for emission standard IMO Tier II – Auxiliary GenSet , Page 62 and the following. For the description of the principal design criteria for coolers see paragraph Cooler dimensioning, general, Page 191.

MOV-016/LT cooling water temperature control valve

This is a motor-actuated three-way regulating valve with a linear characteristic. It is to be installed as a mixing valve. It maintains the LT cooling water at set point temperature (32 °C standard).

The three-way valve is to be designed for a pressure loss of 0.3 – 0.6 bar. It is to be equipped with an actuator with low positioning speed. For adjustment of the valve please follow instructions given in MAN Energy Solutions planning documentation. The actuator must permit manual emergency adjustment.

The actual LT flow temperature is measured by a temperature sensor, directly downstream of the three-way mixing valve in the supply pipe to charge air cooler stage 1.

This sensor has to be installed by the shipyard. To ensure instantaneous measurement of the mixing temperature of the three-way mixing valve, the distance to the valve should be 5 to 10 times the pipe diameter.

For single engine plants, the control function may be taken over by the SaCoS control unit. For multi engine plants, MAN Energy Solutions can supply a suitable external controller.

Note:
For engine operation with reduced NO_x emission, according to IMO Tier I/IMO Tier II requirement, at 100 % engine load and a seawater temperature of 25 °C (IMO Tier I/IMO Tier II reference temperature), an LT cooling water temperature of 32 °C before charge air cooler stage 2 (HE-008) is to be maintained. For other temperatures, the engine setting has to be adapted. For further details please contact MAN Energy Solutions.

FIL-021/Strainer for cooling water

In order to protect the engine and system components, several strainers are to be provided at the places marked in the diagram. We recommend to install Y-type strainers with a mesh size of 1 – 2 mm depending on the pipe diameter.

HE-005/Nozzle cooling water cooler

The nozzle cooling water system is a separate and closed cooling circuit. It is cooled down by LT cooling water via the nozzle cooling water cooler (HE-005).

Heat data, flow rates and tolerances are indicated in section Planning data for emission standard IMO Tier II – Auxiliary GenSet , Page 62 and the following. The principal design criteria for coolers has been described before in paragraph Cooler dimensioning, general, Page 191. For plants with two main engines only one nozzle cooling water cooler (HE-005) is required. As an option a compact nozzle cooling water module (MOD-005) can be delivered, see section Nozzle cooling water module, Page 201.

HE-007/Fuel oil cooler

This cooler is required to dissipate the heat of the fuel injection pumps during MDO/MGO operation. For the description of the principal design criteria for coolers see paragraph Cooler dimensioning, general, Page 191. For plants with more than one engine, connected to the same fuel oil system, only one MDO/MGO cooler is required. In case the fuel oil cooler is recooled by seawater, we recommend to use a double-wall type cooler.

In case fuels with very low viscosity are used (e.g. arctic diesel or military fuels), a chiller system may be necessary to meet the minimum required fuel viscosity (see section Fuel oil system, Page 208). Contact MAN Energy Solutions in that case.

T-075/LT cooling water expansion tank

The expansion tank compensates changes in system volume and losses due to leakages. It is to be arranged in such a way, that the tank bottom is situated above the highest point of the system at any ship inclination.

The expansion pipe shall connect the tank with the suction side of the pump(s), as close as possible. It is to be installed in a steady rise (minimum 5°) to the expansion tank, without any air pockets. Minimum required diameter is DN 32 for L engines and DN 40 for V engines.

For the recommended installation height and the diameter of the connecting pipe, see table Service tanks capacities, Page 75.

The tank must have the following equipment:

- Sight glass for level monitoring or other suitable device for continuous level monitoring
- Low-level alarm switch
- Overflow and filling connection
- Inlet for corrosion inhibitor
- Venting pipe

To prevent oxidation of the cooling water caused by “splashing”, the venting pipe must be connected to the tank below the minimum water level.

1-string system

For plants with interconnected LT and HT systems, the minimum tank volume should be determined by the following equation, depending on the number of cylinders:

$V = 0.5 + V_{expansion} * n_{engine}\ [m^3]$

The expansion volume is given in table Cooling water expansion volume, Page 195, below.

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Parameter	Unit	Value			
Number of cylinders		6	7	8	9
Expansion volume (HT and LT system)	litre	13	15	18	20

Table 93: Cooling water expansion volume

2-string system

The effective tank capacity should be high enough to keep approximately 2/3 of the tank content of T-002. In case of twin-engine plants with a common cooling water system, the tank capacity should be by approximately 50 % higher. The tanks T-075 and T-002 should be arranged side by side to facilitate installation. In any case the tank bottom must be installed above the highest point of the LT system at any ship inclination.

HT cooling water system

General

The HT cooling water system consists of the following coolers and heat exchangers:

- Charge air cooler stage 1 (HE-010)
- Cylinder and valve head cooling (D-001)
- Cooler for HT cooling water (HE-003)
- HT cooling water preheater (H-027)

Each engine has its own attached HT cooling water pump. The outlet temperature of the cylinder cooling water is regulated to 90 °C after the engine by the temperature control valve TCV-007, which is installed on the GenSet frame.

The shipyard is responsible for the correct cooling water distribution, ensuring that each engine will be supplied with cooling water at the flow rates required by the individual engines, under all operating conditions. To meet this requirement, orifices, flow regulation valves, by-pass systems etc. are to be installed where necessary. Check total pressure loss in HT circuit. The delivery height of the attached pump must not be exceeded.

P-002/HT cooling water service pump, attached

The engine is equipped with a HT cooling water service pump (attached). For details see section GenSet design and components – Water systems, Page 182.

HE-003/Cooler for HT cooling water

If the engines cooling water system is installed as a 2-string system, a cooler for HT cooling water must be installed. The heat from the HT cooling water can either be transferred to the LT cooling system or directly to the seawater.

For heat data, flow rates and tolerances of the heat sources see section Planning data for emission standard IMO Tier II – Auxiliary GenSet , Page 62 and the following. For the description of the principal design criteria for coolers see paragraph Cooler dimensioning, general, Page 191.

T-002/HT cooling water expansion tank 2-string system

The expansion tank compensates changes in system volume and losses due to leakages. It is to be arranged in such a way, that the tank bottom is situated above the highest point of the system at any ship inclination.

The expansion pipe shall connect the tank with the suction side of the pump(s), as close as possible. It is to be installed in a steady rise (minimum 5°) to the expansion tank, without any air pockets. Minimum required diameter is DN 32 for L engines and DN 40 for V engines.

For the required volume of the tank, the recommended installation height and the diameter of the connection pipe, see table Service tanks capacites, Page 75.

Tank equipment:

- Sight glass for level monitoring or other suitable device for continuous level monitoring
- Low-level alarm switch
- Overflow and filling connection
- Inlet for corrosion inhibitor
- Venting pipe

To prevent oxidation of the cooling water caused by “splashing”, the venting pipe must be connected to the tank below the minimum water level.

Engine preheating

To secure a perfect combustion and at the same time avoid cold corrosion, the engine must be preheated, in stand-by mode or before starting on HFO. One part is the preheating of the engine’s water jackets and valve heads by the HT cooling water. The second part is the preheating of the charge air right after starting by the LT cooling water by-pass valve MOV-003.

On figure Cooling water system diagram 1-string, Page 187, two different arrangements of the preheating equipment are shown.

- External, installed in the plant, one for each single GenSet.
- External, installed in the plant, common for all GenSets.

At 1-string systems, the LT cooling water flow must be shut off to be able to preheat the engine effectively. Usually that is done by automatically actuated valves. Electrically or pneumatically driven valves shall be used. Valves actuated by engine lube oil must not be used, because of the very real risk of cooling water entering the lubricating oil system due to a broken actuator diaphragm.

MOD-004/HT cooling water preheating module

All preheating equipment can be integrated and installed as one single unit. As an option MAN Energy Solutions can supply a compact HT cooling water preheating module (MOD-004). Please contact MAN Energy Solutions to check the hydraulic circuit and electric connections. Figure Example – Compact HT cooling water preheating module, Page 197 shows an example of such a preheating module.

The main components of the HT cooling water preheating module are the HT cooling water preheating pump and the HT cooling water preheater.

P-047/HT preheating pump

An electrically driven pump becomes necessary to circulate the HT cooling water during preheating. The flow through each cylinder should be approximately 2.5 l/min with flow from top and downwards.

HE-027/Preheater

The preheater must be designed to preheat the engine up to 60 °C. To prevent a too quick and uneven heating of the engine, the preheating temperature of the HT cooling water at engine inlet must remain mandatory below 90 °C and the circulation amount may not exceed 30 % of the nominal flow. The maximum heating power has to be calculated accordingly.

The preheater must be designed to preheat the engine up to 60 °C. To prevent a too quick and uneven heating of the engine, the preheating temperature of the HT cooling water at engine inlet must remain mandatory below 90 °C and the circulation amount may not exceed 30 % of the nominal flow. The maximum heating power has to be calculated accordingly.

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For preheating the HT cooling water from 10 °C to 60 °C within 8 hours, the capacity of the external preheater should be 2.5 to 3.0 kW per cylinder. These values include the radiation heat losses from the outer surface of the engine. Also a margin of 20 % for heat losses of the cooling system has been considered.

For the quantity of cooling water inside the engine see table Cooling water and oil volume of engine, Page 75.

Please avoid an installation of the preheater in parallel to the engine driven HT pump. In this case, the preheater may not be operated while the engine is running. Preheaters operated on steam or thermal oil may cause alarms since a post-cooling of the heat exchanger is not possible after engine start (preheater pump is blocked by counter pressure of the engine driven pump).

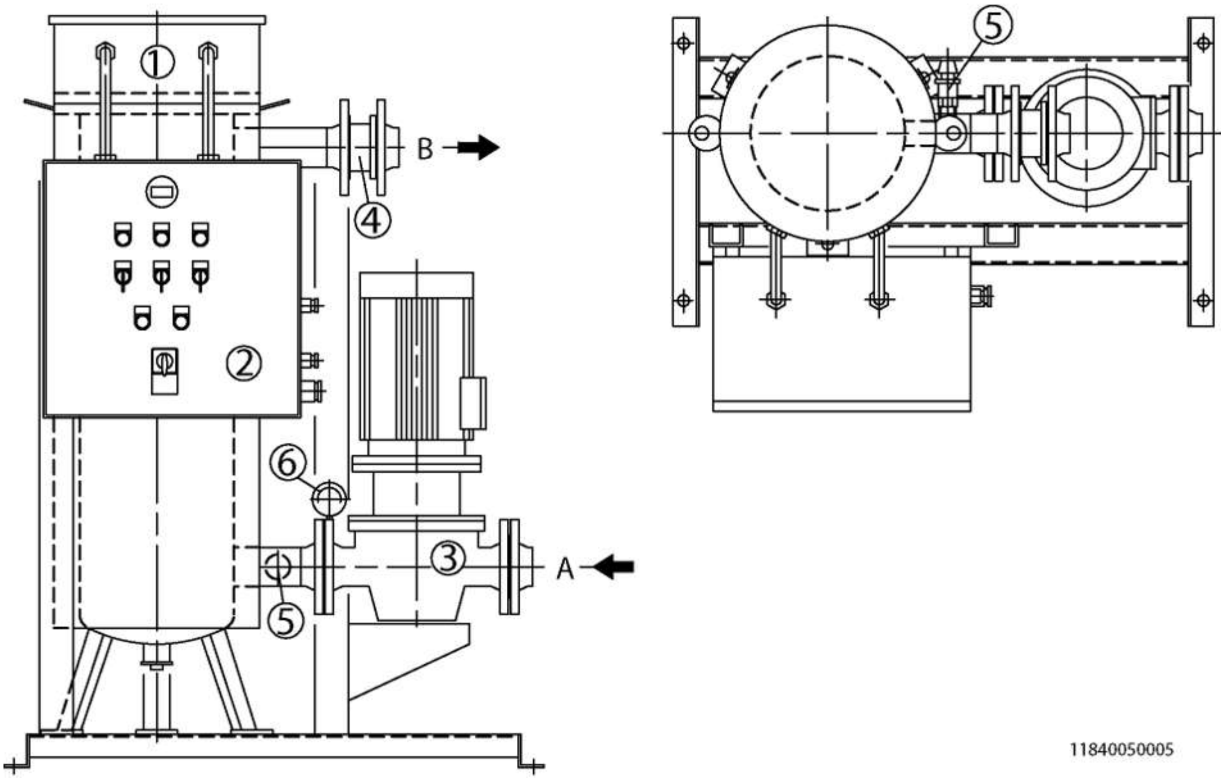

Figure 59: Example – Compact HT cooling water preheating module

1	Electric flow heater	5	Safety valve
2	Switch cabinet	6	Manometer (filled with glycerin)
3	Circulation pump	A	Cooling water inlet
4	Non-return valve	B	Cooling water outlet

Preheating of the main engine with surplus heat

The preheating of the main engine with cooling water from auxiliary engines is also possible, provided that the cooling water is treated in the same way. In that case, the expansion tanks of the two cooling systems have to be installed at the same level. Furthermore, it must be checked, if the available heat is sufficient to pre-heat the main engine. This depends on the number of auxiliary engines in operation and their load. It is recommended to install a separate preheater for the main engine, as the available heat from the auxiliary engines may be insufficient during operation in port.

Preheating of the auxiliary engines with surplus heat

As shown in the diagrams, the auxiliary engines are preheated in stand-by position with surplus heat from the running engines. If the engines are preheated with reverse cooling water direction, from the top and downwards, an optimal heat distribution is reached in the engine. This method is at the same time more economical since the need for heating is less and the water flow is reduced. Due to the pressure difference, the HT cooling water pumps of the running engines provide, the GenSets are preheated automatically via the venting pipe.

Preheating of charge air

During low load operation the low temperature cooling water is by-passed on LT side of charge air cooler and led directly to lube oil cooler. This is done to raise charge air temperature and improve combustion. At the connection F3 for the expansion tank there is a non-return valve with Ø 3 mm hole. This is for the internal connections of the engine to improve preheating of the engine at stand-by.

Engine post-cooling

It is required to cool down the engine for a period of 15 minutes after shut-down. For this purpose the stand-by pump can be used. In case that neither an electrically driven HT cooling water pump nor an electrically driven stand-by pump is installed (e.g. multi-engine plants with engine driven HT cooling water pump without electrically driven HT stand-by pump, if applicable by the classification rules), it is possible to cool down the engine by a separate small preheating pump. If the optional HT cooling water preheating module (MOD-004) with integrated circulation pump is installed, it is also possible to cool down the engine with this small pump. However, the pump used to cool down the engine, has to be electrically driven and started automatically after engine shut-down.

5.4.5 External cooling water system – Collection and supply system

T-074/Cooling water collecting tank

The tank is to be dimensioned and arranged in such a way that the cooling water content of the circuits of the cylinder, turbocharger and nozzle cooling systems can be drained into it for maintenance purposes.

This is necessary to meet the requirements with regard to environmental protection (water has been treated with chemicals) and corrosion inhibition (re-use of conditioned cooling water).

Volumes for the engine are listed in table Cooling water and oil volume of engine, Page 75.

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P-031/Cooling water filling pump (not indicated in the diagram)

To refill the HT- and LT cooling water system after maintenance, we recommend to install a cooling water filling pump. The pump shall be installed below the cooling water collecting tank with pipe connections to the related systems.

5.4.6 Nozzle cooling system

P-005/Nozzle cooling water pump

The centrifugal (non self-priming) pump discharges cooling water via the nozzle cooling water cooler (HE-005) and the strainer for cooling water (FIL-021) to the header pipe on the engine and then to the individual injection valves.

HE-005/Nozzle cooling water cooler

The nozzle cooling water cooler is to be connected in the LT cooling water circuit according to schematic diagram. Cooling of the nozzle cooling water is effected by the LT cooling water.

If an antifreeze is added to the cooling water, the resulting lower heat transfer rate must be taken into consideration. The cooler is to be provided with venting and draining facilities.

TCV-005/Nozzle cooling water temperature control valve

The nozzle cooling water temperature control valve with thermal-expansion elements regulates the flow through the cooler to reach the required inlet temperature of the nozzle cooling water. It has a regulating range from approximately 55°C (valve begins to open the pipe from the cooler) to 65°C (pipe from the cooler completely open).

FIL-021/Strainer for cooling water

To protect the nozzles for the first commissioning of the engine a strainer for cooling water has to be provided.

We recommend to install Y-type strainers. For further operation of the engine, we recommend to use a cartridge with mesh size of about 1 mm to catch particles.

The strainers have to be installed in horizontal pipes or pipes with flow direction downwards.

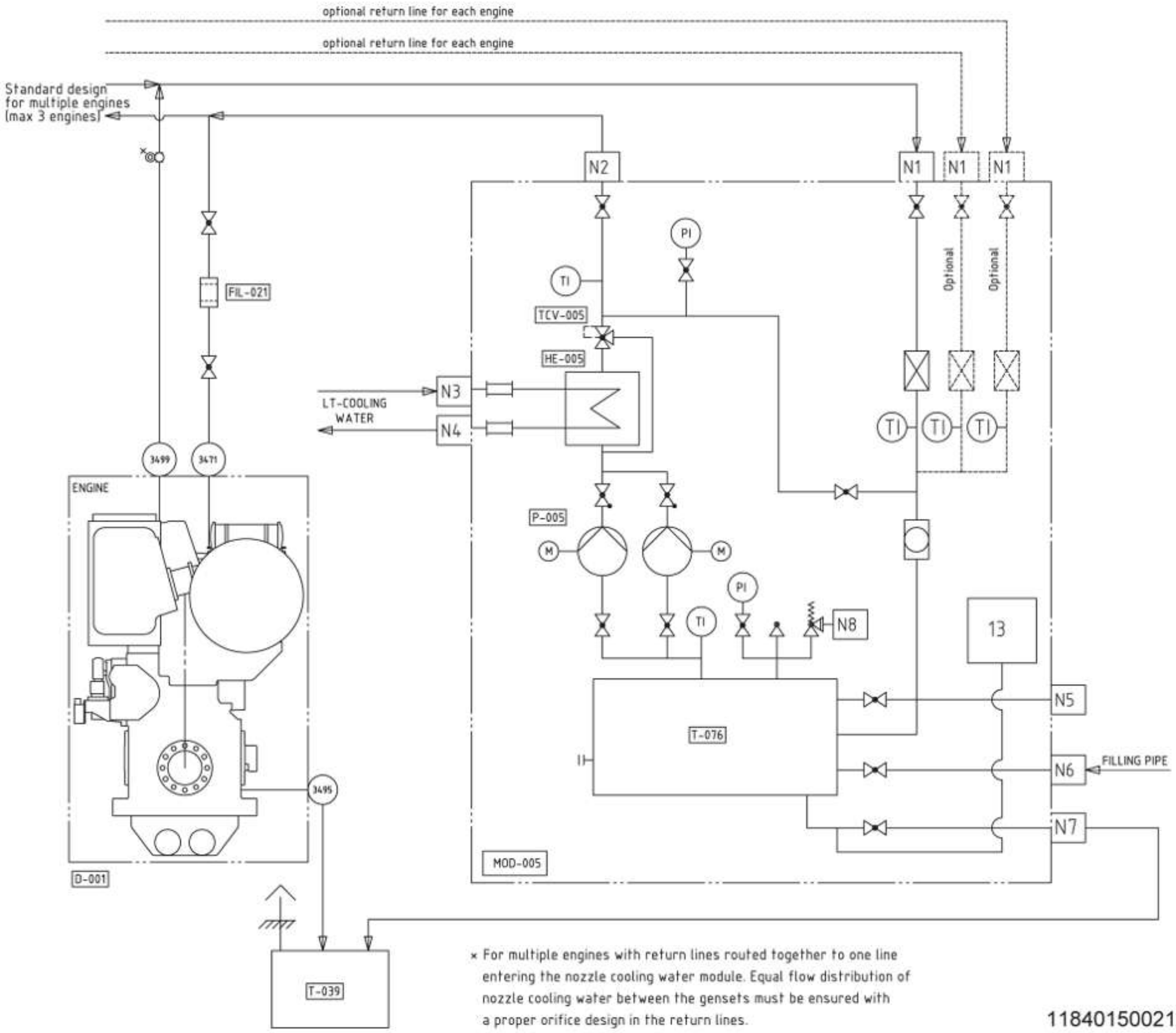

Figure 60: Nozzle cooling system diagram

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Components			
D-001	Diesel engine	P-005	Nozzle cooling water pump
FIL-021	Strainer for commissioning	T-039	Cooling water storage tank
HE-005	Nozzle cooling water cooler	T-076	Nozzle cooling water service tank
MOD-005	Nozzle cooling water module	TCV-005	Nozzle cooling water temperature control valve
Major engine connections			
3471	Nozzle cooling water inlet	3494	Nozzle cooling water outlet
3495	Nozzle cooling water drain		
Connections to the nozzle cooling module			
N1	Nozzle cooling water return from engine	N6	Filling connection
N2	Nozzle cooling water outlet to engine	N7	Discharge
N3	Cooling water inlet	N8	From savety valve
N4	Cooling water outlet	13	Expansion pot
N5	Check for "oil in water"		

5.4.7 Nozzle cooling water module

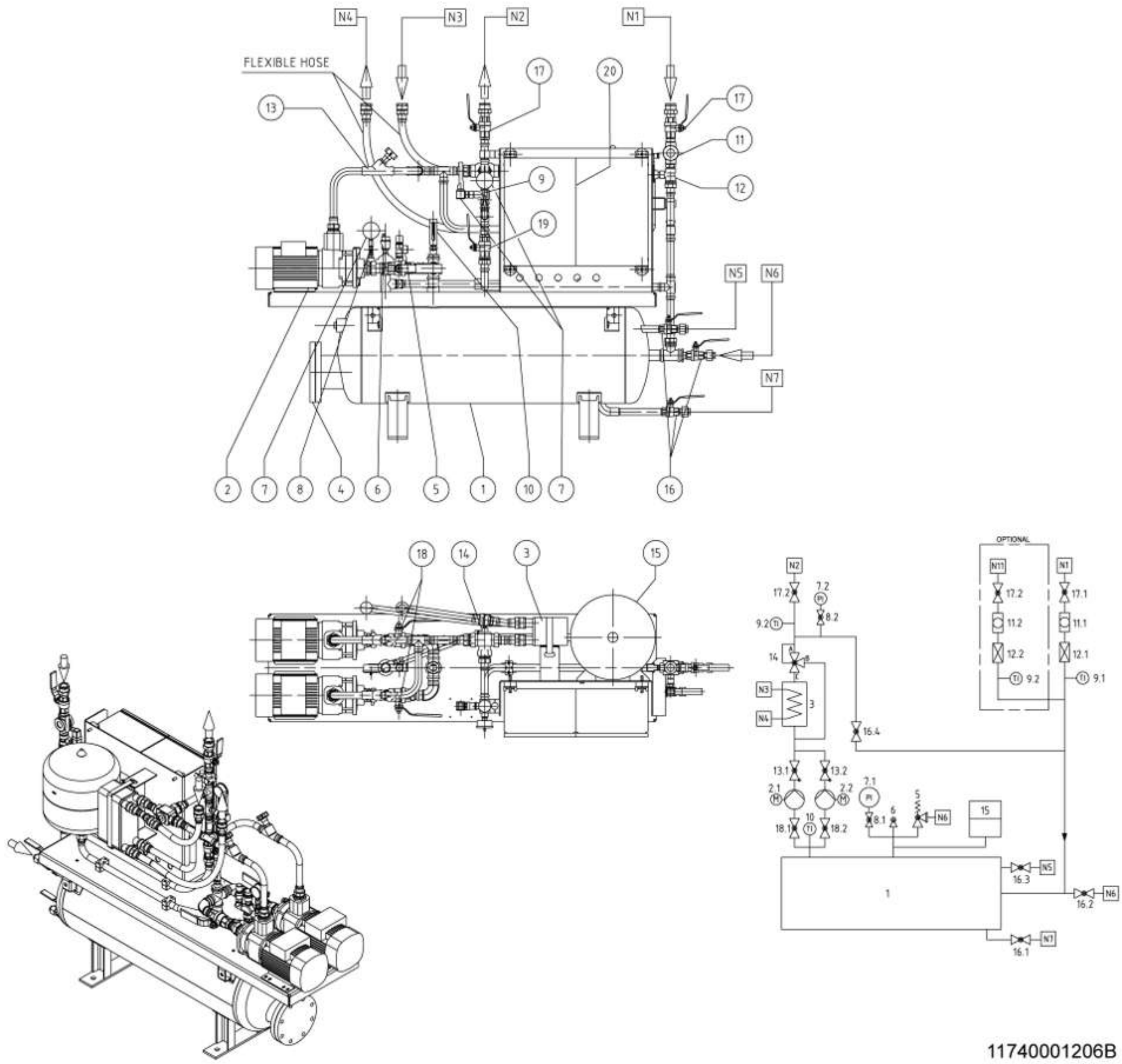
General

In HFO operation, the nozzles of the fuel injection valves are cooled by fresh-water circulation, therefore a nozzle cooling water system is required. It is a separate and closed system re-cooled by the LT cooling water system, but not directly in contact with the LT cooling water. The separate nozzle cooling water system ensures easy detection of damages at the nozzles. Even small fuel leakages are visible via the sight glass. The closed system also prevents the engine and other parts of the cooling water system from pollution by fuel oil. Cleaning of the system is quite easy and only a small amount of contaminated water has to be discharged to the sludge tank. In case the nozzle cooling water is not contaminated, it may be drained to the cooling water collecting tank. The nozzle cooling water is to be treated with corrosion inhibitor according to MAN Energy Solutions specification. For further information see section Specification of engine coolant, Page 147.

Note:
In diesel engines designed to operate prevalently on HFO the injection valves are to be cooled during operation on HFO. In the case of MGO or MDO operation exceeding 72 h, the nozzle cooling is to be switched off and the supply line is to be closed. The return pipe has to remain open.
In diesel engines designed to operate exclusively on MGO or MDO (no HFO operation possible), nozzle cooling is not required. The nozzle cooling system is omitted.

Design

The nozzle cooling water module consists of a storage tank, on which all components required for nozzle cooling are mounted.



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Part list

1	Tank	11	Sight glass
2	Circulation pump	12	Flow switch set point
3	Plate heat exchanger	13	Valve with non-return
4	Inspection hatch	14	Temperature regulating valve
5	Safety valve	15	Expansion pot
6	Automatic venting	16	Ball type cock
7	Pressure gauge	17	Ball type cock
8	Valve	18	Ball type cock
9	Thermometer	19	Ball type cock
10	Thermometer	20	Switch cabinet

Connections to the nozzle cooling module

N1	Nozzle cooling water return from engine	N5	Check for "oil in water"
N2	Nozzle cooling water outlet to engine	N6	Filling connection
N3	Cooling water inlet	N7	Discharge
N4	Cooling water outlet		

Figure 61: Example: Compact nozzle cooling water module

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Alarm limits

MAN Energy Solutions recommends the following alarm limits during operation of nozzle cooling water module:

- Alarm nozzle cooling water pressure low: 2.8 bar, L
- Alarm nozzle cooling water temperature high: 70° C, H

5.5 Bilge water/oily water

5.5.1 Introduction

For operation and maintenance of the engine, several pipes and tanks for supply of fresh water and disposal of bilge/oily water are to be provided.

A water cleaning system for bilge water in accordance with MARPOL requirements and rules of classification societies and local authorities must be installed. Oily water or water treated with chemical additives must not be discharged into the sea.

5.5.2 Turbocharger washing equipment

The turbocharger of engines operating on heavy fuel oil or MDO must be cleaned at regular intervals. This requires the installation of a freshwater supply line from the sanitary fresh water system to the turbine washing equipment and dirty-water drain pipes via a funnel (for visual inspection) to the bilge system. A fresh water connection DN 25 with shut-off valve, pressure reducing device (2–4 bar) with integrated filter and pressure gauge (0–6 bar) is to be provided.

The water lance must be removed after every washing process. This is a precautionary measure, which serves to prevent an inadvertent admission of water to the turbocharger.

The turbocharger washing equipment is completely mounted on the turbocharger.

For further information contact MAN Energy Solutions.

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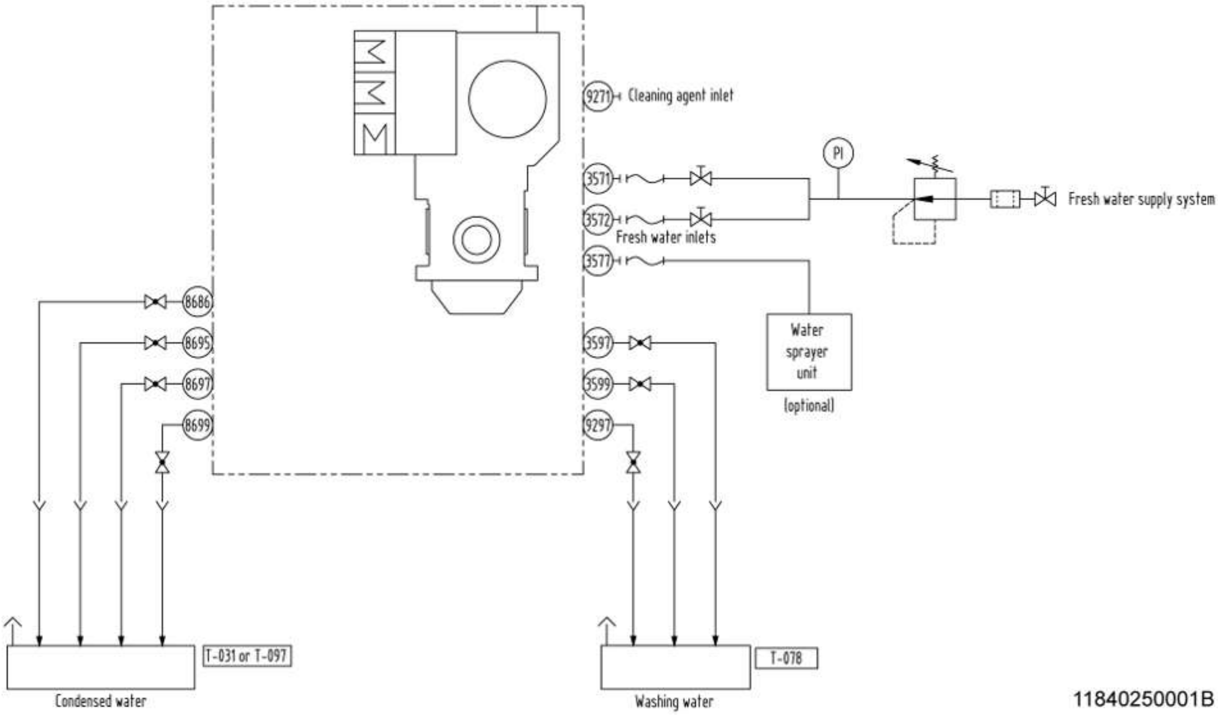

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	Components		
T-031	Condensate collecting tank	T-097	Bilge
T-078	Waste water tank		
	Sanitary water engine connections		
3571	Inlet connection for turbine cleaning device wet	3597	Dirty water drain from turbocharger
3572	Inlet connection for turbine cleaning device wet	3599	Dirty water drain from turbocharger
3577	Inlet connection for compressor cleaning device wet		
	Condensed water engine connections		
8686	Condensed water drain from charge air manifold	8697	Condensed water drain
8695	Condensed water drain	8699	Condensed water drain from charge air manifold
	Washing water engine connections		
9271	Charge air cooler cleaning agent inlet	9297	Charge air cooler cleaning agent drain

Figure 62: P&ID washing water/condensed water

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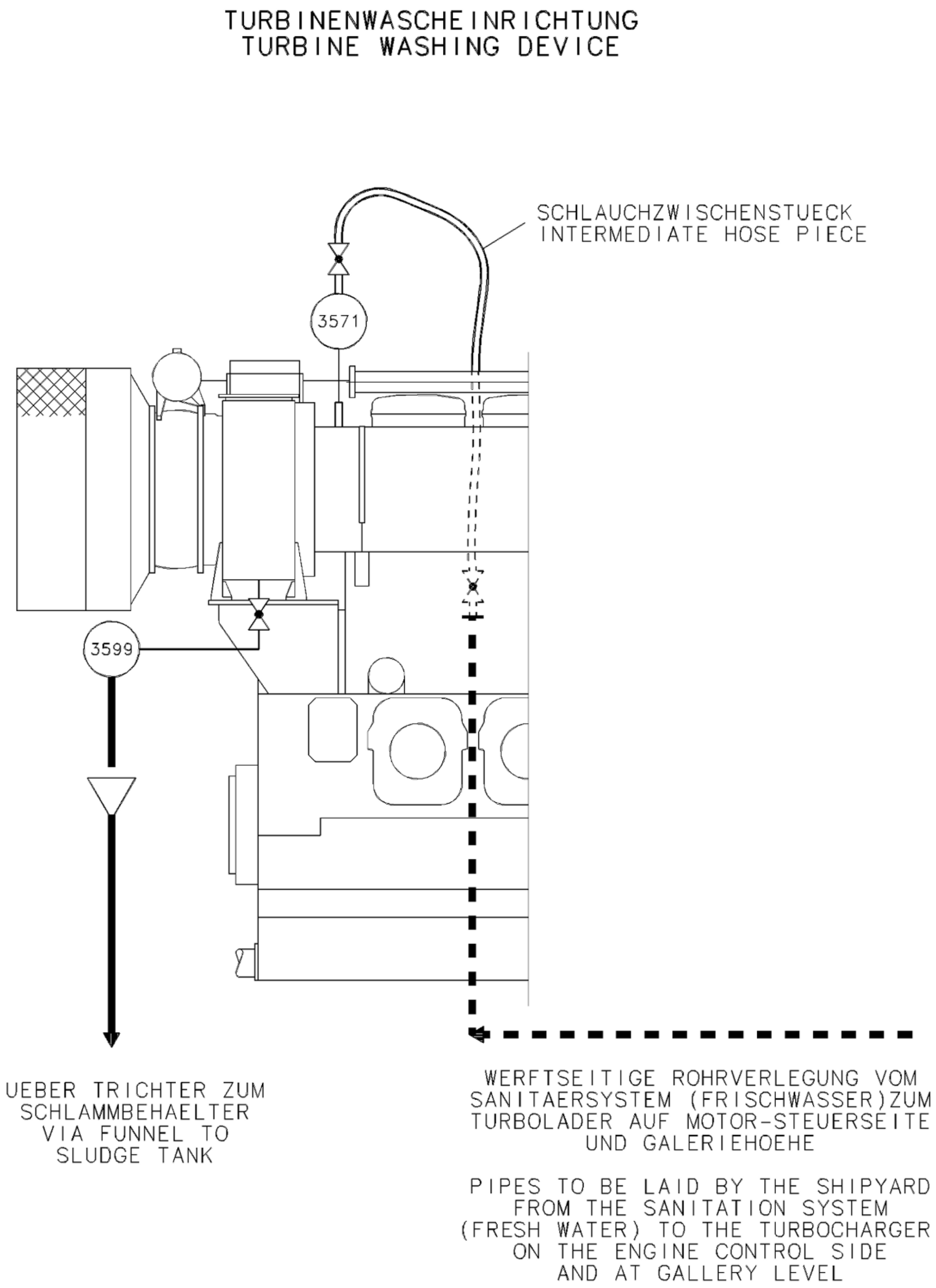

Figure 63: Cleaning turbine

5.5.3 Cleaning of charge air cooler

The cooler bundle can be cleaned without being removed. Prior to filling with cleaning solvent, the charge air cooler and its adjacent housings must be separated from the turbocharger and charge air pipe using blind flanges.

- The casing must be filled and drained with a firehose with shut-off valve.
- If the cooler bundle is contaminated with oil, the charge air cooler casing is to be filled with freshwater and a liquid detergent additive.
- Insert the ultrasonic cleaning device after addition of the cleaning agent in default dosing portion.
- Flush with freshwater at least two times.

The contaminated water must be removed after every sequence and drained into the bilge or an oily/dirty water tank.

Recommended cleaning medium:

"PrimeServClean MAN C 0186"

Note:
When using cleaning agents:
The instructions of the manufacturers must be observed. In particular the data sheets with safety relevance must be followed. The temperature of these products has (due to the fact that some of them are inflammable) to be at least 10 °C lower than the respective flash point. The waste disposal instructions of the manufacturers must be observed. All terms and conditions of the classification societies as well as MARPOL requirements must be fulfilled.

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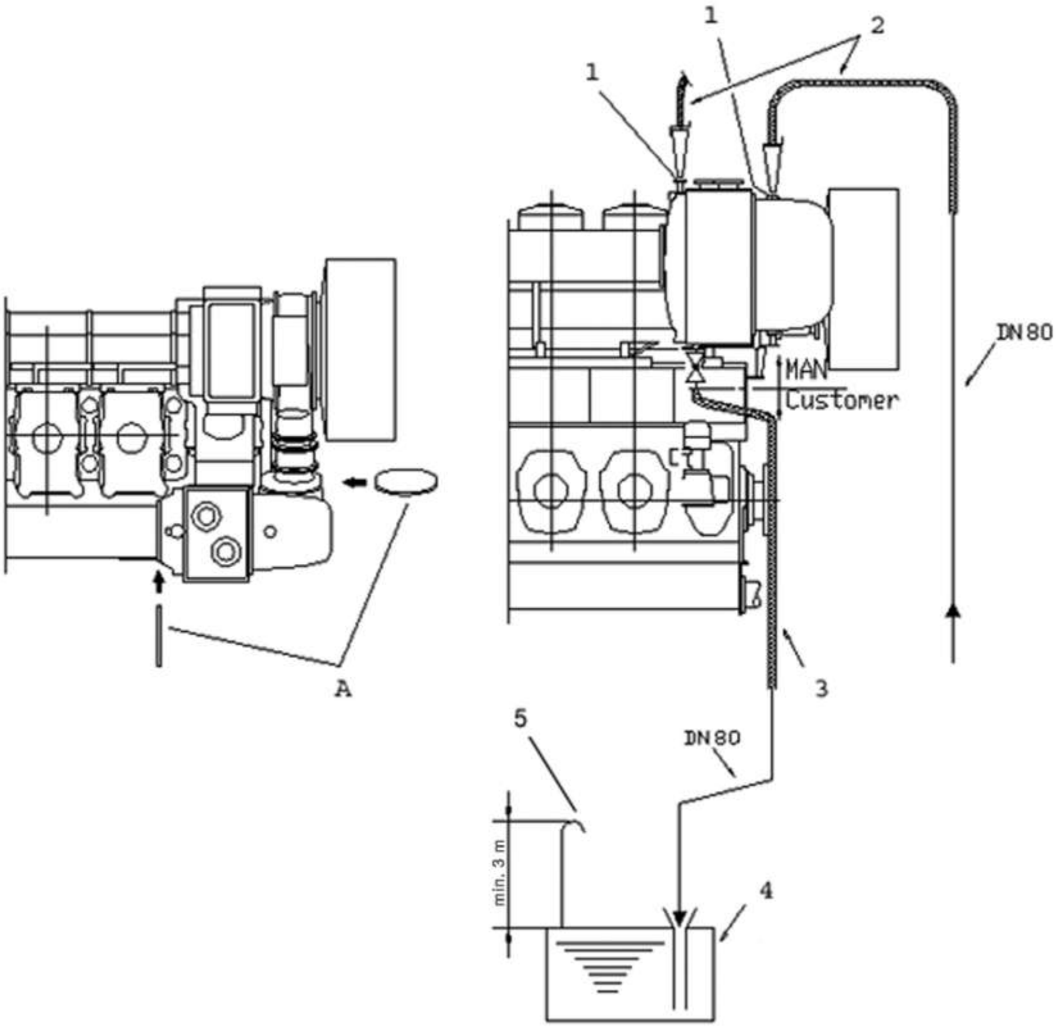

1 Installation ultrasonic cleaning
2 Firehose with sprag nozzle
3 Firehose
4 Dirty water collecting tank.
Required size of dirty water collecting tank: Volume at the least 4-multiple charge air cooler volume.
5 Ventilation
A Isolation with blind flanges

Figure 64: Principle layout

5.5.4 Condensate monitoring tank drain

The condensate deposition in the charge air cooler is drained via the condensate monitoring tank. The condensate can be drained to the bilge.

If sailing mainly in tropical areas with high amount of condensate, the installation of a separate condensate holding tank might be useful to avoid the unnecessary use of an oily water separator. This condensate might be directly discharged to the sea. Nevertheless, oil monitoring of the condensate is mandatory.

5.5.5 Nozzle cooling water drain

It might occur, that the nozzle cooling water becomes contaminated with fuel oil due to a nozzle failure.

For such an event, a draining possibility to the sludge tank should be provided. As the cooling water volume is quite low, the draining can be done manually (e.g. with a bucket or a temporary hose).

5.5.6 Condensate drain starting air system

The condensed water from condensate traps related to the starting air system may be led to the bilge. The function of the drains should be monitorable (e.g. via funnels, sight glasses or other devices).

5.6 Fuel oil system

5.6.1 General

The fuel oil system must be designed and built to supply the diesel engine with fuel oil, which meets all requirements specified by MAN Energy Solutions. In order to achieve this purpose, plant equipment for storage, transfer, purification, heating and cooling, measuring and monitoring installations as well as piping and control systems are necessary. The shown system diagrams are for guidance only. Both, an integrated system according to the uni fuel concept as well as a separated system for supplying the auxiliary engines exclusively, are possible. They have to be adapted in each case to the actual engine type, pipe layout and applicable classification rules.

Uni fuel concept

Auxiliary GenSet plants are installed together with the main propulsion engines (e.g. on container vessels) to support them and to ensure the electrical power supply on board. The fuel oil system can be designed as an uni fuel system, indicating that the propulsion engine and the GenSets are running on the same fuel oil and are fed from a common fuel oil system.

Emergency MDO supply system

Always a separate and pure MDO supply system for the auxiliary engines is installed. It ensures the independent fuel oil supply in case of an emergency (e.g. fault within HFO system or blackout) or to flush the engines with distillate fuel before repair or maintenance. At multi-engine plants this system allows to operate e.g one GenSet in MDO mode, while the other GenSets are still running in HFO mode. The separate emergency MDO supply system is not designed for continuous operation, but only for temporary emergency operation.

Fuel types

Different local emission regulations on the one hand and economic reasons on the other hand, require the storage of more and more different sorts of fuel oil on board. Besides distillate fuel oils (DMA, DMB), high-viscosity and heavy fuel oils (RMK fuels) are important to operate large vessels economically.

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Since January 2015 more strictly emission regulations concerning the sulphur content of fuels used within the so called „sulphur emission control areas (SECAs)" apply. As a result several "ultra low sulphur" fuel oils are offered. From an engine manufacturer's point of view there is no lower limit for the sulphur content of fuel oil. MAN Energy Solutions has not experienced any trouble with the currently available low sulphur fuels, that is related to the sulphur content. However new fuel production methods are applied (desulphurisation, uncommon blending components), which will challenge the whole fuel oil system.

In the following section the abbreviation MDO (marine diesel oil) is used as synonym for all distillate fuels, such as DMA, DFA (former MGO) and DMB, DFB (former MDO) acc. to ISO 8217. The abbreviation HFO (heavy fuel oil) will be used generally for RM-fuels with high content of residual oils (RMA - RMK) according to ISO 8217. Further information about all approved fuels is given in section Specification for engine supplies, Page 119.

Mixing of fuels

Different fuels are mixed inevitably in tanks, pipes and engines. As a result incompatibility reactions may occur and lead to damages of the engine and the plant system. To avoid incompatibility reactions it is recommended to check the compatibility between all handled fuels, especially between low sulphur (LS)/ultra low sulphur (ULS) and conventional fuels, by lab (e.g. PrimeServLab) or with an onboard kit before bunkering. Test methods following ASTM D2781, ASTM D4740 or ASTM D7060 may be suitable for rough estimation of fuel compatibility.

Low mixture ratios between HFO and MDO normally effect no incompatibility reactions:

- Max. MDO content in HFO: 5 % vol.
- Max. HFO content in MDO: 2 % vol.

However incompatibility reactions cannot be excluded completely, especially when using HFO with high asphaltene content and less aromatic MDO. Compatibility tests are required in any case.

Withdrawal points for samples

Fuel oil sampling points are to be provided upstream and downstream of each filter, to verify the effectiveness of these system components.

Piping

The fuel oil system design pressure is PN16 (see section External pipe dimensioning, Page 159). The system is to be protected from higher pressure levels by corresponding safety valves. Additional safety valves, not displayed in the P&ID, might become necessary depending on the actual fuel oil system design.

Material

The casing material of pumps and filters should be EN-GJS (nodular cast iron), in accordance to the requirements of the classification societies.

5.6.2 Marine diesel oil (MDO) treatment system

A prerequisite for safe and reliable engine operation with a minimum of servicing is a properly designed and well-functioning fuel oil treatment system.

The schematic diagram, see figure MDO treatment system diagram, Page 212 shows the system components required for fuel oil treatment for marine diesel oil (MDO).

T-015/Diesel fuel oil storage tank

The minimum effective capacity of the tank should be sufficient for the operation of the propulsion plant, as well as for the operation of the auxiliary diesels for the maximum duration of voyage including the resulting sediments and water. Regarding the tank design, the requirements of the respective classification society are to be observed.

The diesel fuel oil storage tank should be provided with a sludge space with a tank bottom inclination of preferably 10° and sludge drain valves at the lowest point to drain the settled sludge at regular intervals.

Tank heating

The tank heater must be designed so that the MDO temperature is at least 10 °C minimum above the pour point. The supply of the heating medium must be automatically controlled as a function of the MDO temperature.

Fuel with biodiesel

In case fuel oils with up to 7 % of biodiesel (FAME) are used, there is an increased risk of degradation especially due to microbial activity which can threaten engine performance. In order to minimise this risk, long storage periods of this fuel have to be avoided. Furthermore all distillate tanks are to be supplied with a drainage system to prevent bacterial growth by water accumulation.

T-021/Sludge tank

If disposal by an incinerator plant is not planned, the tank has to be dimensioned so that it is capable of absorbing all residues which accumulate during the operation in the course of a maximum duration of voyage. The content of this tank must not be added to the engine fuel oil. In order to enable the emptying of the tank, it must be heated.

The heating is to be dimensioned so that the content of the tank can be heated to approximately 40 °C. If the sludge tank is used for the disposal of leakages or sludge of heavy fuel oil plants, the heating must be dimensioned to heat the tank content up to 60 °C.

P-073/Diesel fuel oil separator feed pump

The supply pumps should always be electrically driven, i.e. not mounted on the diesel fuel oil separator, as the delivery volume can be matched better to the required throughput.

H-019/Fuel oil preheater

In order to achieve the separating temperature, a separator adapted to suit the fuel oil viscosity should be fitted.

The fuel oil preheater must be able to heat the diesel oil up to 40 °C and the size must be selected accordingly. However the medium temperature prescribed in the separator manual must be observed and adjusted.

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A reliable temperature control (offset ± 1 °C) even for variable fuel oil flow rates must be installed.

CF-003/Diesel fuel oil separator

A self-cleaning separator must be provided. The diesel fuel oil separator is dimensioned in accordance with the separator manufacturers' guidelines.

The required flow rate (Q) can be roughly determined by the following equation:

$$Q = \frac{P \times b_e}{\rho}$$

Q [l/h]	Separator flow rate
P [kW]	Total engine output
b_e [g/kWh]	Fuel oil consumption
ρ [g/l]	Density at separating temp approximately 870 kg/m^3 = g/dm^3

With the evaluated flow rate, the size of the separator has to be selected according to the evaluation table of the manufacturer. The separator rating stated by the manufacturer should be higher than the flow rate (Q) calculated according to the above formula.

For the first estimation of the maximum fuel oil consumption (b_e), increase the specific table value by 15 %, see section Planning data for emission standard IMO Tier II – Auxiliary GenSet , Page 62.

For project-specific values contact MAN Energy Solutions.

In the following, characteristics affecting the fuel oil consumption are listed exemplary:

- Tropical conditions
- The engine-mounted pumps
- Fluctuations of the calorific value
- The consumption tolerance

Regarding required limits on water and particles in the fuel after separation please refer to table Requirements for diesel fuel.

Note:
If a homogeniser is used, it must never be installed between the settling tank and separator as otherwise it will not be possible to ensure satisfactory separation of harmful contaminants, particularly seawater.

Withdrawal points for samples

Fuel oil sampling points are to be provided upstream and downstream of each separator, to verify the effectiveness of these system components.

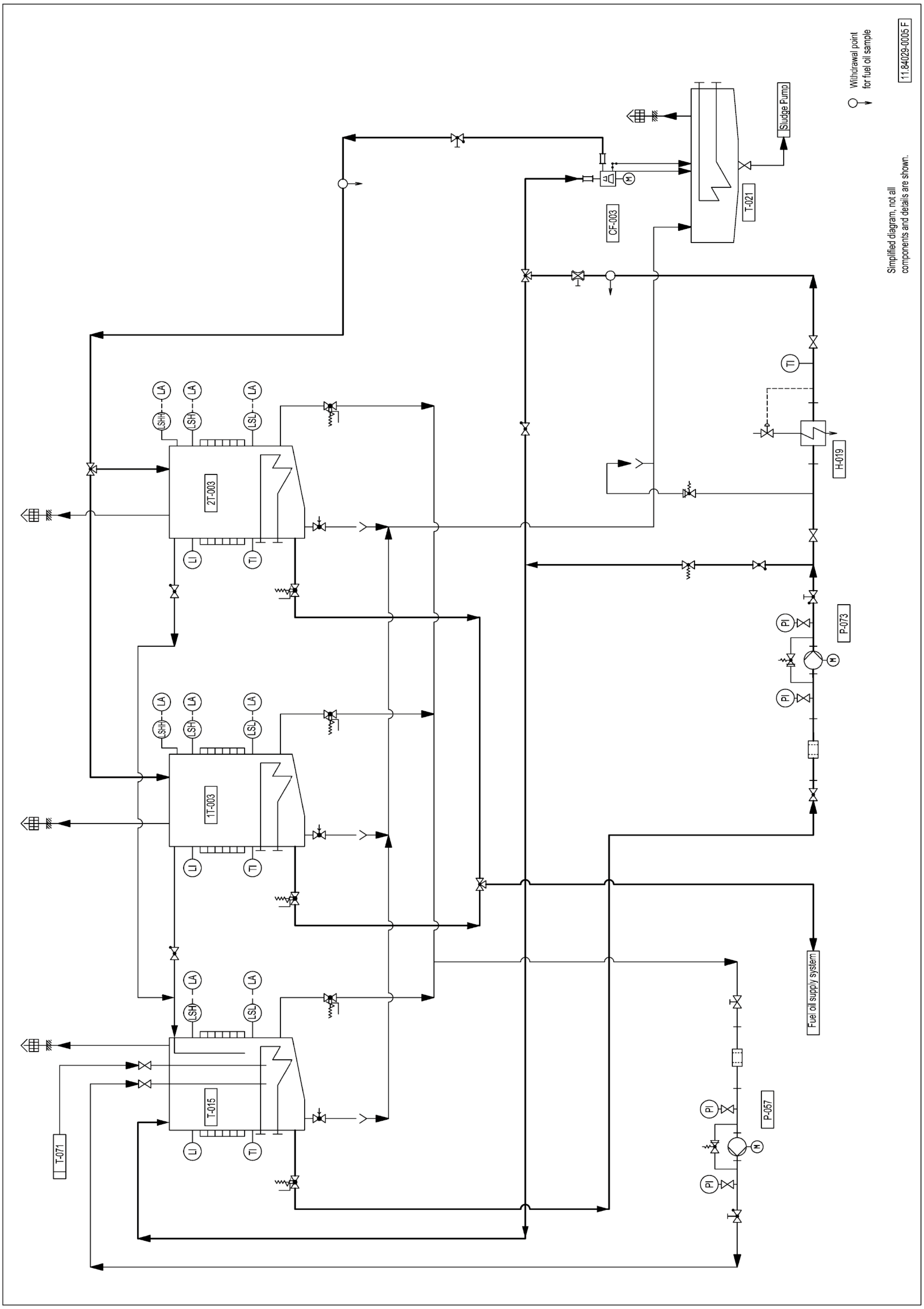
T-003/Diesel fuel oil service tank

See description in paragraph T-003/Diesel fuel oil service tank, Page 223.

T-071/Clean leakage fuel oil tank

See description in paragraph T-071/Clean leakage fuel oil tank, Page 230.

MDO treatment system diagram


T-071
T-015
1T-003
2T-003
LSH
LSL
LA
LI
TI
PI
P-057
P-073
H-019
CF-003
T-021
Sludge Pump
Fuel oil supply system
Withdrawal point for fuel oil sample
Simplified diagram, not all components and details are shown.
11.84029-0005 F

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	Components		
CF-003	Diesel fuel oil separator	T-015	Diesel fuel oil storage tank
H-019	Fuel oil preheater	T-021	Sludge tank
P-057	Diesel fuel oil transfer pump	1,2 T-003	Diesel fuel oil service tank
P-073	Diesel fuel oil separator feed pump	T-071	Clean leakage fuel oil tank

Figure 65: Fuel oil treatment with separator CF-003

5.6.3 Heavy fuel oil (HFO) treatment system

A prerequisite for safe and reliable engine operation with a minimum of servicing is a properly designed and well-functioning fuel oil treatment system.

The schematic diagram, see figure HFO treatment system diagram shows the system components required for fuel treatment of heavy fuel oil (HFO).

Bunker fuel oil

Fuel compatibility problems are avoidable if mixing of newly bunkered fuel oil with remaining fuel oil can be prevented by a suitable number of bunkers. Moreover the overall fuel oil system (all fuel oil tanks, piping and so on) must be designed to limit mixing of different bunker batches to an absolute minimum. Heating coils in bunkers must be designed so that the HFO in it is at a temperature of at least 10°C minimum above the pour point.

P-038/HFO transfer pump

The HFO transfer pump discharges fuel from the bunkers into the HFO settling tanks. Being a screw pump, it handles the fuel oil gently, thus prevent water being emulsified in the fuel oil. Its capacity must be sized to fill the complete HFO settling tank within ≤ 2 hours.

T-016/HFO settling tank

Two HFO settling tanks should be installed, in order to obtain thorough pre-cleaning and to allow fuels of different origin to be kept separate. When using RM-fuels we recommend two HFO settling tanks for each fuel type (high sulphur HFO, low sulphur HFO).

Size

Pre-cleaning by settling is the more effective the longer the solid material is given time to settle. The storage capacity of the HFO settling tank should be designed to hold at least a 24-hour supply of fuel oil at full load operation, including sediments and water the fuel oil contains.

The minimum volume (V) to be provided is:

$$V = \frac{5.7 \times P}{1{,}000}$$

V [m³]	Minimum volume
P [kW]	Engine rating

Tank heating

The heating surfaces should be dimensioned that the HFO settling tank content can be evenly heated to 75°C within 6 to 8 hours. The heating should be automatically controlled, depending on the fuel oil temperature.

In order to avoid:

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- Agitation of the sludge due to heating, the heating coils should be arranged at a sufficient distance from the tank bottom.
- The formation of asphaltene, the fuel oil temperature should not be permissible to exceed 75°C.
- The formation of carbon deposits on the heating surfaces, the heat transferred per unit surface must not exceed 1.1 W/cm^2.

Design

The HFO settling tank is to be fitted with baffle plates in longitudinal and transverse direction in order to reduce agitation of the fuel oil in the tank in rough seas as far as possible. The suction pipe of the HFO separator must not reach into the sludge space. One or more sludge drain valves, depending on the slant of the tank bottom (preferably 10°), are to be provided at the lowest point. The HFO settling tank is to be insulated against thermal losses.

Sludge must be removed from the HFO settling tank before the separators draw fuel oil from it.

T-021/Sludge tank

If disposal by an incinerator plant is not planned, the tank has to be dimensioned so that it is capable of absorbing all residues which accumulate during the operation in the course of a maximum duration of voyage. The content of this tank must not be added to the engine fuel oil. In order to enable the emptying of the tank, it must be heated.

The heating is to be dimensioned so that the content of the tank can be heated to approximately 60 °C.

P-015/Heavy fuel oil separator feed pump

The supply pumps should preferably be of the free-standing type, i.e. not mounted on the heavy fuel oil separator, as the delivery volume can be matched better to the required throughput.

H-008/Heavy fuel oil preheater

To reach the separating temperature a heavy fuel oil preheater matched to the fuel oil viscosity has to be installed.

A reliable temperature control (setpoint 98 °C ± 1 °C for HFO) for different fuel oil flow rates must be installed.

CF-002/Heavy fuel oil separator

Main principle of separators as well as settling tanks is the density difference between fuel oil, particles and water. Small particles will settle very slowly, especially in RMK-fuels with high viscosity/high density.

Not only good quality fuels, but also poor quality and high viscosity fuels might be used. For each HFO-type two new generation separators must be installed, which are also capable of clean fuels with a density up to 1,010 kg/m^3 (referring to 15 °C).

Recommended separator manufacturers and types:

Alfa Laval: Alcap, type SU

Westfalia: Unitrol, type OSE

Separators must always be provided in sets of at least 2 of the same type

- 1 service separator
- 1 stand-by separator

of self-cleaning type.

The freshwater supplied to the heavy fuel oil separator must be treated as specified by its manufacturer.

Mode of operation

Optimising the operation parameters is to raises the heavy fuel oil separator efficiency up to 98 %. Based on the separator makers recommendations and guidelines the separator cleaning efficiency can be increased by several options.

- Number of separators in operation

  The stand-by separator is always to be put into service, to achieve the best possible fuel cleaning effect with the separator plant as installed. The piping of both heavy fuel oil separators is to be arranged in accordance with the makers advice, preferably for both parallel and series operation.

  Separator operation in parallel means each unit works with i.e. a 50 % flow rate of the separator design-flow (based on the 100 % engine load fuel oil consumption). More hints for the differences between design flow and different possible operation flow can be found in the separator maker manuals. The discharge flow of the separator supply pump is to be split up equally between the two separators in parallel operation.

- Fuel temperature

  The required fuel oil temperature at separator inlet is stated in the separator manual and must be observed. When cleaning heavy fuel oil the inlet temperature should be around 98 °C. A longer HFO residence time in each separator in combination with a high separation temperature may reduce the amount of small and light foreign particles (i.e. cat fines in the range of 5 micron to 10 micron). Some separator manufacturers offer fully automatic and so-called hot separation systems. These systems raise the fuel oil temperature temporarily above 98 °C to make fine particles be separated more efficiently.

- Fuel flow rate

  Generally the engines are not running all together and not always at 100 % load. Hence the current fuel oil consumption is lower than the design flow rate of the separators.
  The separator module and its control must allow a reduction of the flowrate, depending on the actual fuel oil consumption. This will increase the separators efficiency. There are at least two options of reducing the flowrate through the separator:
  1. Using only one feed pump for two separators to split the flow to 50 % for each separator.
  2. Using frequency controlled feed pumps, controlled by the separator control in dependence of the continuously measured fuel oil consumption.

- Homogenisation

  As a result of emulsification or homogenisation the water contained in the fuel will be dissipated in very small droplets, which can hardly be removed by the separators. Furthermore cat fines are hydrophilic and will create non-separable aggregates together with the water droplets. The same applies when homogenising fuel in tanks, whereby the settling process will be hindered. Water and particles which normally shall settle down at the bottom of the tank then get into the fuel supply system and will not be removed.
  Therefore, homogenisers must not be utilised if the homogenised fuel is delivered to the heavy fuel oil separator or either directly or indirectly to the heavy fuel oil settling or service tanks.

Various operating parameters affect the heavy fuel oil separation efficiency. These include temperature (which controls both, fuel oil viscosity and density), flow rate and separator maintenance. Figure Separation efficiency depend-

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ence on particle size, density difference, viscosity and flow rate, Page 217 shows, how the operating parameters affect the separator efficiency. However all operating parameters have always be observed and adjusted according to the separators operating manual.

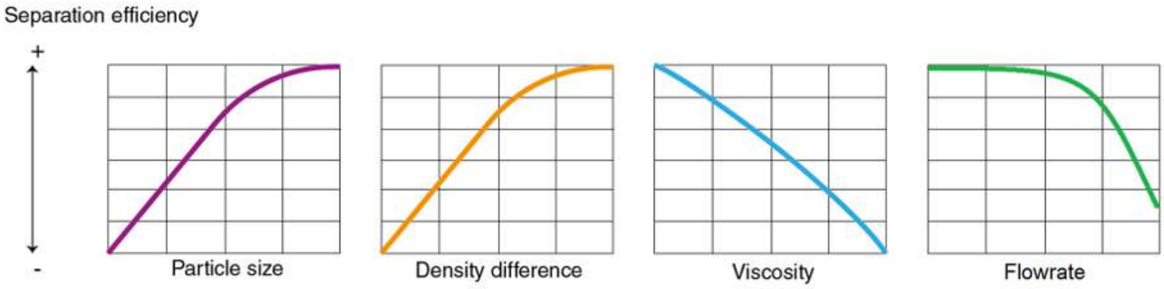


Figure 66: Separation efficiency dependence on particle size, density difference, viscosity and flow rate (reference: Diagram 1 – 3: "CIMAC Paper No. 51 – Onboard Fuel Oil Cleaning", CIMAC Congress, 2013)

Size

The HFO separators are dimensioned in accordance with the separator manufacturers' guidelines. The required design flow rate (Q) can be roughly determined by the following equation:

$$Q = \frac{P \times b_e}{\rho}$$

Q [l/h]	Separator flow rate
P [kW]	Total engine output
b_e [g/kWh]	Fuel oil consumption
ρ [g/l]	Density at separating temp approximately 930 kg/m^3 = [g/l]

With the evaluated flow rate, the size of the separator has to be selected according to the evaluation table of the manufacturer. The separator rating stated by the manufacturer should be higher than the flow rate (Q) calculated according to the above formula.

For the first estimation of the maximum fuel oil consumption (b_e), increase the specific table value by 15 %, see section Planning data for emission standard IMO Tier II – Auxiliary GenSet , Page 62.

For project-specific values contact MAN Energy Solutions.

In the following, characteristics affecting the fuel oil consumption are listed exemplary:

- Tropical conditions
- The engine-mounted pumps
- Fluctuations of the calorific value
- The consumption tolerance

Regarding required limits on water and particles in the fuel after separation please refer to table Requirements for diesel fuel.

Note:
If a homogeniser is used, it must never be installed between the settling tank and separator as otherwise it will not be possible to ensure satisfactory separation of harmful contaminants, particularly seawater.

Withdrawal points for samples

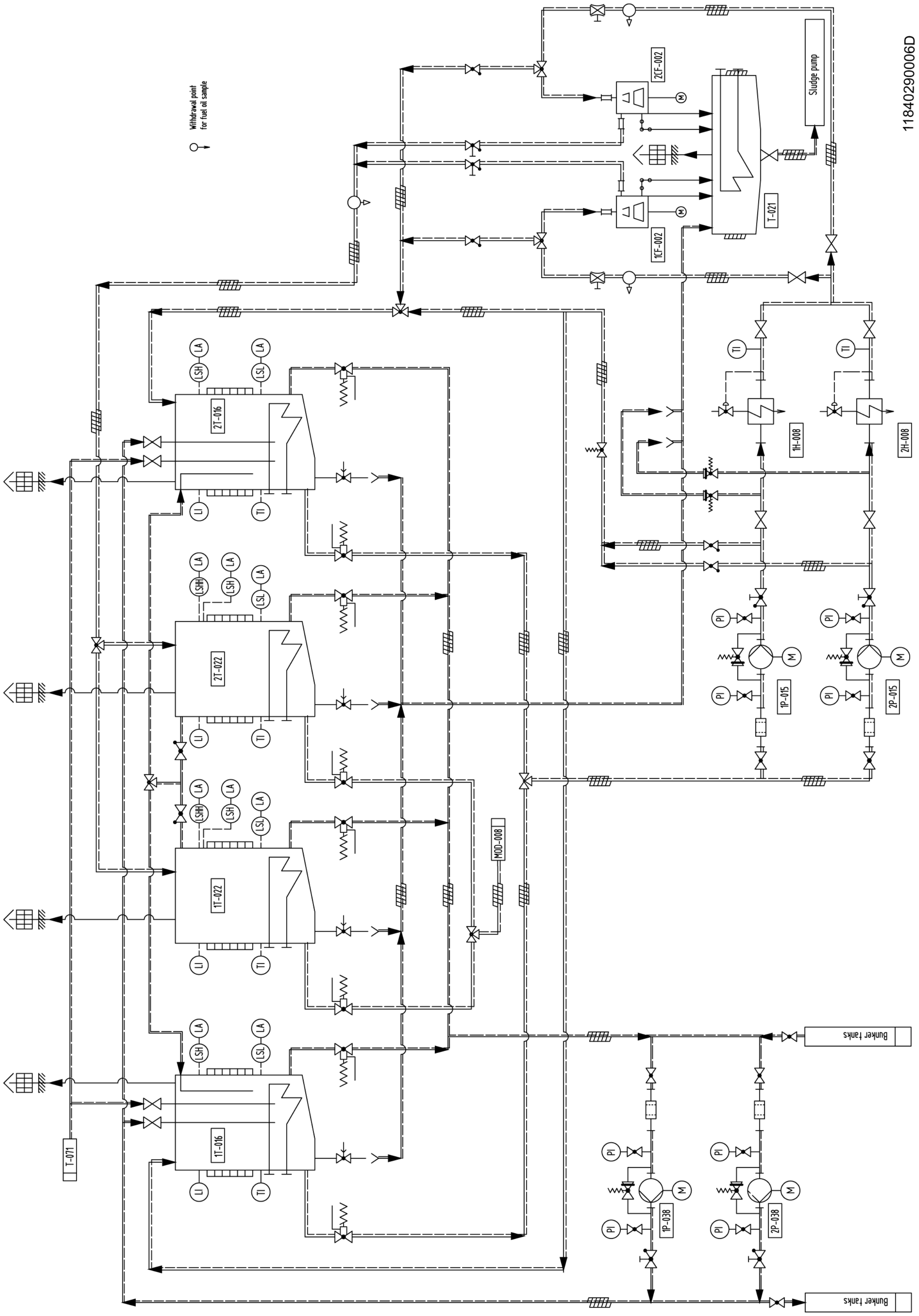
Fuel oil sampling points are to be provided upstream and downstream of each separator, to verify the effectiveness of these system components.

T-022/Heavy fuel oil service tank

See description in paragraph T-022/Heavy fuel oil service tank, Page 223.

T-071/Clean leakage fuel oil tank

See description in paragraph T-071/Clean leakage fuel oil tank, Page 230.


Withdrawal point for fuel oil sample
11840290006D
Sludge pump
2CF-002
1CF-002
T-021
1H-008
2H-008
1P-015
2P-015
2T-016
2T-022
1T-022
1T-016
MOD-008
T-071
1P-038
2P-038
Bunker Tanks
Bunker Tanks

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Components

1,2 CF-002	HFO separator	1,2 T-016	HFO settling tank
1,2 H-008	HFO preheater	T-021	Sludge tank
MOD-008	Fuel oil module	1,2 T-022	HFO service tank
1,2 P-015	HFO separator feed pump	T-071	Clean leakage fuel oil tank
1,2 P-038	HFO transfer pump		

Figure 67: HFO treatment system diagram

5.6.4 GenSet design and components – Fuel oil system

General

Some essential fuel oil cleaning and measuring equipment is already installed at the engine itself or at the GenSet frame. Also completely installed is the piping to the fuel oil duplex filter, from the filter to the engine as well as the fuel oil return line and the leakage pipes from the engine to the plant. If the engine is equipped with a leakage drain split piping or sealed plunger (SP) injection pumps, two separate leakage connections exist at the GenSet: One for the dirty leakage (lube oil and particle contaminated) and one for the clean and reusable leakage.

FIL-013/Fuel oil duplex filter

The absolute mesh size of the fuel oil duplex filter is 25 µm (sphere passing mesh). To keep the engine running, it is possible to switch over to the second chamber, if one filter element is clogged and must be cleaned or changed. If the filter elements are removed for cleaning, the filter chamber must be emptied completely. This prevents dirt particles remaining in the filter casing from migrating to the clean oil side of the filter. The main design criterion is the permissible filter area load, specified by the filter manufacturer.

Parameter	Unit	Value
Filter mesh size (sphere passing mesh)	µm	25
Design pressure	bar	16
Design temperature	°C	≥ 150

Table 94: Design data

FSH-001/Leakage fuel oil monitoring tank

The monitoring tank is attached to the GenSet.

Following items are carried to the monitoring tank:

- high-pressure pump overflow
- leakage from fuel injectors and buffer pistons
- escaping fuel from burst control pipes

To warm up the leakage, fuel oil supplied to the engine passes through the tank. The tank is equipped with a level switch, which initiates an alarm in case of a larger leakage flow than normal. All parts of the monitored leakage system (pipes and monitoring tank) have to be designed for a fuel rate as shown in the table in section Leakage rate, Page 73. Most classification societies require the installation of monitoring tanks for unmanned engine rooms, some for manned rooms as well.

Fuel oil system diagram

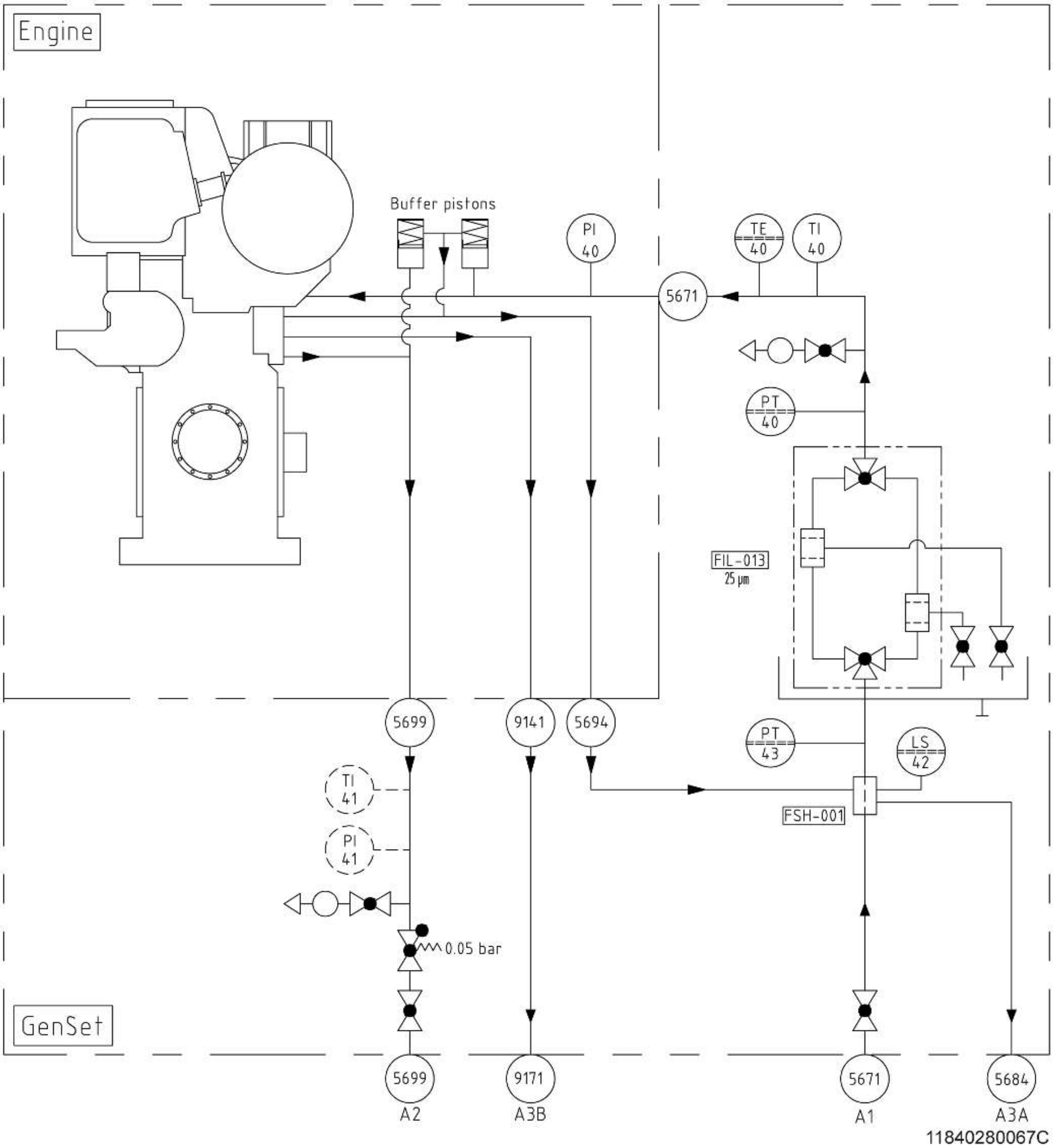

Figure 68: Fuel oil system diagram

Engine pipe connections			
5671	Fuel oil inlet	5694	Clean fuel oil leakage drain
9141	Dirty fuel oil leakage drain from pump bank	5699	Fuel oil outlet
GenSet pipe connections			
5671/A1	Fuel oil inlet	5684/A3A	Clean fuel oil leakage drain

5699/A2	Fuel oil outlet	9171/A3B	Dirty fuel oil leakage drain from GenSet 1
GenSet equipments			
FIL-013	Duplex filter	FSH-001	Fuel oil leakage monitoring tank

5.6.5 Fuel oil supply system

General

Normally one or two main engines are connected to one fuel system. Auxiliary engines can be connected to the same fuel system as well, see figure Uni fuel oil system diagram, Page 232. A separate and pure MDO supply system for the auxiliary engines increases the availability of the GenSets. It is designed for short time operation in case of an emergency or for maintenance purposes.

MDO viscosity

At engine inlet the MDO-fuel viscosity must be > 2.0 and < 11 cSt (see section Marine diesel oil (DMB, DFB) specifications). The fuel oil temperature has to be adapted accordingly. It must be ensured, that the MDO fuel temperature of maximum 45 °C at engine inlet (for all MDO qualities) is not exceeded. Therefore a tank heating and a cooler in the fuel return pipe are required.

HFO viscosity

To ensure that high-viscosity fuel oils (HFO) achieve the specified injection viscosity between 12 and 14 cSt (see section Residual fuel specification (HFO) and Viscosity-temperature diagram (VT diagram), Page 146) a preheater must be installed. The preheating temperature of up to 150 °C, may cause degassing problems in conventional, pressureless systems.

A remedial measure is adopting a pressurised system in which the required system pressure is 1 bar above the evaporation pressure of water.

Fuel	Injection viscosity[1]	Temperature after final heater HFO	Evaporation pressure	Required system pressure
mm^2/50 °C	mm^2/s	°C	bar	bar
180	12	126	1.4	2.4
320	12	138	2.4	3.4
380	12	142	2.7	3.7
420	12	144	2.9	3.9
500	14	141	2.7	3.7
700	14	147	3.2	4.2

[1] For fuel viscosity depending on fuel temperature please see section Viscosity-temperature diagram (VT diagram), Page 146.

Table 95: Injection viscosity and temperature after final heater heavy fuel oil

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The indicated pressures are minimum requirements due to the fuel characteristic. Nevertheless, to meet the required fuel pressure at the engine inlet (see section Planning data for emission standard IMO Tier II – Auxiliary GenSet , Page 62 and the following), the pressure in the fuel oil mixing tank and booster circuit becomes significant higher as indicated in this table.

T-003/Diesel fuel oil service tank

The classification societies specify that at least two service tanks for each fuel type to be installed on board. One tank supplies the engines with purified MDO, while the other tank receives purified MDO and allows remained particles to settle down to the tank bottom. The minimum tank capacity of each tank should, in addition to the MDO consumption of other consumers, enable a full load operation of minimum eight operating hours for all engines under all conditions.

The service tank should be provided with a sludge space with a tank bottom inclination of preferably 10° and sludge drain valves at the lowest point to drain the settled sludge at regular intervals. Overflow pipes from the diesel fuel oil service tank T-003 to the diesel fuel oil storage tank T-015, with heating coils and insulation must be installed.

If DMB fuel with 11 cSt (at 40 °C) is used, the tank heating is to be designed to keep the tank temperature at minimum 40 °C. For lighter types of MDO it is recommended to heat the tank in order to reach a fuel oil viscosity of 11 cSt or less. Rules and regulations for tanks, issued by the classification societies, must be observed.

The required minimum MDO capacity of each service tank is:

V_{MDOST}= (Q_px t_ox M_s)/(3 x 1000 l/m^3)		
Required min. volume of one diesel fuel oil service tank	V_{MDOST}	m^3
Required supply pump capacity, MDO 45 °C See paragraph P-008/Diesel fuel oil supply pump and P-018/Fuel oil supply pump, Page 224.	Q_p	l/h
Operating time t_o = 8 h	t_o	h
Margin for sludge MS = 1.05	M_S	-

Table 96: Required minimum MDO capacity

In case more than one engine, or different engines are connected to the same fuel system, the service tank capacity has to be increased accordingly.

Overflow

To enable a continuous separator cleaning flow independent from the fuel oil consumption, the diesel fuel oil service tank should be equipped with an overflow pipe. The overflow pipe shall be installed from the bottom of the service tank to the top of the settling tank. In this way heavy particles and water collecting at the lower part of the service tank will recirculate into the settling tank.

T-022/HFO service tank

The HFO cleaned in the heavy fuel oil separator is passed to the service tank, and as the separators are in continuous operation, the tank is always kept filled.

To fulfil this requirement it is necessary to fit the HFO service tank T-022 with overflow pipes, which are connected with the HFO settling tanks T-016. The tank capacity is to be designed for at least eight-hours' fuel supply at full load so as to provide for a sufficient period of time for separator maintenance.

The tank should have a sludge space with a tank bottom inclination of preferably 10° with sludge drain valves at the lowest point and it is to be equipped with heating coils.

The sludge must be drained from the service tank at regular intervals.

The heating coils are to be designed for a tank temperature of 75°C.

The rules and regulations for tanks issued by the classification societies must be observed.

HFO with high and low sulphur content must be stored in separate service tanks.

Overflow

To enable a continuous separator cleaning flow independent from the fuel oil consumption, the diesel fuel oil service tank should be equipped with an overflow pipe. The overflow pipe shall be installed from the bottom of the service tank to the top of the settling tank. In this way heavy particles and water collecting at the lower part of the service tank will recirculate into the settling tank.

CK-002/Three-way valve for fuel oil changeover

This valve is used for changing over from MDO/MGO operation to heavy fuel operation and vice versa. This valve can be operated manually or automatically. It is equipped with two limit switches for remote indication and suppression of alarms from the viscosity measuring and control system during MDO/MGO operation.

STR-010/Suction strainer

To protect the fuel oil supply pumps, an approximately 0.5 mm gauge (sphere-passing mesh) strainer is to be installed at the suction side of each supply pump.

P-018/Fuel oil supply pump

The capacity of the supply pump must be at least 160% of the maximum fuel oil consumption.

$Q_P = (P \times (br_{ISO} / 1{,}000) \times f \times S) / \rho$		
Required supply pump delivery capacity	Q_P	m^3/h
Engine output at 100% MCR	P_1	kW
Specific engine fuel oil consumption (ISO) at 100% MCR	br_{ISO}	g/kWh
Factor for pump dimensioning	f = 1.6	-
Safety factor for consideration of attached pumps and tropical conditions	S = 1.1	-
Min. fuel density at 15°C	ρ	kg/m^3

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Note:
The fuel density shall be chosen according the fuel with the lowest density, for which the system is designed for (in general DMA, min. density 820 kg/m^3 at 15°C).

In case more than one engine is connected to the same fuel oil system, the pump capacity has to be increased accordingly.

Table 97: Simplified fuel oil supply pump dimensioning

The delivery height of the fuel oil supply pump shall be selected according to the required system pressure (see table Injection viscosity and temperature after final heater heavy fuel oil, Page 222), the required pressure in the mixing tank and the resistance of the automatic filter, flowmeter and piping system.

		Injection system
		bar
Positive pressure at the fuel module inlet due to tank level above fuel module level	–	0.10
Pressure loss of the pipes between fuel module inlet and mixing tank inlet	+	0.20
Pressure loss of the automatic filter	+	0.50
Pressure loss of the fuel flow measuring device	+	0.10
Pressure in the fuel oil mixing tank	+	5.70
Operating delivery height of the supply pump	=	6.40

Table 98: Example for the determination of the expected operating delivery height of the fuel oil supply pump

It is recommended to install fuel oil supply pumps designed for the following pressures:

Engines with conventional fuel oil injection system: Design delivery height 7.0 bar, design output pressure 7.0 bar.

Engines with common rail injection system: Design delivery height 8.0 bar, design output pressure 8.0 bar.

HE-025/Fuel oil cooler, supply circuit

If no fuel is consumed in the system while the pump is in operation, the finned-tube cooler prevents excessive heating of the fuel. Its cooling surface must be adequate to dissipate the heat that is produced by the pump to the ambient air.

In case of continuos MDO/MGO operation, a water cooled fuel oil cooler is required to keep the fuel oil temperature below 45°C.

PCV-009/Pressure limiting valve

This valve is used for setting the required system pressure and keeping it constant. It returns in the case of

- engine shutdown 100%, and of
- engine full load 37.5% of the quantity delivered by the fuel oil supply pump back to the pump suction side.

FIL-003/Fuel oil automatic filter, supply circuit

The fuel oil automatic filter (supply circuit) should be a type that causes no significant pressure drop in the system during flushing sequence. The automatic filter must be equipped with differential pressure indication and switches.

As a reference an acceptable value for a pressure decrease during back flushing is 0.3 – 0.5 bar. The design criterion relies on the filter surface load, specified by the filter manufacturer.

Parameter	Unit	Value
Filter mesh size (sphere passing mesh)	µm	10
Design pressure	bar	16
Design temperature	°C	≥ 100

Table 99: Design data

A by-pass pipe in parallel to the fuel oil automatic filter (supply circuit) is required. Only during maintenance on the automatic filter, the by-pass must be opened; the fuel is then filtered by the fuel oil duplex filter FIL-013. This operating mode is not permissible for continuous operation.

FQ-003/Fuel oil flowmeter

In case a fuel oil consumption measurement is required, a fuel oil flowmeter must be installed downstream the fuel oil automatic filter (supply circuit) FIL-003.

A by-pass line must be provided in case of flowmeter failure or maintenance.

T-011/Fuel oil mixing tank

The mixing tank compensates pressure surges which occur in the pressurised part of the fuel system.

For this purpose, there has to be an air cushion in the tank. As this air cushion is exhausted during operation, compressed air (max. 10 bar) has to be refilled via the control air connection from time to time.

Before prolonged shutdowns the system is changed over to MDO/MGO operation.

The tank volume shall be designed to achieve gradual temperature equalisation within 5 minutes in the case of half-load consumption.

The tank shall be designed for the maximum possible service pressure, usually approximately 10 bar and is to be accepted by the classification society in question.

The expected operating pressure in the fuel oil mixing tank depends on the required fuel oil pressure at the inlet (see section Planning data for emission standard IMO Tier II – Auxiliary GenSet , Page 62) and the pressure losses of the installed components and pipes.

		Injection system
		bar
Required max. fuel oil pressure at engine inlet	+	8.00
Pressure difference between fuel oil inlet and outlet engine	–	2.00
Pressure loss of the fuel oil return pipe between engine outlet and mixing tank inlet, e.g.	–	0.30

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		Injection system
		bar
Pressure loss of the flow balancing valve (to be installed only in multi-engine plants, pressure loss approximately 0.5 bar)	–	0.00
Operating pressure in the fuel oil mixing tank	=	5.70

Table 100: Example for the determination of the expected operating pressure of the fuel oil mixing tank

This example demonstrates, that the calculated operating pressure in the fuel oil mixing tank is (for all HFO viscosities) higher than the min. required fuel oil pressure (see table Injection viscosity and temperature after final heater heavy fuel oil, Page 222).

P-003/Fuel oil booster pump

To cool the engine mounted high-pressure pumps, the capacity of the booster pump has to be at least 300 % of maximum fuel oil consumption at injection viscosity.

$Q_{P2} = P_1 x\ br_{ISO} x\ f_5$		
Required booster pump delivery capacity with HFO at 145 °C	Q_{P2}	l/h
Engine output at 100 % MCR	P_1	kW
Specific engine fuel oil consumption (ISO) at 100 % MCR	br_{ISO}	g/kWh
Factor for pump dimensioning ▪ For diesel engines operating on main fuel HFO: $f_5 = 3.90 \times 10^{-3}$	f_5	l/g
Note: The factor f_5 includes the following parameters: ▪ 300 % fuel oil flow at 100 % MCR ▪ Main fuel: HFO 380 mm^2/50 °C ▪ Attached lube oil and cooling water pumps ▪ Tropical conditions ▪ Realistic lower heating value ▪ Specific fuel oil weight at pumping temperature ▪ Tolerance In case more than one engine is connected to the same fuel oil system, the pump capacity has to be increased accordingly.		

Table 101: Simplified fuel oil booster pump dimensioning

The delivery height of the fuel oil booster pump is to be adjusted to the total resistance of the booster system.

		Injection system
		bar
Pressure difference between fuel inlet and outlet engine	+	2.00
Pressure loss of the flow balancing valve (to be installed only in multi-engine plants, pressure loss approximately 0.5 bar)	+	0.00
Pressure loss of the pipes, mixing tank – Engine mixing tank, e.g.	+	0.50
Pressure loss of the final heater heavy fuel oil max.	+	0.80

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		Injection system
		bar
Pressure loss of the indicator filter	+	0.80
Operating delivery height of the booster pump	=	4.10

Table 102: Example for the determination of the expected operating delivery height of the fuel oil booster pump

It is recommended to install booster pumps designed for the following pressures:

Engines with conventional fuel oil injection system: Design delivery height 7.0 bar, design output pressure 10.0 bar.

Engines common rail injection system: Design delivery height 10.0 bar, design output pressure 14.0 bar.

VI-001/Viscosimeter

This device regulates automatically the heating of the final heater HFO depending on the viscosity of the circulating fuel oil, to reach the viscosity required for injection.

H-004/Final heater HFO

The capacity of the final heater shall be determined on the basis of the injection temperature at the nozzle, to which at least 4 K must be added to compensate for heat losses in the piping. The piping for both heaters shall be arranged for single and series operation.

Parallel operation with half the throughput must be avoided due to the risk of sludge deposits.

HE-007/Fuel oil cooler CK-003/Three-way valve (fuel oil cooler/by-pass)

The purpose of the fuel oil cooler is to ensure that the viscosity of MDO will not become too low at engine inlet.

When switching from HFO to MDO operation, the three-way valve (fuel oil cooler/by-pass) CK-003 must be actuated slowly to lead MDO through the fuel oil cooler HE-007. It is then cooled by LT cooling water.

That way, the MDO which was heated while circulating via the injection pumps, is cooled before it returns to the fuel oil mixing tank T-011.

The cooler should be opened only after flushing the system with MDO.

The cooling medium used for the fuel oil cooler is preferably fresh water from the central cooling water system. Based on the fuel oils available on the market with a viscosity ≥ 2.0 cSt at 40 °C, a fuel inlet temperature ≤ 40 °C is expected to be sufficient to achieve 2.0 cSt at engine inlet. In such case, the central cooling water/LT cooling water at 36 °C can be used as coolant. For the lowest viscosity distillate fuels, a water cooled fuel oil cooler may be not enough to sufficiently cool down the fuel to the required temperature. In this case it is recommended to install a so-called “chiller” that removes heat through vapor compression or an absorption refrigerant cycle.

The thermal design of the cooler is based on the following data:

$P_c = P_1 x\ br_{ISO1} x\ f_1$

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$Q_c = P_1 x\ br_{ISO1} x\ f_2$		
Cooler outlet temperature MDO[1] T_{out} = 45 °C	T_{out}	°C
Dissipated heat of the cooler	P_c	kW
MDO flow for thermal dimensioning of the cooler[2]	Q_c	l/h
Engine output power at 100 % MCR	P_1	kW
Specific engine fuel oil consumption (ISO) at 100 % MCR	br_{ISO1}	g/kWh
Factor for heat dissipation: $f_1 = 2.68 \times 10^{-5}$	f_1	-
Factor for MDO flow: $f_2 = 2.80 \times 10^{-3}$	f_2	l/g

Note:
In case more than one engine, or different engines are connected to the same fuel oil system, the cooler capacity has to be increased accordingly.

[1] This temperature has to be normally max. 45 °C. Only for very light MGO fuel types this temperature has to be even lower in order to preserve the min. admissible fuel oil viscosity in engine inlet (see section Viscosity-temperature diagram (VT diagram), Page 146).

[2] The max. MDO/MGO throughput is identical to the delivery quantity of the installed fuel oil booster pump P-003.

Table 103: Calculation of cooler design

The recommended pressure class of the fuel oil cooler is PN16.

T-008/Fuel oil damper tank

The injection nozzles cause pressure peaks in the pressurised part of the fuel oil system. In order to protect the viscosity measuring and control unit, these pressure peaks have to be equalised by a compensation tank. The volume of the pressure peaks compensation tank is 20 l.

Alternatively a metal bellow damper can be used in combination with an air cushion in the fuel oil mixing tank.

FBV-010/Flow balancing valve

The flow balancing valve at engine outlet is to be installed only (one per engine) in multi-engine arrangements connected to the same fuel system. It is used to balance the fuel flow through the engines. Each engine has to be fed with its correct, individual fuel flow.

PCV-011/Fuel oil spill valve

The spill valve is only required for multi-engine arrangements, installed in bypass to each engine.

In case two or more engines are operated with one common fuel oil system, it must be possible to separate one engine from the fuel circuit for maintenance purposes, while the other engines keep running. In order to avoid excessive pressure in the pressurised system, fuel which cannot circulate through the shut-off engine, has to be rerouted via this valve to the return pipe. This valve is adjusted to open in case the pressure, in comparison to normal operation (multi-engine operation), is exceeded. This valve should be designed as pressure relief valve, not as safety valve.

V-002/Shut-off cock

The stop cock is only required for multi-engine operation and is closed during normal operation. When one engine is separated from the fuel circuit for maintenance purposes, this cock has to be opened manually.

T-006/Leakage oil collecting tank

Dirty leak fuel and leak oil are collected in the leakage oil collecting tank. It must be emptied into the sludge tank. The content of the leakage oil collecting tank T-006 must not be added to the engine fuel. It can be burned for instance in a waste oil boiler.

The leakage oil collecting tank T-006 is only necessary if the leakages can not flow directly into the sludge tank T-021 by gravity.

MOV-017/Leakage fuel oil switch-over valve

Depending on the supplied fuel oil type, the operation leakage of the high-pressure injection system can be drained into the HFO or distillate clean leakage fuel oil tank by switching over this valve.

Note:
It must be ensured that no HFO contamination is led into the distillate clean leakage fuel oil tank.

T-071/Clean leakage fuel oil tank

Injection pump overflow and other clean fuel oil that escapes from the injection system is led to the clean leakage fuel oil tanks.

From there the content of the distillate clean leakage fuel oil tank (1 T-071) must be emptied into the diesel fuel oil storage tank (T-015). The content of the HFO clean leakage fuel oil tank (2 T-071) must be emptied into the heavy fuel oil settling tank (T-016). The installation of these two clean leakage fuel oil tanks enables an effective separation of different fuel oil types.

The amount of clean operation leakage differs in a broad range, depending on the wear of the injection pumps, the type of fuel oil and the operating temperatures.

For data regarding the leak rate, see table(s) Leakage rate, Page 73.

Clean leakage fuel oil from the clean leakage fuel oil tanks 1,2 T-071 can be used again after passing the fuel oil separator.

Leakage fuel oil flows pressureless (by gravity only) from the engine into these tanks (to be installed below the engine connections). Pipe clogging must be avoided by trace heating and by a sufficient downward slope.

It must be ensured that the leakage fuel oil is well diluted with fresh fuel before entering the engine again. Nevertheless, leakage oil collecting tank T-006 is still required to collect lube oil leakages from lube oil drains (and other).

In case the described clean leakage fuel oil tank T-071 is installed, leakages from the following engine connections are to be conducted into this tank:

Engine type	Connection
L engine	5684

Table 104: Connections clean leakage fuel oil tank

The tank must be heated and insulated and its content must be pumped into the high sulphur (HS) heavy fuel oil settling tank T-016.

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T-021/Sludge tank

See description in paragraph T-021/Sludge tank, Page 215.

Uni fuel oil system diagram

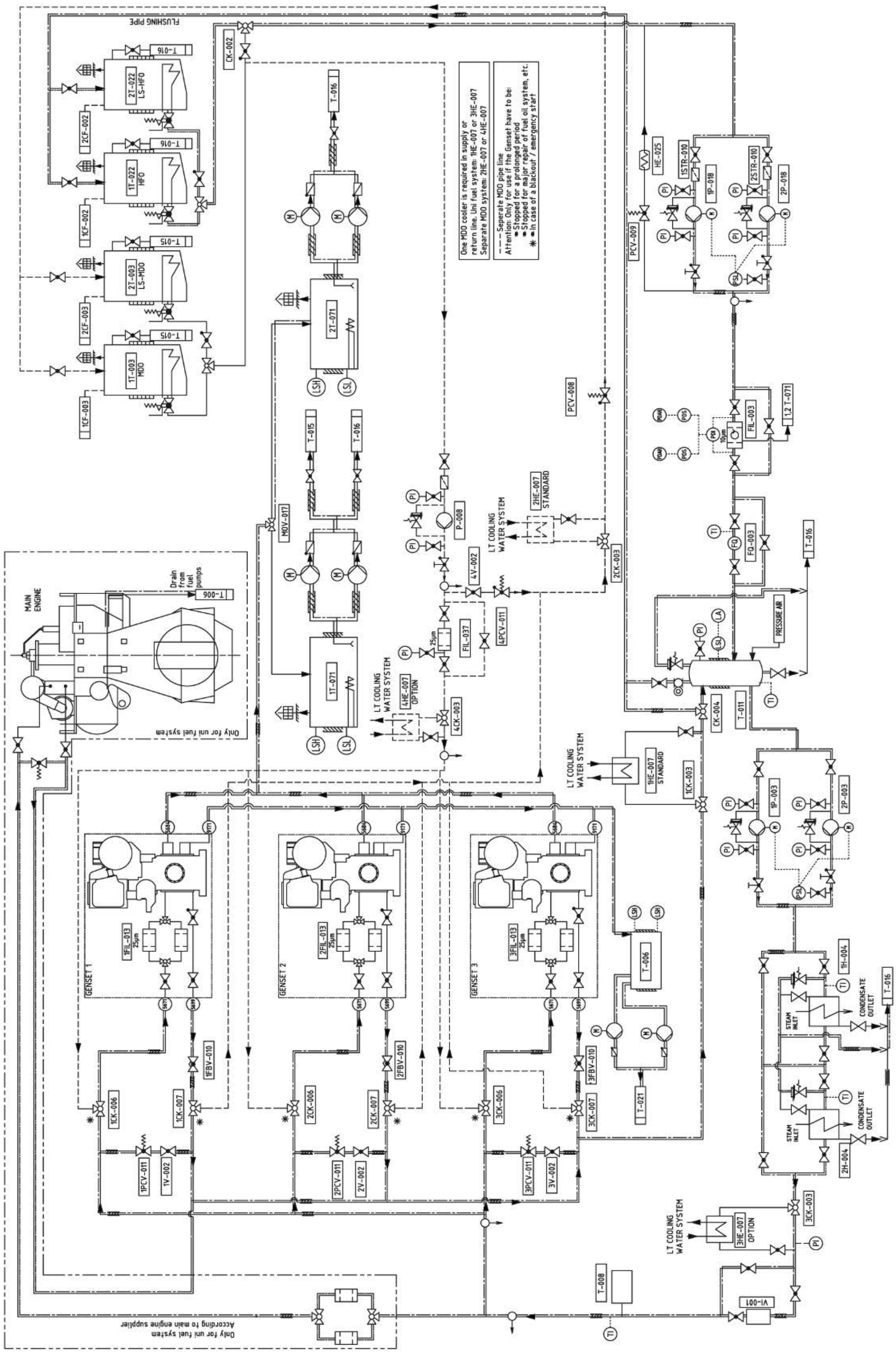

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Figure 69: Uni fuel oil system diagram

Engine room separate MDO system			
CF-003	MDO separator	PCV-008	Pressure retaining valve
CK-003	Switching to MDO cooler	T-003	MDO service tank
FIL-037	Fuel oil simplex filter	T-015	MDO storage tank
HE-007	Diesel oil cooler	T-071	Clean leakage fuel oil tank
MOV-017	Leakage fuel oil switch-over valve	V-002	Shut-off cock
P-008	MDO booster pump		
GenSet			
FIL-013	Duplex filter		
Engine room			
CK-002	Switching valve MDO and HFO	FBV-010	Flow balancing valve
CK-006	Switching valve MDO and HFO (in)	T-006	Leakage oil tank
CK-007	Switching valve MDO and HFO (out)	T-021	Sludge tank
Engine room uni fuel oil system			
CF-002	HFO separator	PCV-009	Pressure limiting valve
CK-003	Switching to MDO cooler	PCV-011	Pressure limiting valve
CK-004	Switching to MDO flushing	STR-010	Y-type strainer
FIL-003	Fuel oil automatic filter	T-008	Damper tank
FQ-003	Flowmeter fuel oil	T-011	Fuel oil mixing tank
H-004	Final heater HFO	T-016	HFO settling tank
HE-007	Diesel oil cooler	T-022	HFO service tank
HE-025	Finned tube cooler	T-071	Clean leakage fuel oil tank
P-003	Booster pump	V-002	Shut-off cock
P-018	HFO supply pump	VI-001	Viscosimeter
GenSet pipe connections			
5671/A1	Fuel oil inlet GenSet	5684/A3A	Clean leakage fuel oil drain
5699/A2	Fuel oil outlet GenSet	9171	Dirty oil drain pump bank

5.6.6 External fuel system – Fuel oil supply at blackout conditions

As the main electrical grid is not available during a blackout, an alternative energy source has to guarantee fuel oil supply. If a sufficient uninterruptible power supply (UPS) system is available, it can be connected to the regular fuel oil supply pumps and run them in spite of blackout.

Alternatively an additional pneumatic pump can be installed. If this pump is connected to a working air system, it must be ensured that this system can always deliver sufficient compressed air required to outlast the blackout operation.

Also the starting air system can be used, if the additional air is considered for design of starting air receivers and the adequate control of the blackout pump is implemented in the ship automation system. Background is that the amount of compressed air required by class societies for engine starts must not be affected. MAN Energy Solutions can design a suitable pneumatic pump and calculate its compressed air consumption.

For a short time the engines can also run by use of a gravity fuel oil tank (MDO/MGO) or in a HFO system by the air pressure cushion in the fuel oil mixing tank (see required pressure in section Operating/service temperatures and pressures, Page 68.

Duration of blackout operation

Duration of the blackout pump operation should last till the regular fuel supply is recovered:

- Duration of the emergency GenSet for connecting to the main electrical grid
- Start-up time of the fuel oil module after main grid is restored
- Buffer time

On the other hand, the duration of the blackout pump operation should be limited by the ship automation system due to:

- Reduction of UPS or compressed air consumption
- Consideration of engine related systems without power supply (e.g. cooling water system might overheat)

Depending on engine load it can be advisable to schedule blackout operation to maximum 90 seconds.

Integration in fuel oil system

In a diesel fuel oil supply system it is recommended to integrate the blackout pump parallel to the regular fuel oil supply pumps. In order to reduce compressed air consumption, it is possible to choose a downsized pump and operate the engine in part load.

For a heavy fuel oil supply system a pneumatic pump delivers fuel oil from MDO service tank into the mixing tank to guarantee low load operation. For high-load operation contact MAN Energy Solutions.

Note:
A fuel oil supply with cold MDO/MGO shortly after HFO-operation will lead to temperature shocks in the injection system and has to be avoided under any circumstances.

5.6.7 Emergency MDO supply system

The separate emergency MDO supply system supplies only the auxiliary engines and is independent from the uni fuel system. It is designed to operate only in case of emergency or for maintenance reasons.

Design and components of the emergency MDO supply system are shown in figure Uni fuel oil system diagram, Page 232.

P-008/Diesel fuel oil supply pump

The supply pump shall keep sufficient fuel pressure before the engine.

The volumetric capacity must be at least 300 % of the maximum fuel oil consumption of the engine, including margins for:

- Tropical conditions
- Realistic heating value and
- Tolerance

To reach this, the diesel fuel oil supply pump has to be designed according to the following formula:

$Q_p = P_1 \times br_{ISO1} \times f_3$		
Required supply pump capacity with MDO 45 °C	Q_p	l/h
Engine output power at 100 % MCR	P_1	kW
Specific engine fuel oil consumption (ISO) at 100 % MCR	br_{ISO1}	g/kWh
Factor for pump dimensioning: $f_3 = 3.75 \times 10^{-3}$	f_3	l/g

Table 105: Formula to design the diesel fuel oil supply pump

In case more than one engine or different engines are connected to the same fuel oil system, the pump capacity has to be increased accordingly.

The discharge pressure shall be selected with reference to the system losses and the pressure required before the engine (see section Planning data for emission standard IMO Tier II – Auxiliary GenSet , Page 62 and the following). Normally the required discharge pressure is 10 bar.

FIL-037/MDO simplex filter

Filter design and size mainly depend on the filter surface load, specified by the filter manufacturer.

Parameter	Unit	Value
Filter mesh size (sphere passing mesh)	µm	25
Design pressure	bar	10
Design temperature	°C	≥ 100

Table 106: Design data

A by-pass pipe in parallel to the filter is required. The system is only designed for short time service.

HE-007/Fuel oil cooler
CK-003/Three-way valve (fuel oil cooler/by-pass)

See description in paragraph HE-007/Fuel oil cooler, CK-003/Three-way valve (fuel oil cooler/by-pass), Page 228.

CK-006/Three-way cock, switching inlet between MDO - HFO
CK-007/Three-way cock, switching return flow between MDO - HFO

The fuel oil system is designed in such a way that in an emergency case the fuel type for the GenSets can be changed independently of the fuel supply to the propulsion engine. For that, a set of manually actuated three-way fuel changing valves CK-006 and CK-007 for each GenSet must be installed.

PCV-008/Pressure retaining valve

In open fuel oil supply systems (fuel loop with circulation through the diesel fuel oil service tank; service tank under atmospheric pressure) this pressure-retaining valve is required to keep the system pressure to a certain value against the diesel fuel oil service tank. It is to be adjusted so that the pressure before engine inlet can be maintained in the required range (see section Operating/service temperatures and pressures, Page 68).

5.6.8 Setting the HFO supply system

General information

The specified flow rate of fuel oil (FO) through the engines is essential for them to function reliably. If the minimum flow is not reached for each engine, problems such as stuck fuel injection pumps may result. The reason for this is that an inadequate flow rate deteriorates the cooling and lubrication properties of fuel, leading to laquering and seizing during HFO operation, or seizing alone in MDO/MGO operation.

It is important to remember that even if plant-related fuel pumps are correctly designed as per the project guide, this does not guarantee the minimum flow through each engine. The entire fuel oil system must be commissioned carefully, as even a single incorrectly adjusted valve can hinder fuel flow through the engines.

Based on the MAN Energy Solutions fuel oil system, the guideline 010.000.023-25 explains how the correct setting is performed and how each engine is supplied with its required fuel flow and pressure, as set out in the project specification for reliable operation. This guideline can also be applied to fuel systems for GenSets alone, without MAN Energy Solutions two-stroke engines. It applies to MAN Energy Solutions marine GenSets with a conventional injection system.

5.6.9 Fuel changeover

The following section give general information about the fuel changeover. Additional and priority information about the fuel changeover procedure is given in the engine operating instruction/manual section “Changeover from diesel oil to heavy fuel oil and vice versa”.

Global fuel changeover

Global fuel changeover means that all GenSets are switched over to the other type of fuel at the same time. This changeover is done by switching the three-way valves for fuel oil changeover CK-002 and is permissible while the engines are running.

Local fuel changeover

The GenSets can be supplied with MDO by the separate emergency MDO supply system (see section Emergency MDO supply system, Page 234). It is designed in such a way that the fuel type for the GenSets can be changed independent of the fuel supply of the propulsion engine. A fuel changeover of a single GenSet is called local changeover and must only be done at stopped engine.

This changeover is done by switching the three-way valves for fuel oil changeover CK-006 and CK-007, see description in paragraph CK-006/Three-way cock, switching inlet between MDO - HFO and CK-007/Three-way cock, switching return flow between MDO - HFO, Page 235.

A local fuel changeover may be necessary if the GenSets have to be:

- Stopped for a prolonged period.
- Stopped for major repair of the fuel system, etc.
- In case of a blackout/emergency start.

The fuel oil system design must enable the performance of the following steps for a local changeover from HFO to MDO:

- Flushing the stopped engine with MDO from separate emergency MDO supply system. The flushing backflow should be lead to the high sulphur (HS) heavy fuel oil service tank.
- Turning the engine crankshaft 3 – 4 times.
- Adjusting the fuel temperature upstream engine and the pump surface temperature to about 45 °C.

Approximately 50 minutes may elapse until a stable fuel oil temperature/viscosity (depending on fuel system) is adjusted and the engine can be started.

The fuel oil temperature change gradient must not be higher than 2 K/min.

5.7 Compressed air system

5.7.1 General

To perform or control the following functions and systems, compressed air is required:

- Engine start
- Emergency stop
- Oil mist detector
- Jet assist
- Turning gear

Each engine requires only one connection for compressed air. For the GenSet internal piping see figure Compressed air system diagram – GenSet, Page 238.

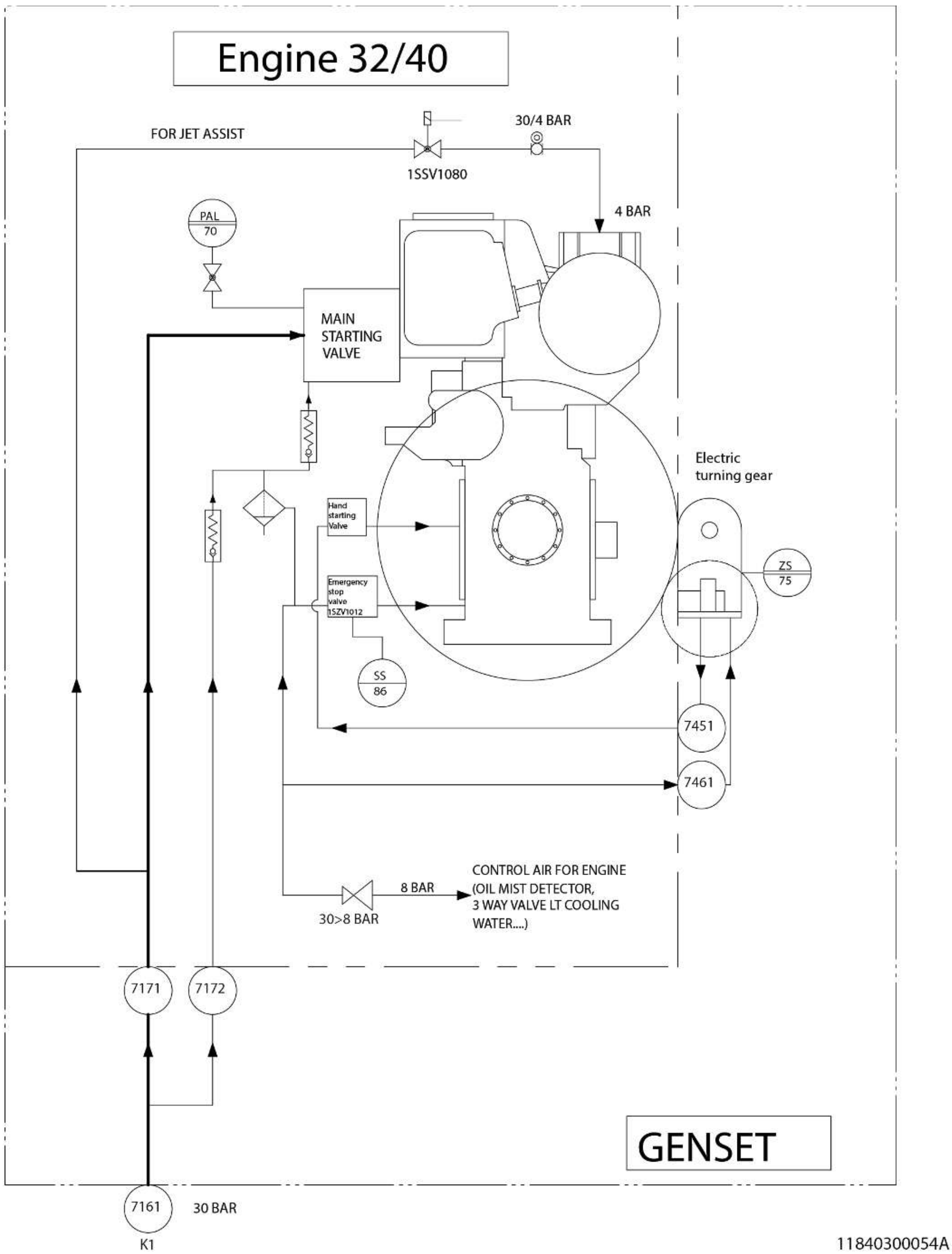
Piping

The pipes to be connected by the shipyard have to be supported immediately behind their connection to the engine. Further supports are required at sufficiently short distance.

Flexible connections for starting air (steel tube type) have to be installed with elastic fixation. The elastic mounting is intended to prevent the hose from oscillating. For detail information please refer to planning and final documentation and manufacturer manual.

Other air consumers for low pressure, auxiliary application (e.g. filter cleaning, TC cleaning, pneumatic drives) can be connected to the start air system after a pressure reduction unit.

Galvanised steel pipe must not be used for the piping of the system.



	On engine connections
7171	Air inlet (Main starting valve)
7172	Control air and emergency stop
	On GenSet connections
7161/K1	Starting air inlet on GenSet
7451	Air outlet from turning gear
7461	Air inlet to turning gear

Figure 70: Compressed air system diagram – GenSet

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5.7.2 External compressed air system – Description

Compressed air system diagram

The compressed air supply to the engine plant requires starting air receivers and starting air compressors of a capacity and air delivery rating which will meet the requirements of the relevant classification society.

This external compressed air system should be common for both, propulsion and auxiliary engines. Seperate tanks should only be installed in turbine driven vessels or if the auxiliary engines are installed far away from the propulsion plant. Between the compressor and the air receivers an oil and water separator should be installed in the line, equipped with automatic drain facilities.

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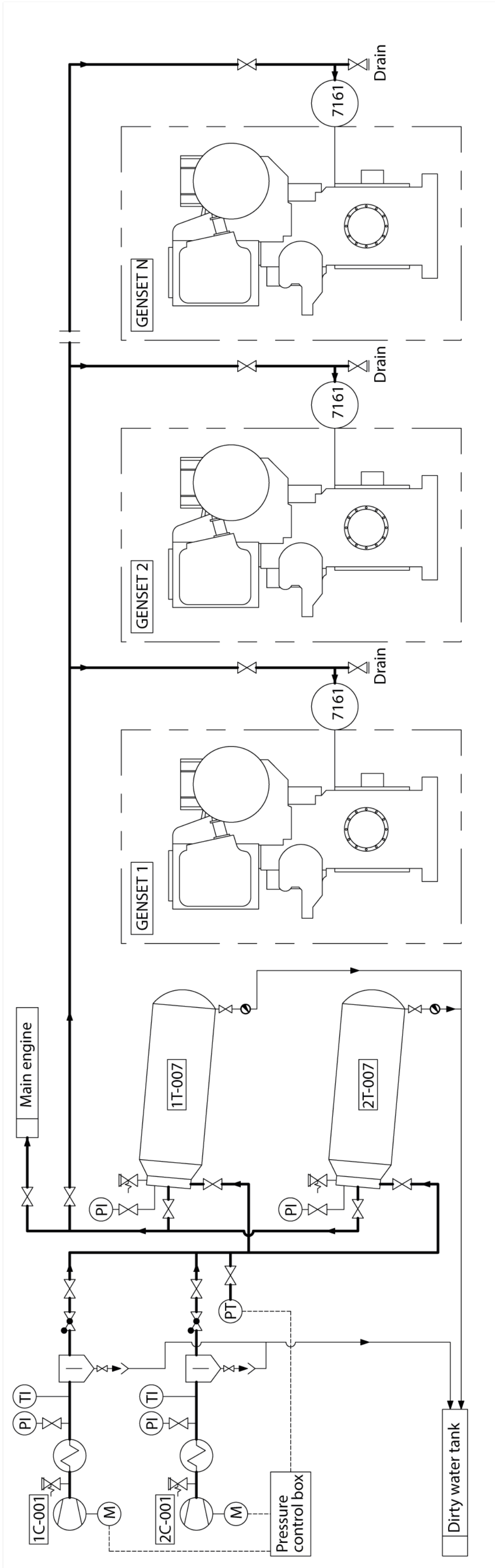

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	Components		
1,2 C-001	Starting air compressor	1,2 T-007	Starting air receiver
	On GenSet connections		
7161	Starting air inlet on GenSet		

Figure 71: Compressed air system

Installation

In order to protect the engine starting and control equipment against condensation water the following should be observed:

- The air receiver(s) should always be installed with good drainage facilities. Receiver(s) arranged in horizontal position must be installed with a slope downwards of min. 3 – 5 degrees.
- Pipes and components should always be treated with rust inhibitors.
- The starting air pipes should be mounted with a slope towards the receivers, preventing possible condensed water from running into the compressors.
- Drain valves should be mounted at lowest position of the starting air pipes and receivers.

The installation also has to ensure that during emergency discharging of the safety valve no persons can be compromised.

It is not permissible to weld supports (or other) on the air receivers. The original design must not be altered. Air receivers are to be bedded and fixed by use of external supporting structures.

Other air consumers for low pressure, auxiliary application (e.g. filter cleaning, TC cleaning, pneumatic drives) can be connected to the start air system after a pressure reduction unit.

Galvanised steel pipe must not be used for the piping of the system.

5.7.3 External compressed air system – Dimensioning starting air receivers, compressors

General requirements of classification societies

The equipment provided for starting the engines must enable the engines to be started from the operating condition 'zero' with shipboard facilities, i.e. without outside assistance.

1 C-001, 2 C-001/Starting air compressor

These are multi-stage compressor sets with safety valves, cooler for compressed air and condensate traps.

The operational compressor is switched on by the pressure control at low pressure then switched off when maximum service pressure is attained.

A max. service pressure of 30 bar is required. The standard design pressure of the starting air receivers is 30 bar and the design temperature is 50 °C.

The service compressor is electrically driven, the auxiliary compressor may also be driven by a diesel engine. The capacity of both compressors is identical.

Two or more starting air compressors must be provided. At least one of the air compressors must be driven independently of the main engine and must supply at least 50 % of the required total capacity.

The total capacity of the starting air compressors is to be calculated so that the air volume necessary for the required number of starts is topped up from atmospheric pressure within one hour.

The compressor capacities are calculated as follows:

$$P = \frac{V \times 30}{1000}$$

P [Nm³/h]	Total volumetric delivery capacity of the compressors
V [litres]	Total volume of the starting air receivers at 30 bar service pressure

As a rule, compressors of identical ratings should be provided. An emergency compressor, if provided, is to be disregarded in this respect.

1 T-007, 2 T-007/Starting air receiver

The starting air supply must be split up into at least two starting air receivers of the same size, which can be used independently of each other. Depending on the number of required starting manoeuvres and the consumption volume per manoeuvre, the size of the starting air receivers can be calculated according to the given formula. The exact number of required starting manoeuvres depends on the arrangement of the system and on the special requirements of the classification society.

For the air consumption of the engine see table Starting air and control air consumption, Page 60. Per each starting manoeuvre, the volume of one jet-assist manoeuvre has to be considered. For more information concerning jet assist, see section Jet assist, Page 243. The starting air consumption of an alternator plant is approximately 50 % higher than stated for the single engine.

Service pressure	max. 30 bar
Minimum starting air pressure	min. 10 bar

Calculation for starting air receiver of engines without jet assist and Slow Turn:

$$V = \frac{V_{Start\ Ref}}{JRef} * JTotal * (Z_{St} + Z_{Safe}) \,/\, (p_{max} - p_{min})$$

Calculation for starting air receiver of engines with jet assist and Slow Turn:

$$V = \left(\frac{V_{Start\ Ref}}{JRef} * JTotal * (Z_{St} + Z_{Safe}) + \frac{V_{Jet}}{5\ sec} * Z_{Jet} * t_{Jet} + \frac{V_{Slowturn\ Ref}}{JRef} * JTotal * Z_{SL}\right) \,/\, (p_{max} - p_{min})$$

V [litre]	Required receiver capacity
$V_{Start\ Ref}$ [litre]	Air consumption per nominal Start Ref value[1)], to be recalculated from Nm³ to litre
J_{Ref}	Reference moment of inertia J_{Ref} [1)], basis for stated air consumption
J_1	Moment of inertia of crankshaft and damper of the engine[2)]
J_2	Moment of inertia of flywheel of the engine[2)]
$J_{Plant\ attached\ to\ the\ flywheel}$	Plant specific moment of inertia attached to the flywheel, that needs to be accelerated by the engine's starting air system and can not be separated from the engine by a clutch during starting-up

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J_{Total}	Total moment of inertia of engine and plant, that needs to be accelerated by the engine's starting air system
z_{st}	Number of starts required by the classification society
z_{Safe}	Number of starts as safety margin
V_{Jet} [litre]	Assist air consumption per jet assist[1)], to be recalculated from Nm^3 to litre
z_{Jet}	Number of jet assist procedures[3)]
t_{Jet} [sec]	Duration of jet assist procedures
$V_{Slow\ Turn\ Ref}$	Air consumption per Slow Turn Ref value[1)], to be recalculated from Nm^3 to litre
z_{sl}	Number of Slow Turn manoeuvres
p_{max} [bar]	Maximum starting air pressure (normally 30 bar)
p_{min} [bar]	Minimum starting air pressure (15 bar)

[1)] Tabulated values see section Starting air and control air consumption, Page 60.

[2)] Tabulated values see section Moments of inertia – Crankshaft, damper, flywheel, Page 89.

[3)] The required number of jet manoeuvres has to be checked with yard or ship owner. To make a decision, consider the information in section Jet assist, Page 243.

If other consumers (i.e. auxiliary engines, ship air etc.) which are not listed in the formula are connected to the starting air receiver, the capacity of starting air receiver must be increased accordingly, or an additional separate air receiver has to be installed.

5.7.4 External compressed air system – Jet assist

General

Air consumption

At each engine start the engine control system activates jet assist to accelerate the start-up of the GenSet. Thus for each starting attempt the air volume of one jet assist manoeuvre must be considered additionally.

Auxiliary GenSet

The data in following table is not binding. The required number of jet manoeuvres for one engine has to be checked with yard or ship owner. For decision see also section Start-up and load application, Page 35.

The value shown in the following table are based on diesel oil mode.

Application	Recommended no. of jet assist with average duration, based on the quantity of manoeuvres per hour
Auxiliary GenSet	3 x 5 sec

Table 107: Value (for guidance only) for the number of jet assist manoeuvres dependent on application

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5.7.5 Slow turn

MAN L32/40 and MAN L32/44 auxiliary GenSets are not equipped with a slow turn device.

5.8 Engine room ventilation and intake air

5.8.1 External general information

Engine room ventilation system

Its purpose is:

- Supplying the engines and auxiliary boilers with combustion air.
- Carrying off the radiant heat from all installed engines and auxiliaries.

Intake air engine

The intake air of the engine must be free from spray water, snow, dust and oil mist.

This is achieved by:

- Louvres, protected against the head wind, with baffles in the back and optimally dimensioned suction space so as to reduce the air flow velocity to 1–1.5 m/s.
- Self-cleaning air filter in the suction space (required for dust-laden air, e.g. cement, ore or grain carrier).
- Sufficient space between the intake point and the openings of exhaust air ducts from the engine and separator room as well as vent pipes from lube oil and fuel oil tanks and the air intake louvres (the influence of winds must be taken into consideration).
- Positioning of engine room doors on the ship's deck so that no oil-laden air and warm engine room air will be drawn in when the doors are open.
- Arranging the separator station at a sufficiently large distance from the turbochargers.

As a standard, the engines are equipped with turbochargers with air intake silencers and the intake air is normally drawn in from the engine room.

In tropical service a sufficient volume of air must be supplied to the turbocharger(s) at outside air temperature. For this purpose there must be an air duct installed for each turbocharger, with the outlet of the duct facing the respective intake air silencer, separated from the latter by a space of approximately 1.5 m (see figure Example: Exhaust gas ducting arrangement, Page 272). No water of condensation from the air duct must be permissible to be drawn in by the turbocharger. The air stream must not be directed onto the exhaust manifold.

If the ship operates at arctic conditions, an air preheater must be applied to maintain the engine room temperature above 5°C. In order to reduce power for air preheating, the engines can be supplied by a separate system directly from outside, see section Intake air ducting in case of arctic conditions, Page 245.

Air fans are to be designed so as to maintain a positive air pressure of 50 Pa (5 mm WC) in the engine room.

Radiant heat

The heat radiated from the main and auxiliary engines, from the exhaust manifolds, waste heat boilers, silencers, alternators, compressors, electrical equipment, steam and condensate pipes, heated tanks and other auxiliaries is absorbed by the engine room air.

The amount of air V required to carry off this radiant heat can be calculated as follows:

$$V = \frac{Q}{\Delta t \times cp \times \rho t}$$

V [m³/h]	Air required
Q [kJ/h]	Heat to be dissipated
Δt [°C]	Air temperature rise in engine room (10–12.5)
cp [kJ/kg*k]	Specific heat capacity of air (1.01)
ρt [kg/m³]	Air density at 35°C (1.15)

Ventilator capacity

The capacity of the air ventilators (without separator room) must be large enough to cover at least the sum of the following tasks:

- The combustion air requirements of all consumers.
- The air required for carrying off the radiant heat.

A rule-of-thumb applicable to plants operating on heavy fuel oil is 20–24m³/kWh.

Moreover it is recommended to apply variable ventilator speed to regulate the air flow. This prevents excessive energy consumption and cooling down of engines in stand-by.

Maximum engine room temperature

The engine room ventilation must ensure a maximum engine room temperature, with following boundary conditions:

- Maximum air temperature in the area of the engine and its components ≤ 45°C.
- Maximum air temperature at least 5 K below the flash point of any liquids, that is present within the engine room.

5.8.2 External air supply with or without arctic conditions

General recommendations for external intake air system of vessels

The design of the intake air system ducting is crucial for reliable operation of the engine. The following points need to be considered:

- Every single engine must be provided with a dedicated intake air system. It is not allowed to combine air intake systems of different engines.
- According to classification rules, it may be required for arctic operation to install two air inlets from the exterior, one at starboard and one at portside.
- It must be prevented that exhaust gas and oil dust is sucked into the intake air duct as fast filter blocking might occur.

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- In case of arctic operation, suitable corrosion and low temperature resistant materials should be applied. Stainless steel S316 L might be suitable. For non-arctic operation, a steel duct with C5-M-coating acc. DIN EN ISO 12944 might be sufficient.
- Inside the duct, there must not be any parts (e.g. bolts, nuts, stiffening, etc.) that could fall off and move towards the engine. Installations, that are absolutely necessary (e.g. light behind filter wall) must be specially secured (self-locking nuts, screwed covers instead of clamped covers etc.).
- Due to the air flow, load changes and other external forces, (especially during ice breaking, if applicable) the intake air pipe is subject to heavy vibrations. Additionally engine and propeller exciting frequencies have to be taken into account. This has to be considered within the overall layout and the intake air duct needs to be reinforced sufficiently.
- Thermal expansion has to be considered for the layout and foundation of the duct (e.g. flexible mounting, additional compensators).
- Suitable drainage arrangements to remove any water from the intake air ducting should be provided. Backflow of air through drains has to be avoided (e.g. by syphons) and regularly checked for proper functioning. Adequate heating is required to prevent icing of drains.
- The air duct and its components need to be insulated properly. Especially a vapor barrier has to be applied to prevent atmospheric moisture freezing in the insulation material.
- An (automatic) shut-off flap should be installed to prevent a chimney effect and cooling down of engine during stand-still (maintenance or stand-by of engine). This flap is to be monitored and engine start should only be allowed in fully-open position. As an alternative, the intake system can be closed by a roller shutter or tarpaulin in front of the filter.
- The overall pressure drop of the intake air system ducting and its components is to be limited to 20 mbar. Moreover the differential pressure of the intake air filter must be monitored to keep this requirement. For additional safety, other components as the droplet separator and the weather hood can be monitored by differential pressure devices. During commissioning and maintenance work, checking of the air intake system back pressure by means of a temporarily connected measuring device may become necessary. For this purpose, a measuring socket is to be provided approximately 1–2 metres before the turbocharger, in a straight length of pipe at an easily accessible position. Standard pressure measuring devices usually require a measuring socket size of 1/2".
- The turbocharger as a flow machine is dependent on a uniform inflow. Therefore, the ducting must enable an air flow without disturbances or constrictions. For this, multiple deflections with an angle > 45° within the ducting must be avoided.
- The intake air must not flow against the direction of the compressor rotation, otherwise stalling could occur.
- It is recommended to verify the layout of the intake air piping by CFD calculations up to the entry of the compressor of the turbocharger.
- The maximum specified air flow speed of 20-25 m/s should not be exceeded at any location of the pipe.
- A silencer is recommended to reduce the noise emissions from engine inlet and charge air blow-off. Sound power levels can be found in the relevant section of the Project Guide. Care must be taken, that no insulation material can escape from the silencer, which can fuse into glass spheres in the combustion chamber.

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Components of intake air ducting

The whole system and its components must be designed suitably robust to withstand pressure peaks occurring from turbocharger surge. This will not happen during normal operation, but it could occur at fast load changes of the engine. This can happen 2–3 times consecutively, until the turbocharger comes back to its normal working range.

The table below shows values at engine inlet connection with a suitable intake air ducting. An unfavorable intake air duct design can also lead to higher values.

Type	Variation	Frequency	Comment
Pressure oscillation	± 40 mbar,5–10 Hz	Permanent	Normal operation/ constant load
Peak pressure (shock wave)	± 300 mbar	Sporadically	Engine emergency stop/ turbocharger surge

The ambient air, which is led to engine by the intake air duct, needs to be conditioned by several components as shown in figure External intake air supply system, Page 249. It needs to be cleaned according to the requirements in section Specification of intake air (combustion air), Page 156. This could be done by the following components:

- Section for cleaning of intake air (1–4)

  A weather hood (1) in combination with a snow trap (2) removes coarse dirt, snow and rain. A heated droplet separator (3) subsequently separates remaining water droplets or snow from the air. An appropriate filter cleans the intake air from particles. (4). A metal grid (e.g. 10x10 mm) after filter wall at intake air room is necessary to avoid filter elements or lost parts getting into air intake system. As a minimum, inlet air must be cleaned by an ISO coarse 45% class filter as per DIN EN ISO 16890. If there is a risk of high inlet air contamination, filter efficiency should be at least ISO ePM10 50% according to DIN EN ISO 16890. See figure External intake air supply system, Page 249.

- Combustion air silencer (5)

  Noise emissions of engine inlet and charge air blow-off can be reduced by a silencer in the intake air duct. It is recommended to apply a mesh (5a) at the outlet of the silencer to protect the turbocharger against any loose parts (e.g. insulation material of silencer, rust etc.) from the intake air duct. This mesh is to be applied even if the silencer will not be supplied. A drain close to the turbocharger is required to separate condensate water. See section Noise, Page 83.

- Overpressure flap (6) (optional)

  Depending on the system volume and chosen components it might be necessary to install a overpressure flap between silencer and engine. Peak pressure pulses (e.g. during emergency stop) are conducted into the engine room via this flap, preventing possible damage to the filter and silencer.

- Shut-off flap/blind plate (7)

  It is recommended to install a shut-off flap to prevent cooling down of the engine during longer standstills under arctic conditions. This flap should be monitored by the engine automation system to prevent engine start with closed flap.
  As an alternative, the intake system can be closed by a roller shutter or tarpaulin in front of the filter.

- Compensator (8) and transition piece (9)

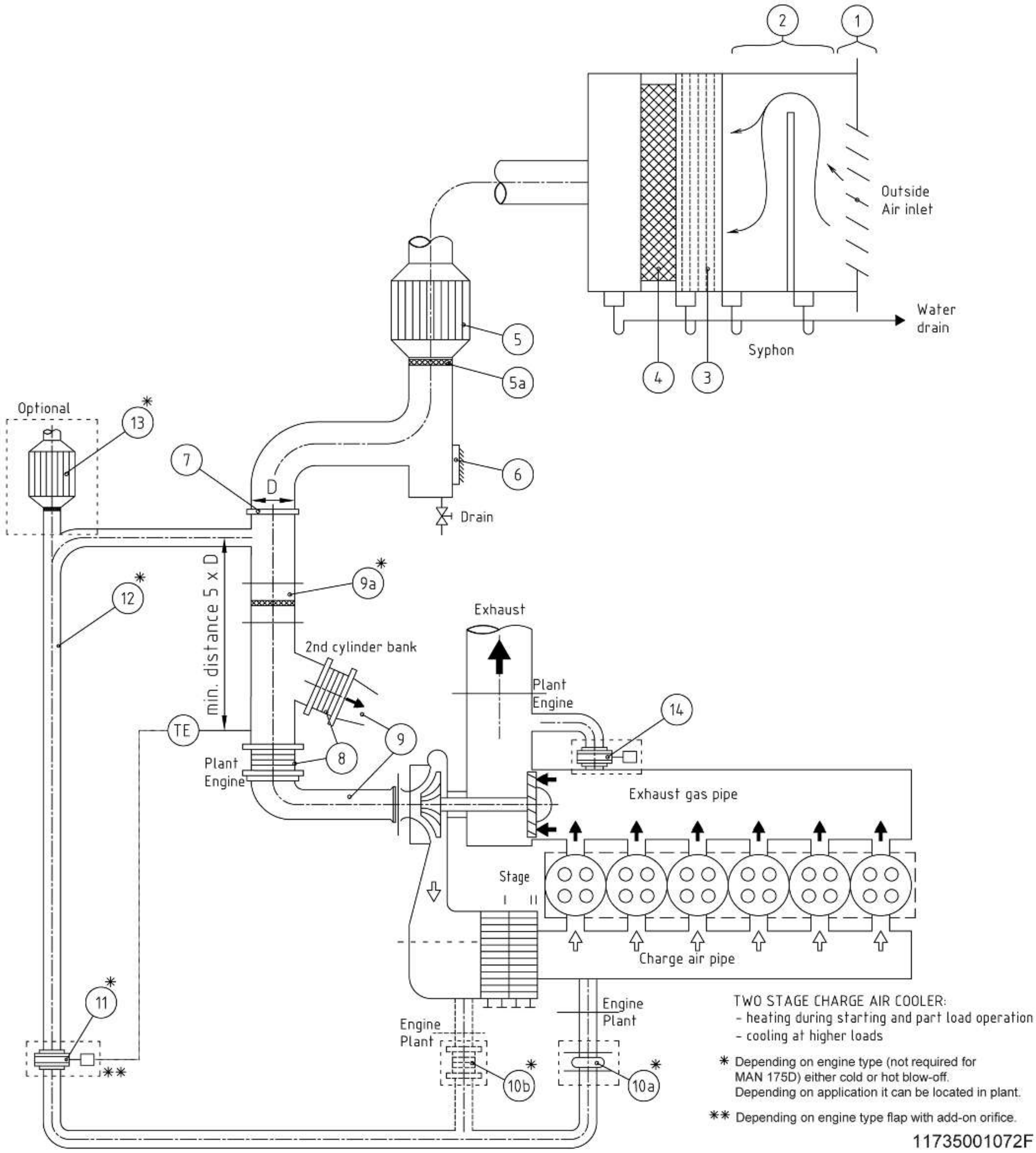
  A steel compensator (rubber might also be considered) has to be installed direct vertically upstream of the 90° transition piece behind turbocharger. A rigid support must be provided as close as possible upstream of the compensator. It has to be noted, that this compensator is solely foreseen to compensate engine-borne movements. Additional compensators might be necessary to cope for thermal expansion.

- Strainer for commissioning phase (9a)

  To prevent residues from installation phase entering the engine during commissioning, a strainer or protective mesh must be installed as close as possible to the turbocharger. After running-in is finished, the strainer must be removed and exchanged by an intermediate pipe. Final performance measurement and engine setting shall be done without intake air strainer.

- Charge air blow-off or recirculation

  For arctic conditions (see section Engine operation under arctic conditions, Page 47) an increased firing pressure, which is caused by higher density of cold air, is prevented by an additional valve, which blows off charge air (11). A compensator (10) connects the engine with the charge air blow-off piping. The blown-off air is taken after (cold blow-off) the charge air cooler or before the charge air cooler (hot blow-off) and is circulated (12) back in the intake air duct or blown out via an additional silencer. A homogenous temperature profile and a correct measurement of intake air temperature in front of compressor has to be achieved. For this a minimum distance of five times the diameter of the intake air duct between inlet of blown-off air and the measuring point must be kept.


1
2
Outside
Air inlet
Water
drain
Syphon
3
4
5
5a
6
Drain
7
D
Optional
13
12
min. distance 5 x D
9a
2nd cylinder bank
Exhaust
Plant
Engine
14
9
8
TE
Plant
Engine
Exhaust gas pipe
Stage
I II
Charge air pipe
Engine
Plant
Engine
Plant
11
10b
10a
TWO STAGE CHARGE AIR COOLER:
- heating during starting and part load operation
- cooling at higher loads
* Depending on engine type (not required for MAN 175D) either cold or hot blow-off. Depending on application it can be located in plant.
** Depending on engine type flap with add-on orifice.
11735001072F

1 Weather hood
2 Snow trap
3 Heated droplet separator
4 Air intake filter 030.120.010
5 Combustion air silencer 030.130.040
5a Protective mesh
6 Overpressure flap (optional)
7 Blind plate/shut-off flap (for maintenance case)
8 Metal bellow expansion joint combustion air (rubber might be considered)
9 Transition piece
9a Intermediate pipe with strainer for running-in phase (to be removed afterwards) 030.120.190
10a Rubber bellow expansion joint – Cold blow-off
10b Metal bellow expansion joint – Hot blow-off
11 Charge air blow-off valve
12 Charge air blow-off pipe
13 Charge air blow-off silencer
14 Waste gate (if required for relevant engine type)

Figure 72: External intake air supply system

5.9 Exhaust gas system

5.9.1 External exhaust gas system – General information

Layout

The flow resistance in the exhaust system has a very large influence on the fuel consumption and the thermal load of the engine. The values given in this document are based on an exhaust gas system which flow resistance does not exceed 30 mbar. If the flow resistance of the exhaust gas system is higher than 30 mbar, contact MAN Energy Solutions for project-specific engine data.

The pipe diameter selection depends on the engine output, the exhaust gas volume and the system back pressure, including silencer and SCR (if fitted). The back pressure also being dependent on the length and arrangement of the piping as well as the number of bends. Sharp bends result in very high flow resistance and should therefore be avoided. If necessary, pipe bends must be provided with guide vanes.

It is recommended not to exceed a maximum exhaust gas velocity of approximately 40 m/s, at stack outlet 35 m/s.

Installation

When installing the exhaust system, the following points must be observed:

- The exhaust pipes of two or more engines must not be joined.
- Because of the high temperatures involved, the exhaust pipes must be able to expand. The expansion joints to be provided for this purpose are to be mounted between fixed-point pipe supports installed in suitable positions. One compensator is required just after the outlet casing of the turbocharger (see section Position of the outlet casing of the turbocharger, Page 273) in order to prevent the transmission of forces to the turbocharger itself. These forces include those resulting from the weight, thermal expansion or lateral displacement of the exhaust piping. For this compensator/expansion joint one sturdy fixed-point support must be provided.
- The exhaust piping should be elastically hung or supported by means of dampers in order to prevent the transmission of sound to other parts of the vessel.
- The exhaust piping is to be provided with water drains, which are to be regularly checked to drain any condensation water or possible leak water from exhaust gas boilers if fitted.

- During commissioning and maintenance work, checking of the exhaust gas system back pressure by means of a temporarily connected measuring device may become necessary. For this purpose, two measuring sockets need to be provided approximately 1 to 2 metres after the exhaust gas outlet of the turbocharger, in a straight length of pipe at an easily accessed position. Standard pressure measuring devices usually require a measuring socket size of 1/2". This measuring socket is to be provided to ensure back pressure can be measured without any damage to the exhaust gas pipe insulation.

5.9.2 External components and assemblies of the exhaust gas system

Exhaust gas silencer and exhaust gas boiler

Mode of operation

The silencer operates on the absorption and resonance principle so it is effective in a wide frequency band. The flow path, which runs through the silencer in a straight line, ensures optimum noise reduction with minimum flow resistance.

A spark arrestor should be provided in the exhaust gas system (e.g. integrated in the silencer).

Note:
Spark arrestors are mandatory for certain ship types.

Installation

If possible, the silencer should be installed towards the end of the exhaust line.

A vertical installation situation is to be preferred in order to avoid formations of gas fuel pockets in the silencer. The cleaning ports of the spark arrestor are to be easily accessible.

Note:
Water entry into the silencer and/or boiler must be avoided, as this can cause damages of the components (e.g. forming of deposits) in the duct.

Exhaust gas boiler

To utilise the thermal energy from the exhaust, an exhaust gas boiler producing steam or hot water may be installed.

Insulation

The exhaust gas system (from outlet of turbocharger, silencer, catalyst, boiler to the outlet stack) is to be insulated to reduce the external surface temperature and airborne noise to the required level.

The relevant provisions concerning accident prevention and those of the classification societies must be observed.

The insulation is also required to avoid temperatures below the dew point on the interior side. In case of insufficient insulation intensified corrosion and soot deposits on the interior surface are the consequence. During fast load changes, such deposits might flake off and be entrained by exhaust in the form of soot flakes.

Insulation and covering of the compensator must not restrict its free movement.

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6 Engine room planning

6.1 Installation and arrangement

6.1.1 General details

Apart from a functional arrangement of the components, the shipyard is to provide for an engine room layout ensuring good accessibility of the components for servicing.

The cleaning of the cooler tube bundle, the emptying of filter chambers and subsequent cleaning of the strainer elements, and the emptying and cleaning of tanks must be possible without any problem whenever required.

All of the openings for cleaning on the entire unit, including those of the exhaust silencers, must be accessible.

There should be sufficient free space for temporary storage of pistons, camshafts, turbocharger etc. dismounted from the engine. Additional space is required for the maintenance personnel. The panels on the engine sides for inspection of the bearings and removal of components must be accessible without taking up floor plates or disconnecting supply lines and piping. Free space for installation of a torsional vibration meter should be provided at the crankshaft end.

A very important point is that there should be enough room for storing and handling vital spare parts so that replacements can be made without loss of time.

In planning marine installations with two or more engines driving one propeller shaft through a multi-engine transmission gear, provision must be made for a minimum clearance between the engines because the crankcase panels of each engine must be accessible. Moreover, there must be free space on both sides of each engine for removing pistons or cylinder liners.

Note:
MAN Energy Solutions delivered scope of supply is to be arranged and fixed by proven technical experiences as per state of the art. Therefore the technical requirements have to be taken in consideration as described in the following documents subsequential:

- Order related engineering documents.
- Installation documents of our sub-suppliers for vendor specified equipment.
- Operating manuals for diesel engines and auxiliaries.
- Project Guides of MAN Energy Solutions.

Any deviations from the principles specified in the aforementioned documents require a previous approval by MAN Energy Solutions.

Arrangements for fixation and/or supporting of plant related equipment deviating from the scope of supply delivered by MAN Energy Solutions, not described in the aforementioned documents and not agreed with us are not permissible.

For damages due to such arrangements we will not take over any responsibility nor give any warranty.

6.1.2 Installation drawings

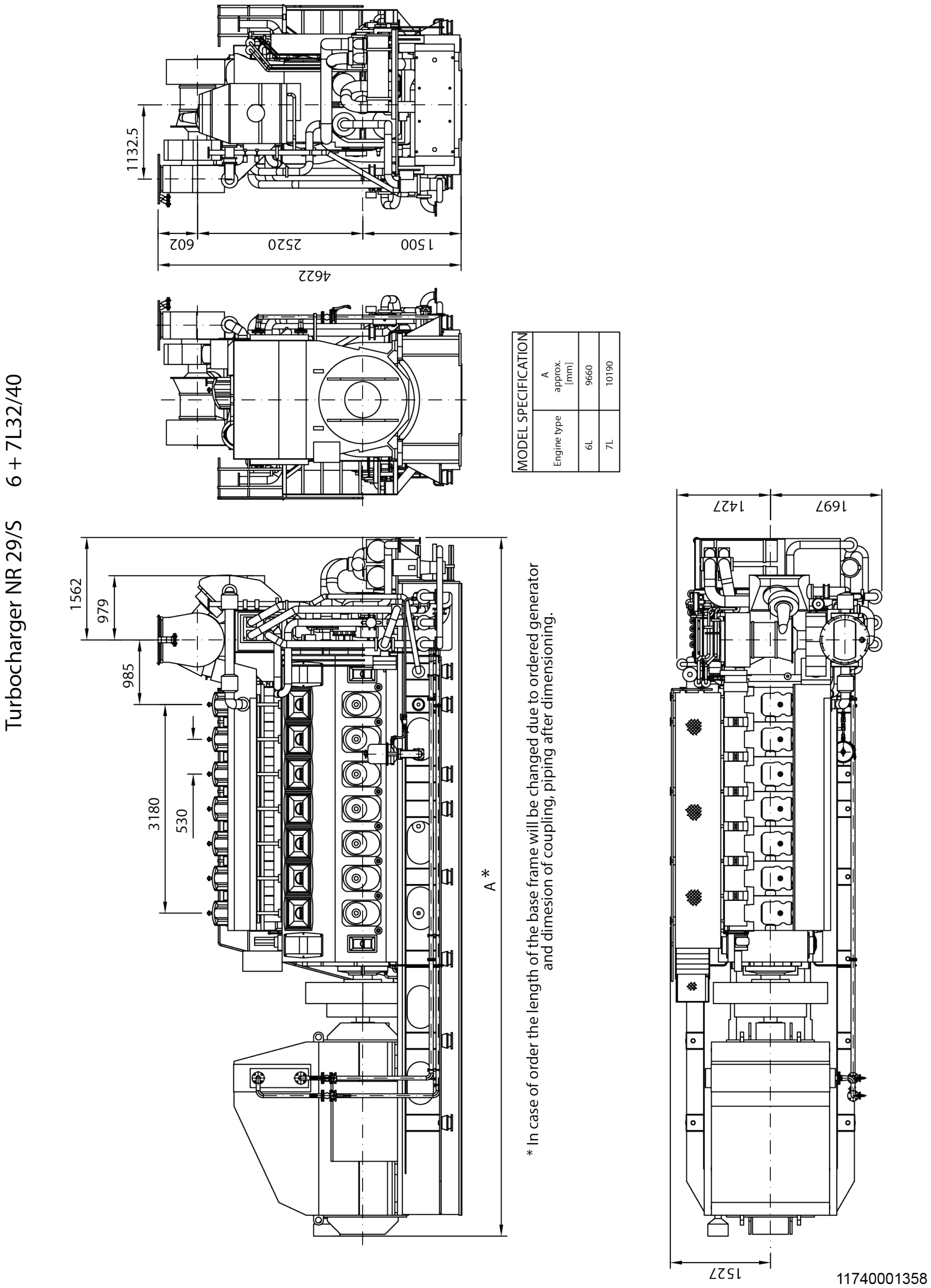

Figure 73: Installation drawing 6L, 7L GenSet

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For space requirements see sections: Space requirement for removal of components, Page 266 and 3D Engine Viewer – A support programme to configure the engine room, Page 260.

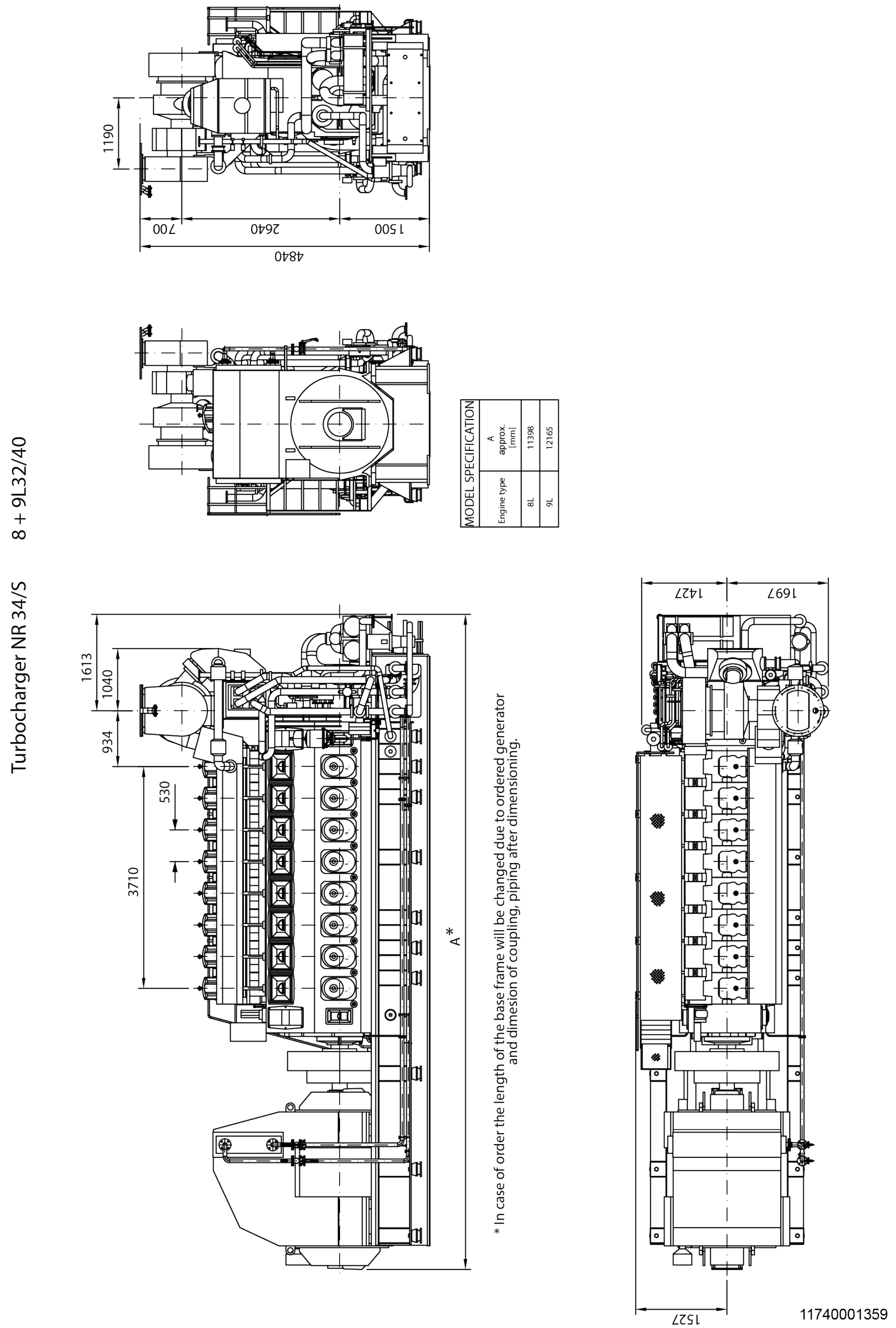

Figure 74: Installation drawing 8L, 9L GenSet

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For space requirements see sections: Space requirement for removal of components, Page 266 and 3D Engine Viewer – A support programme to configure the engine room, Page 260.

6.1.3 Removal dimensions of piston and cylinder liner

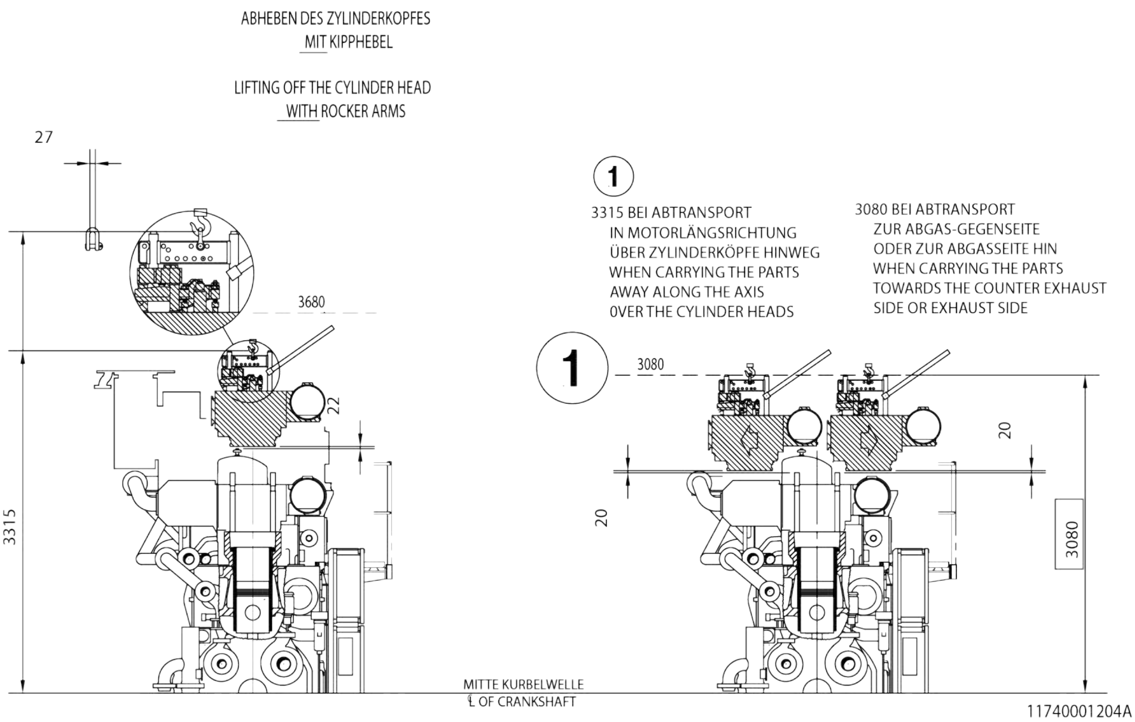

Figure 75: Piston removal – Lifting off the cylinder head with rocker arms – L engine

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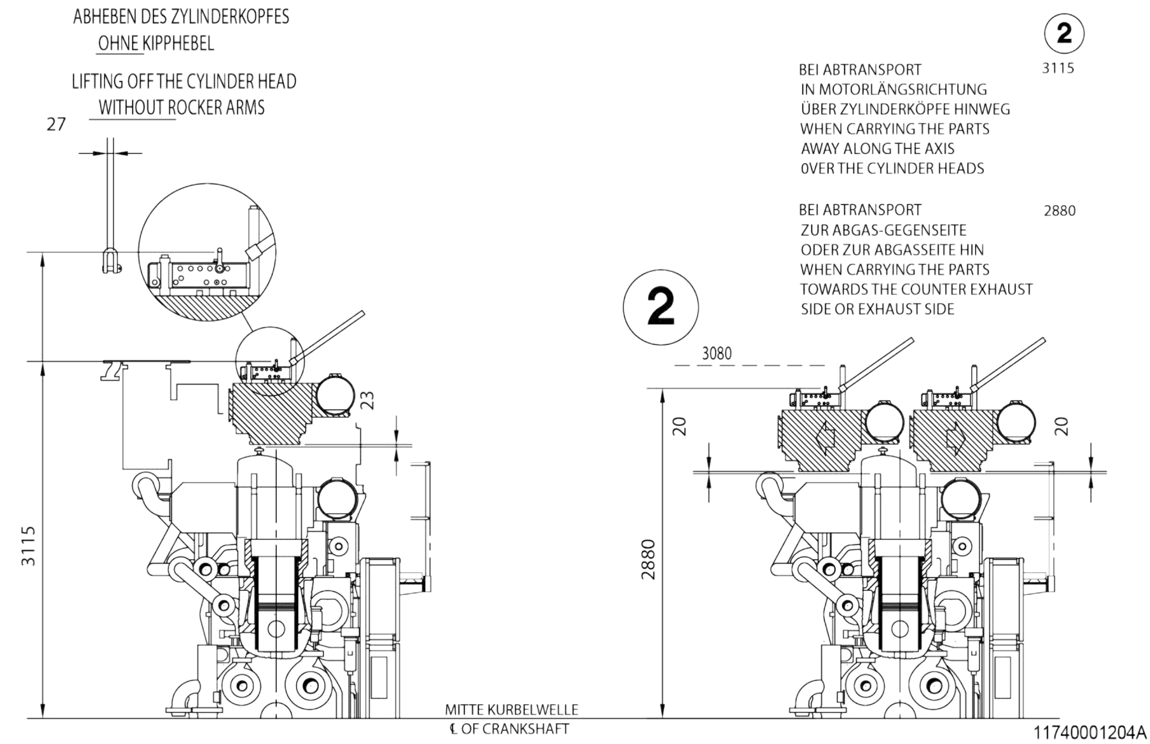

Figure 76: Piston removal – Lifting off the cylinder head without rocker arms – L engine

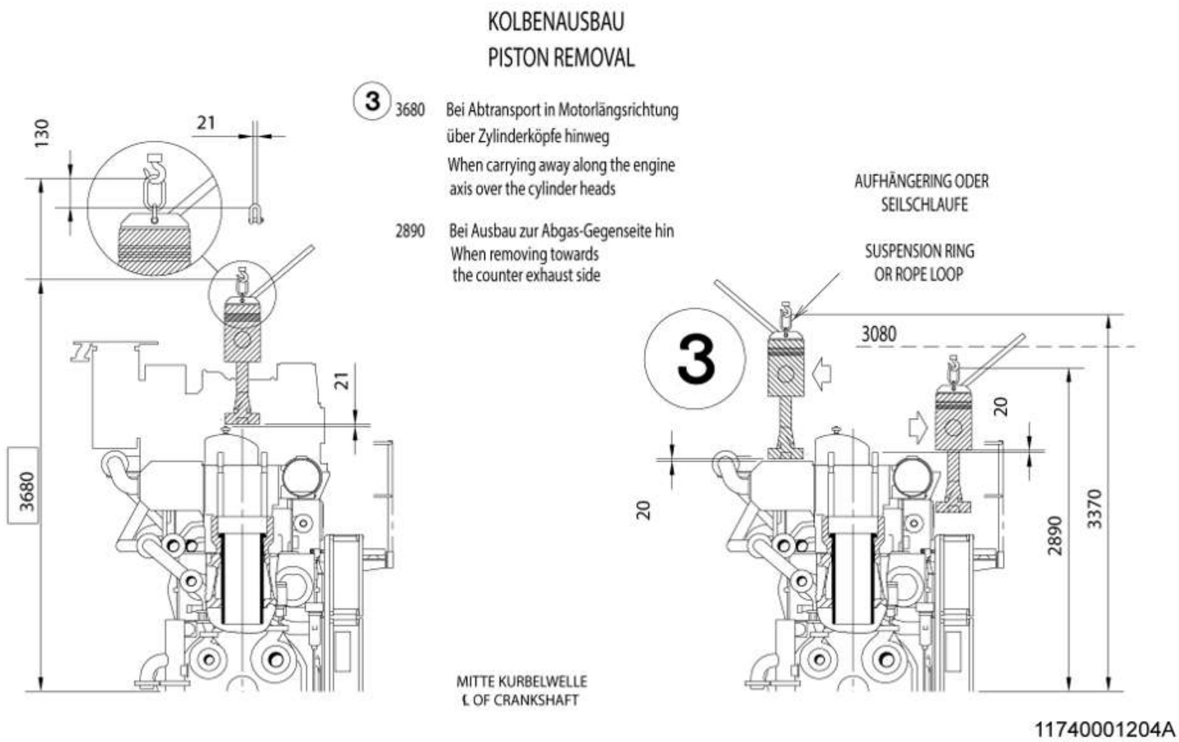

Figure 77: Piston removal – L engine

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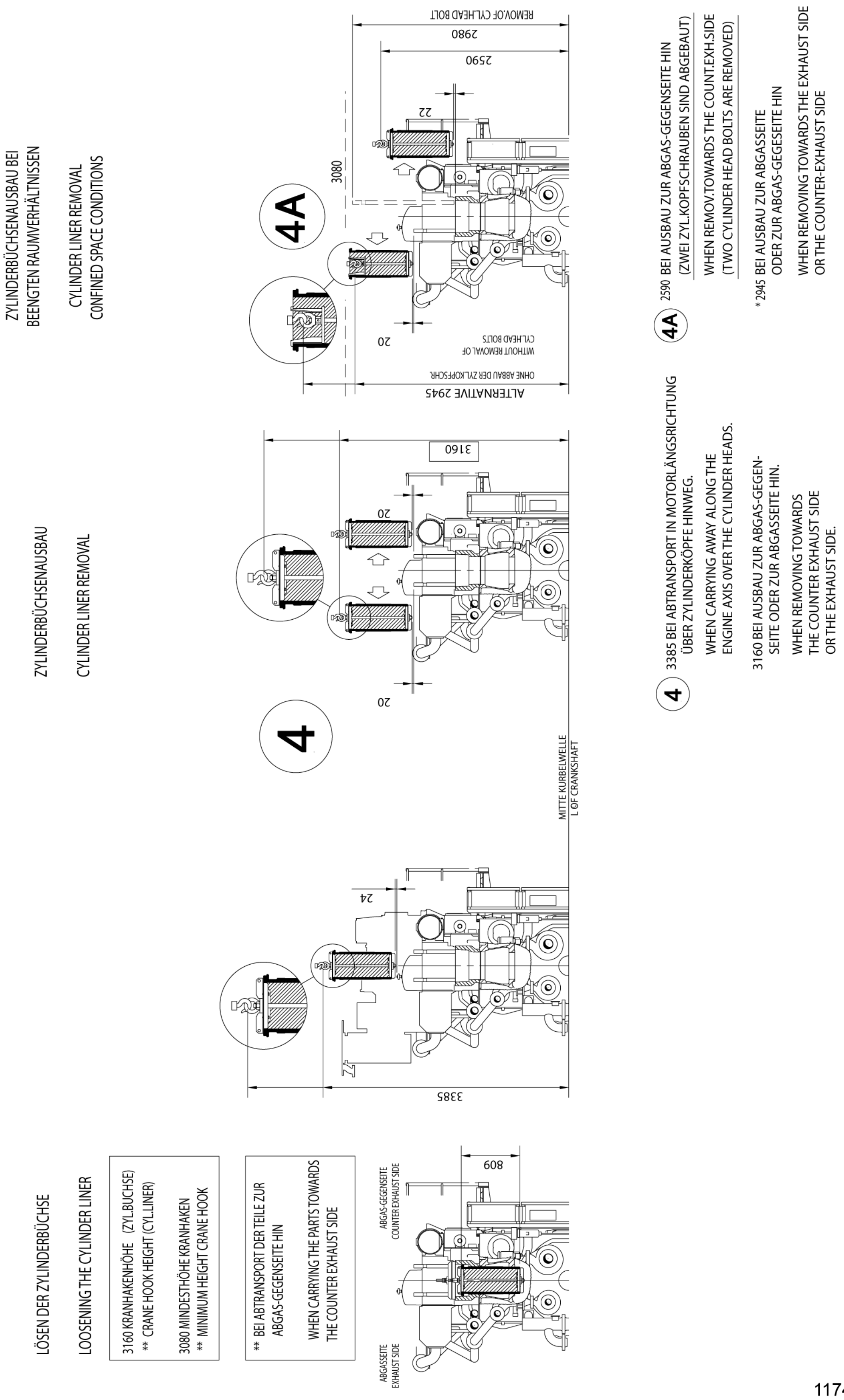

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Figure 78: Cylinder liner removal – L engine

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6.1.4 3D Engine Viewer – A support programme to configure the engine room

MAN Energy Solutions offers a free-of-charge online programme for the configuration and provision of installation data required for installation examinations and engine room planning: The 3D Engine Viewer and the 3D GenSet Viewer.

Easy-to-handle selection and navigation masks permit configuration of the required engine type, as necessary for virtual installation in your engine room.

In order to be able to use the 3D Engine, respectively GenSet Viewer, register on our website under:

https://extranet.mandieselturbo.com/Pages/Dashboard.aspx

After successful registration, the 3D Engine and GenSet Viewer is available under:

https://extranet.mandieselturbo.com/content/appengineviewer/Pages/Default.aspx

by clicking onto the requested application.

In only three steps, you will obtain professional engine room data for your further planning:

- Selection

  Select the requested output, respectively the requested type.
- Configuration

  Drop-down menus permit individual design of your engine according to your requirements. Each of your configurations will be presented on the basis of isometric models.
- View

  The models of the 3D Engine Viewer and the 3D GenSet Viewer include all essential geometric and planning-relevant attributes (e.g. connection points, interfering edges, exhaust gas outlets, etc.) required for the integration of the model into your project.

The configuration with the selected engines can now be easily downloaded.

For 2D representation as:

- .pdf
- .dwg
- .dxf

for 3D as:

- .dgn
- .stp
- .sat
- .igs
- 3D-dxf
- and many others

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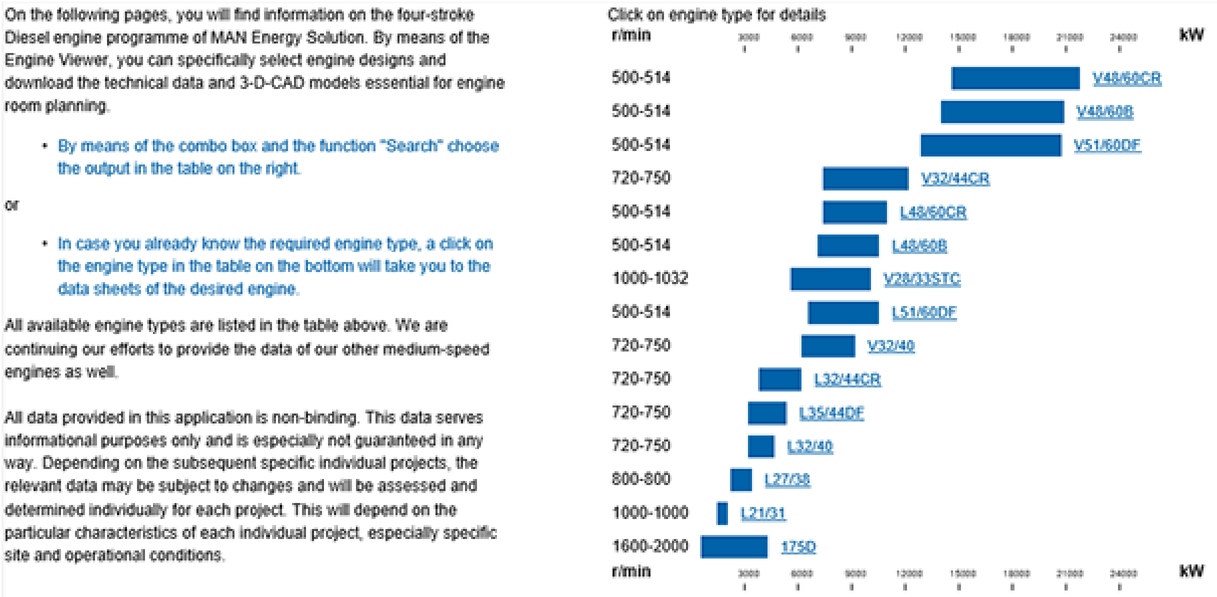

Figure 79: Selection of engine

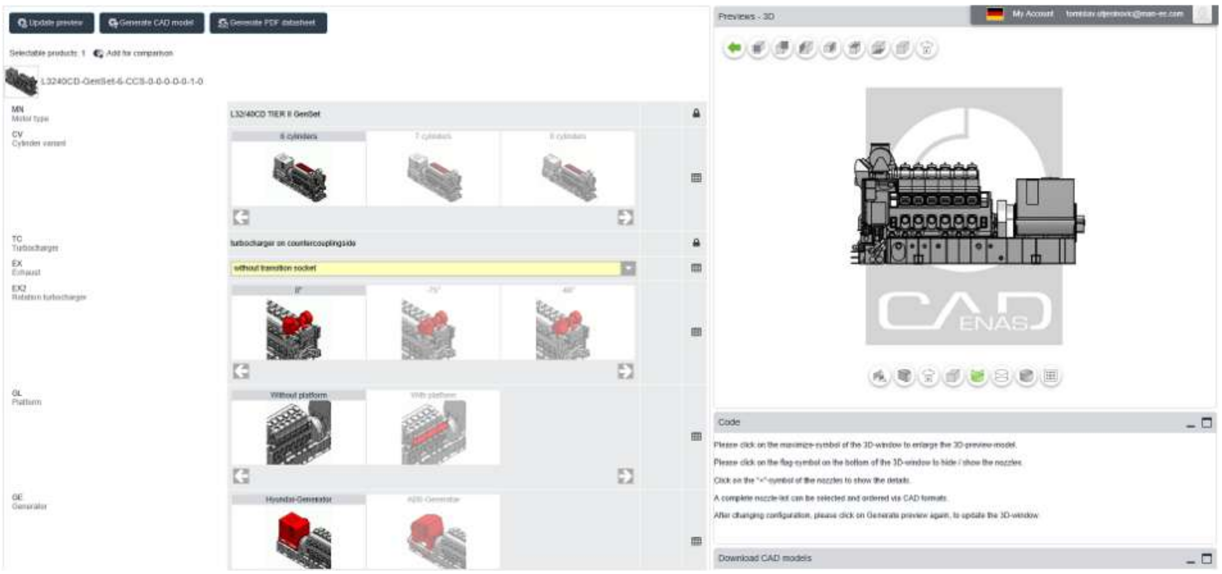
Figure 80: Preselected standard configuration

6.1.5 Lifting device

Lifting gear with varying lifting capacities are to be provided for servicing and repair work on the engine, turbocharger and charge air cooler.

Engine

Component weights

For servicing the engine an overhead traveling crane is required. The lifting capacity shall be sufficient to handle the heaviest component that has to be lifted during servicing of the engine and should foresee extra capacity e.g. to overcome the break loose torque while lifting cylinder heads. The overhead traveling crane can be chosen with the aid of the following table:

Components	Unit	Approximate weights
Cylinder head complete	kg	580
Piston with piston pin and connecting rod (for piston removal)		215
Cylinder liner		175
Charge air cooler		380

Table 108: Component weights

Crane arrangement

The rails for the crane are to be arranged in such a way that the crane can cover the whole of the engine beginning at the exhaust pipe.

The hook position must reach along the engine axis, past the centreline of the first and the last cylinder, so that valves can be dismantled and installed without pulling at an angle.

Similarly, the crane must be able to reach the tie rod at the ends of the engine. In cramped conditions, eyelets must be welded under the deck above, to accommodate a lifting pulley.

The required crane capacity is to be determined by the crane supplier.

Crane design

It is necessary that:

- There is an arresting device for securing the crane while hoisting if operating in heavy seas
- There is a two-stage lifting speed

  Precision hoisting approximately = 0.5 m/min

  Normal hoisting approximately = 2 – 4 m/min

Places of storage

In planning the arrangement of the crane, a storage space must be provided in the engine room for the dismantled engine components which can be reached by the crane. It should be capable of holding two rocker arm casings, two cylinder covers and two pistons. If the cleaning and service work is to be carried out here, additional space for cleaning troughs and work surfaces should be planned.

Transport to the workshop

Grinding of valve cones and valve seats is carried out in the workshop or in a neighbouring room.

Transport rails and appropriate lifting tackle are to be provided for the further transport of the complete cylinder cover from the storage space to the workshop. For the necessary deck openings, see following figures and tables.

Turbocharger

Turbocharger dimensions

Section Turbocharger assignments, Page 20 shows which turbocharger type should be used for which engine variant.

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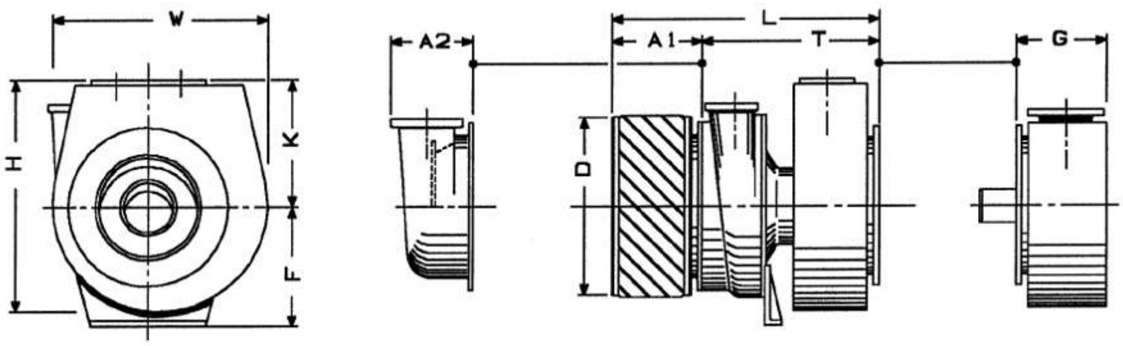

Figure 81: Exemplary illustration of NR turbocharger

Turbocharger type	L [mm]	W [mm]	H [mm]	K [mm]	F [mm]	T [mm]	A1 [mm]	D [mm]	A2 [mm]	G [mm]
NR29/S	Min. 1,275 Max. 1,275	Min. 770 Max. 820	Min. 895 Max. 965	Max. 430	Min. 500 Max. 570	Min. 855 Max. 855	Min. 420 Max. 420	Min. 830 Max. 830	Min. 353.5 Max. 353.5	Min. 402.5 Max. 707
NR34/S	Min. 1,574 Max. 1,574	Min. 853 Max. 870	Min. 935 Max. 1,085	Max. 510	Min. 600 Max. 635	Min. 1,030 Max. 1,030	Min. 544 Max. 544	Min. 1,220 Max. 1,220	Min. 440 Max. 440	Min. 450 Max. 816

Table 109: Dimensions – NR turbocharger

Hoisting rail

A hoisting rail with a mobile trolley is to be provided over the centre of the turbocharger running parallel to its axis, into which a lifting tackle is suspended with the relevant lifting power for lifting the parts, which are mentioned in the table(s) below, to carry out the operations according to the maintenance schedule.

Turbocharger		NR 29/S	NR 34/S
Compressor casing	kg	105	300
Gas admission casing		240	370
Silencer		85	300
Cartridge		190	245
Turbine rotor		45	60
Bearing case		145	185
Space for removal of silencer	mm	210	330
See also table Space required for removal of turbocharger, Page 266.			

Table 110: Hoisting rail of the NR turbocharger

Withdrawal space dimensions

The withdrawal space shown in section Removal dimensions, Page 257 and in the table(s) in paragraph Hoisting rail, Page 263 is required for separating the silencer from the turbocharger. The silencer must be shifted axially by this distance before it can be moved laterally.

In addition to this measure, another 100 mm are required for assembly clearance.

This is the minimum distance between silencer and bulkhead or tween-deck. We recommend to plan additional 300 – 400 mm as working space.

Make sure that the silencer can be removed either downwards or upwards or laterally and set aside, to make the turbocharger accessible for further servicing. Pipes must not be laid in these free spaces.

Fan shafts

The engine combustion air is to be supplied towards the intake silencer in a duct ending at a point 1.5 m away from the silencer inlet. If this duct impedes the maintenance operations, for instance the removal of the silencer, the end section of the duct must be removable. Suitable suspension lugs are to be provided on the deck and duct.

Gallery

If possible the ship deck should reach up to both sides of the turbocharger (clearance 50 mm) to obtain easy access for the maintenance personnel. Where deck levels are unfavourable, suspended galleries are to be provided.

Charge air cooler

For cleaning of the charge air cooler bundle, it must be possible to lift it vertically out of the cooler casing and lay it in a cleaning bath.

Exception MAN 32/40: The cooler bundle of this engine is drawn out at the end. Similarly, transport onto land must be possible.

For lifting and transportation of the bundle, a lifting rail is to be provided which runs in transverse or longitudinal direction to the engine (according to the available storage place), over the centreline of the charge air cooler, from which a trolley with hoisting tackle can be suspended.

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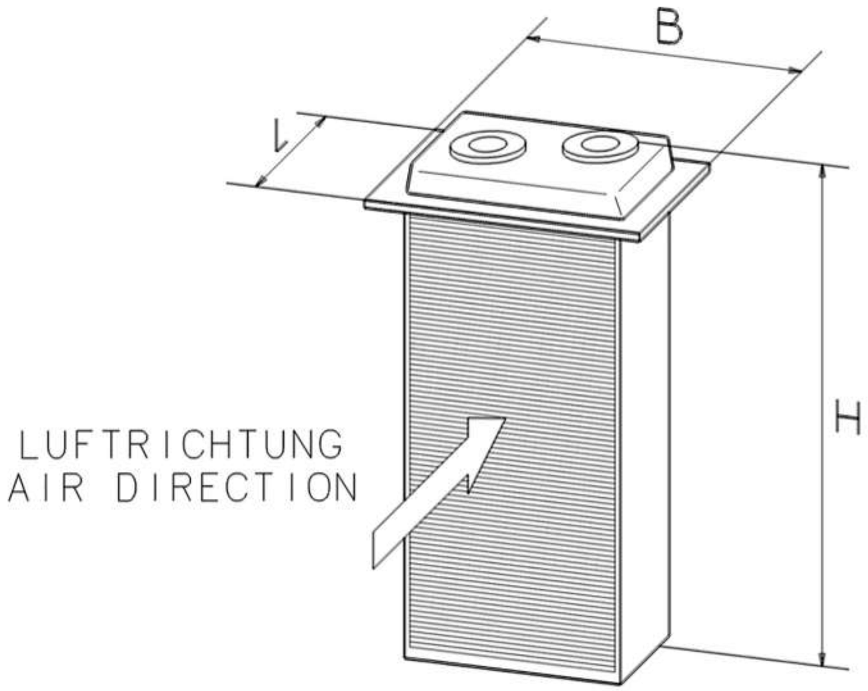

Figure 82: Air direction

Engine type	Weight	Length (L)	Width (B)	Height (H)
	kg	mm	mm	mm
L engine	450	520	712	1,014

Table 111: Weights and dimensions of charge air cooler bundle

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6.1.6 Space requirement for removal of components

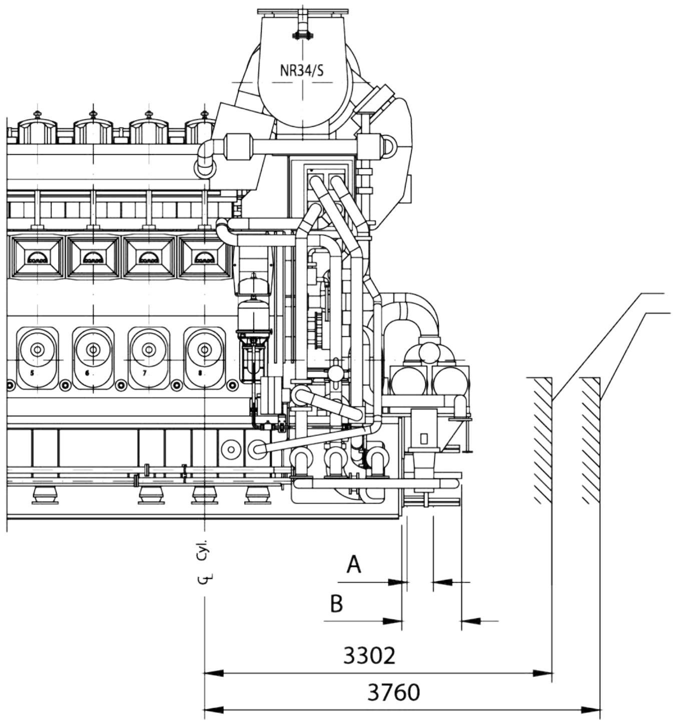

Figure 83: Lube oil cooler removal

No. of cylinders, config		6L	7L	8L	9L
Turbocharger		NR 29/S	NR 29/S	NR 34/S	NR 34/S
A min.	mm	200	227	250	277
A max.		208	236	260	288
B approx.		645	745	795	895
Weight empty	kg	1,133	1,133	1,190	1,190
Weight full		985	985	934	934
The dimension and numbers are given for guidance only.					

Table 112: Dimension and weights for removal of lube oil cooler

No. of cylinders, config		6L	7L	8L	9L
Turbocharger		NR 29/S	NR 29/S	NR 34/S	NR 34/S
C	mm	800	800	1,000	1,000
The dimension and numbers are given for guidance only.					

Table 113: Space required for removal of turbocharger

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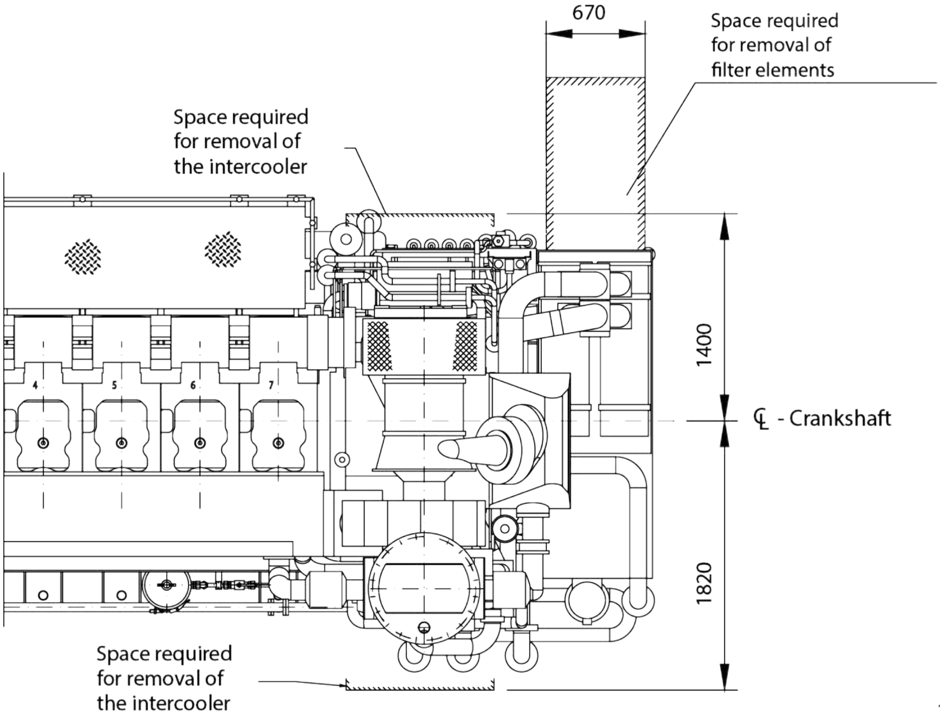

Figure 84: Main filter and intercooler removal

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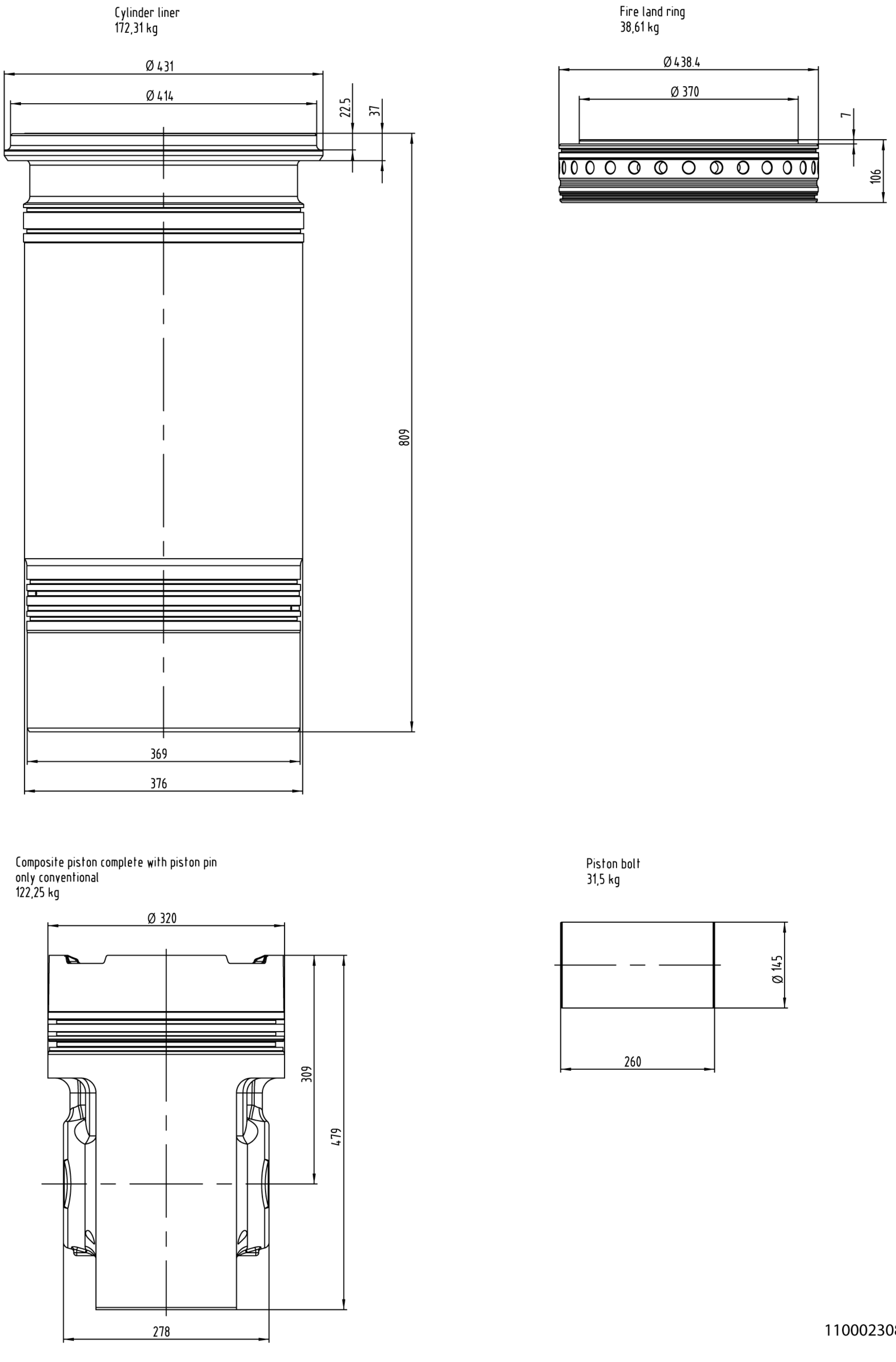
6.1.7 Major spare parts



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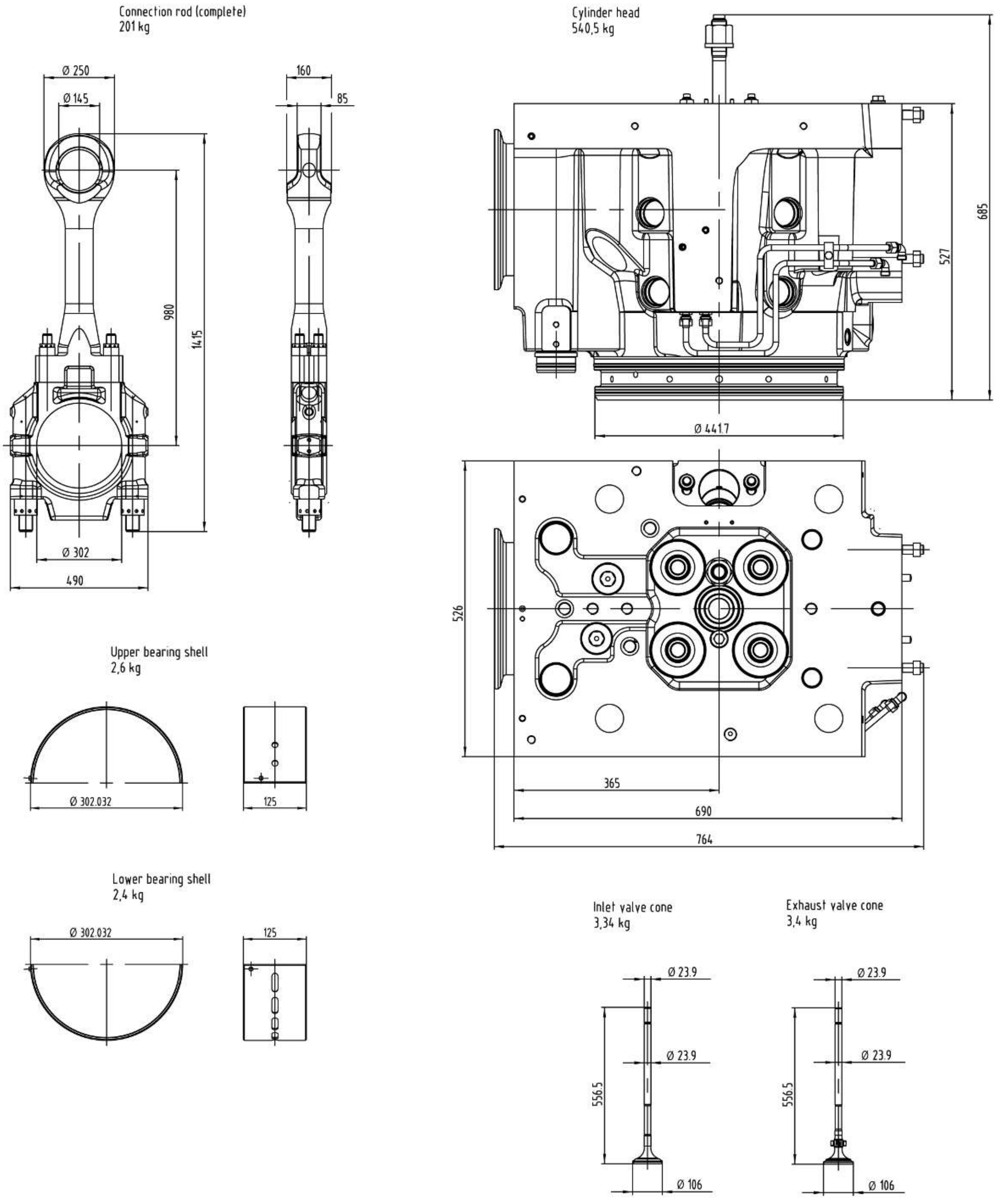

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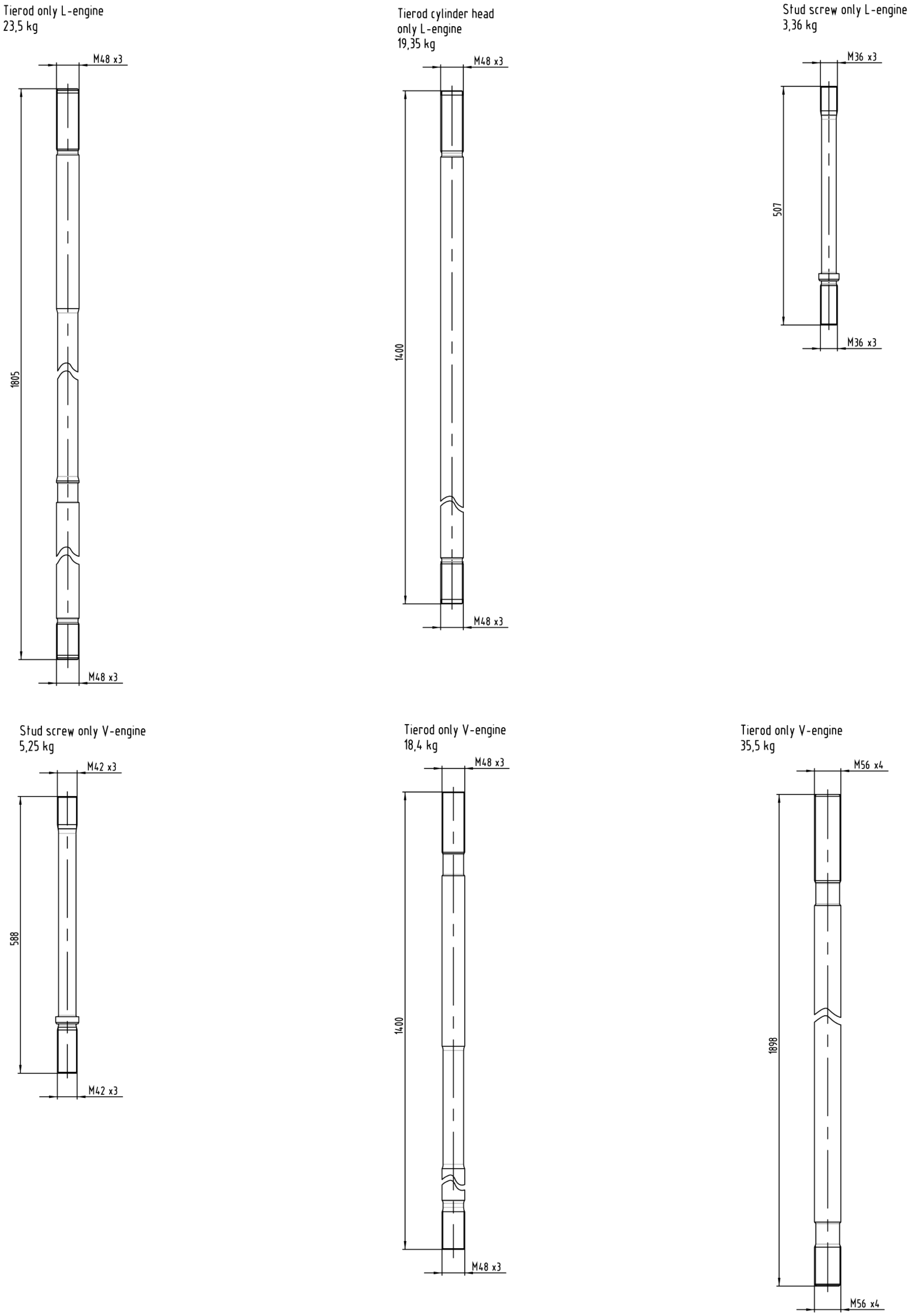

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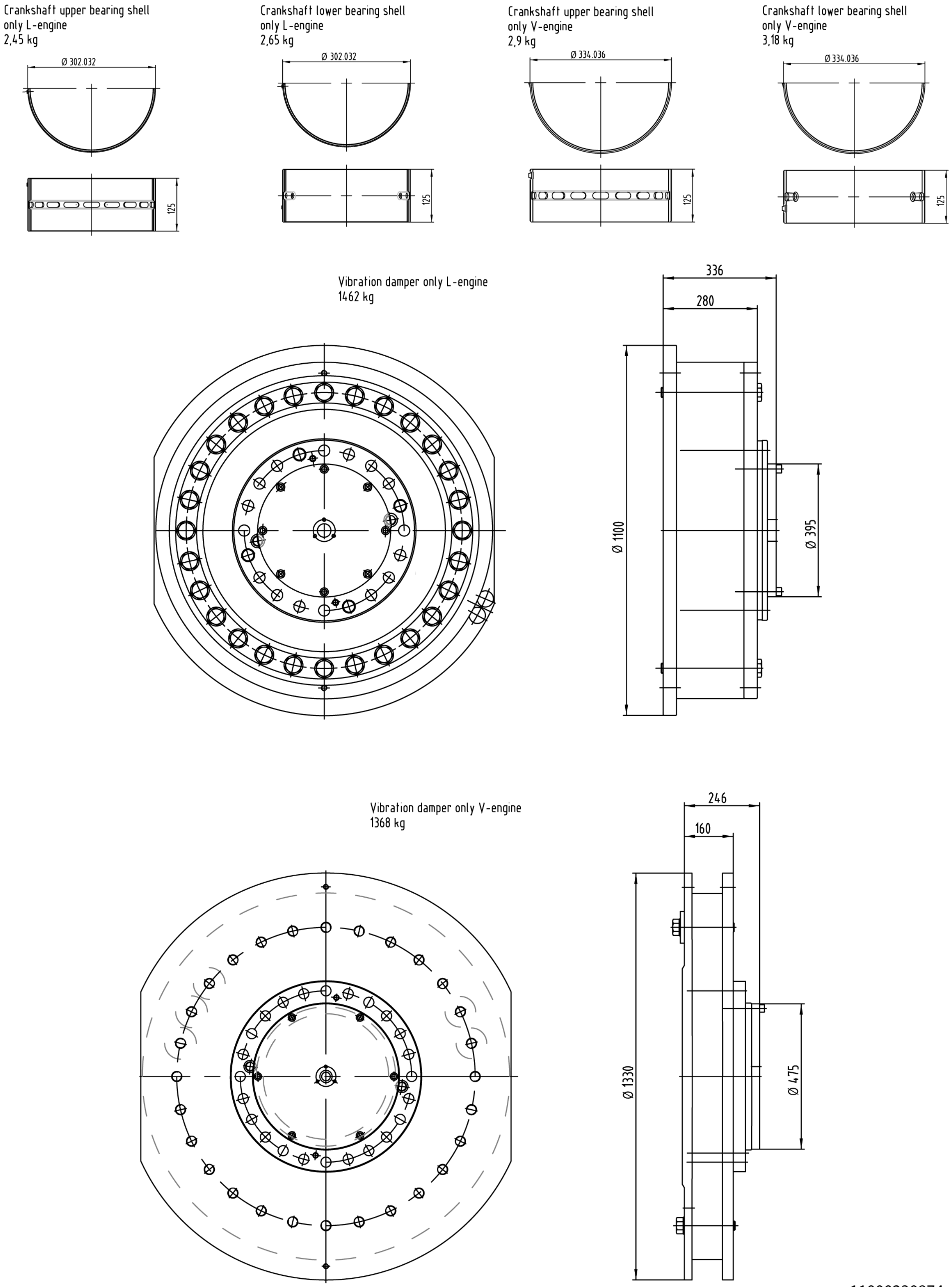

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6.2 Exhaust gas ducting

6.2.1 Example: Ducting arrangement

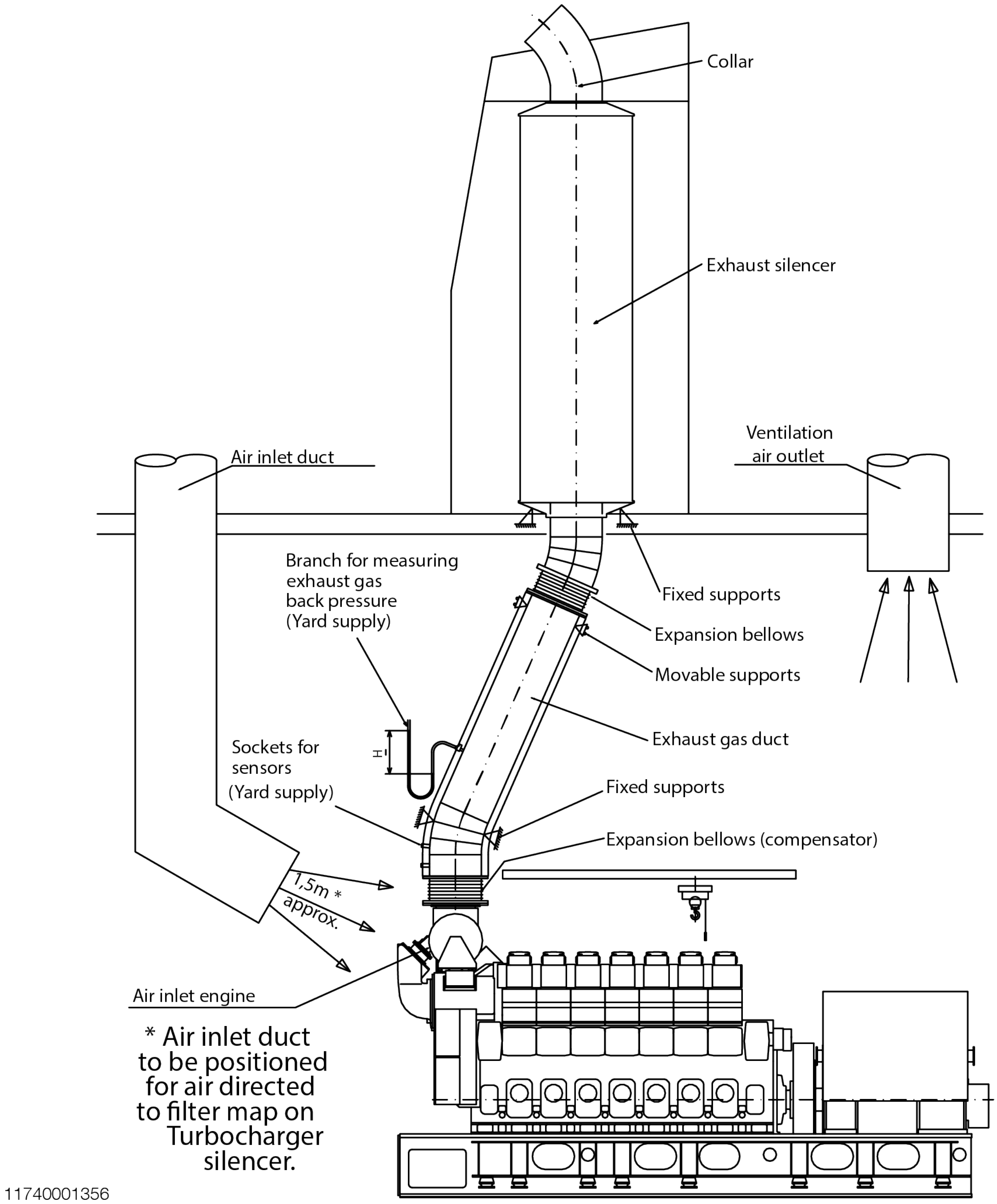

Figure 85: Example: Exhaust gas ducting arrangement

Fix point support

The engine related compensator has to be connected directly to the exhaust gas outlet of the turbocharger (installation of compensator vertically or max. 45° position after turbocharger). In case that the compensator cannot be directly connected to the exhaust gas outlet of the turbocharger, contact MAN Energy Solutions. Immediately downstream of the engine related compensator, it is required to install a strong and rigid fix point to support the exhaust gas pipe. It is not permitted to compensate with the engine related compensator movements or vibrations coming from components or systems installed downstream of this compensator.

6.2.2 Position of the outlet casing of the turbocharger

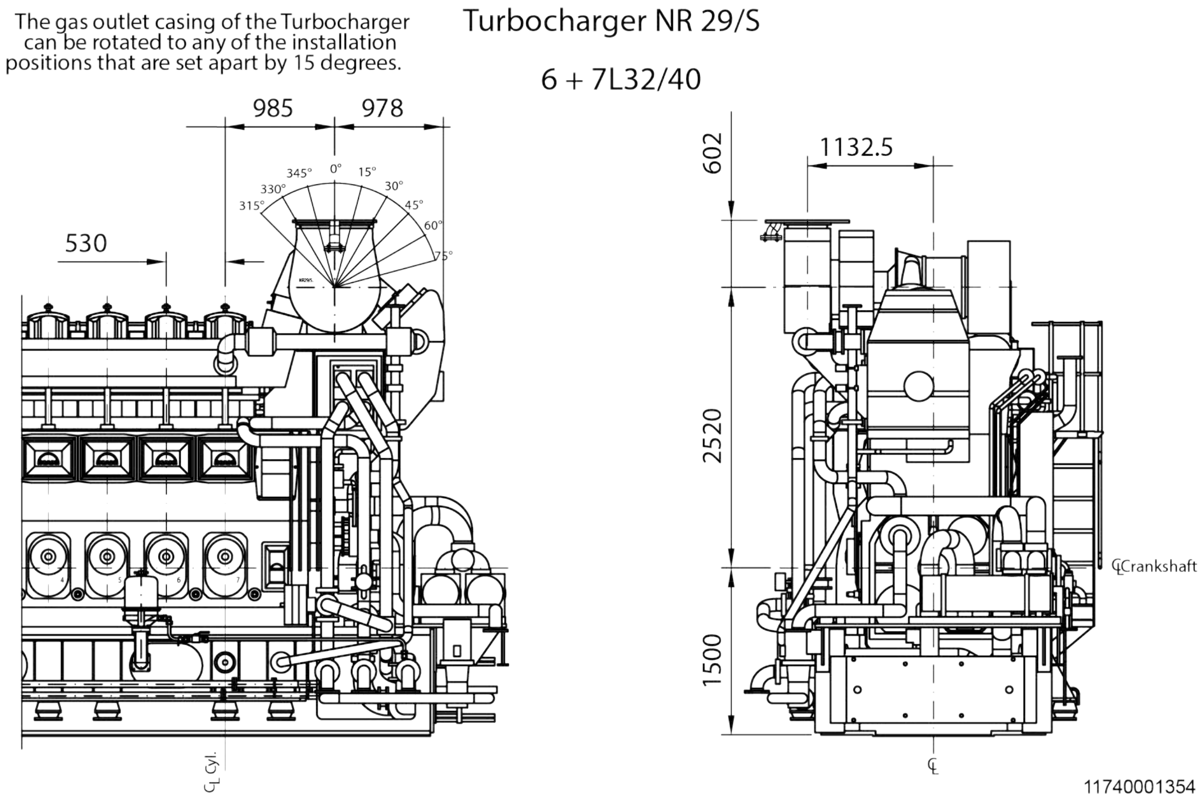

Figure 86: Position of the outlet casing of the turbocharger – 6 + 7L GenSet – NR 29/S

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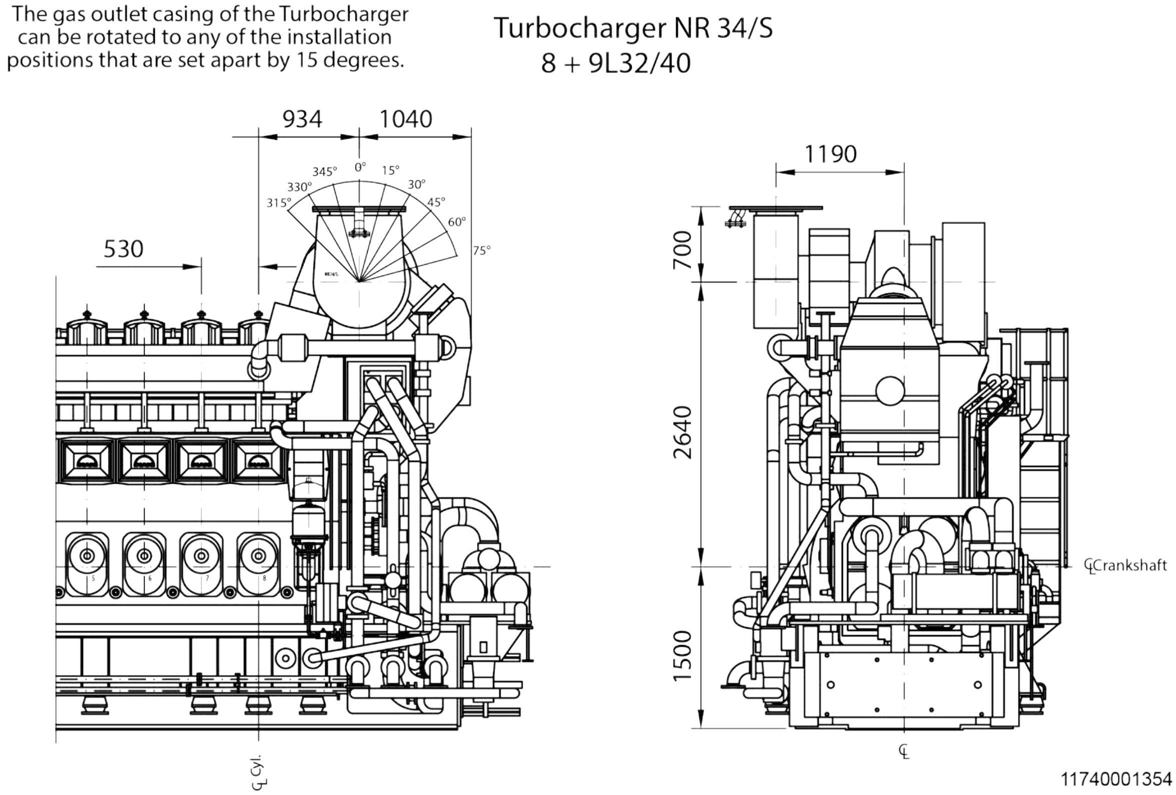

Figure 87: Position of the outlet casing of the turbocharger – 8 + 9L GenSet – NR 34/S

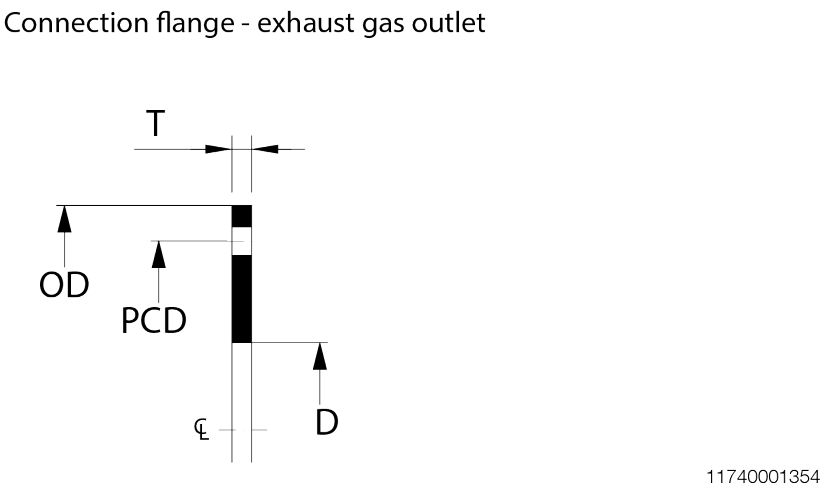

Figure 88: Flange

No. of cylinders, config		6L	7L	8L	9L
Turbocharger		**NR 29/S**	**NR 29/S**	**NR 34/S**	**NR 34/S**
D	mm	614	614	716	716
OD		754	754	856	856
T (max.)		20	20	23	23
PCD		700	700	800	800

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No. of cylinders, config		6L	7L	8L	9L
Turbocharger		**NR 29/S**	**NR 29/S**	**NR 34/S**	**NR 34/S**
Hole thread		M20	M20	M20	M20
Hole thread no.	-	20	20	24	24
The dimension and numbers are given for guidance only.					

Table 114: Dimension of flange – Turbocharger

No. of cylinders, config		6L	7L	8L	9L
Turbocharger		**NR 29/S**	**NR 29/S**	**NR 34/S**	**NR 34/S**
D	mm	614	614	716	716
OD		754	754	856	856
T		20	20	20	20
PCD		700	700	800	800
Hole size		22	22	22	22
Hole no.	-	20	20	24	24
The dimension and numbers are given for guidance only.					

Table 115: Dimension of connecting flange – Compensator, according to DIN 86044

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7 Annex

7.1 Safety instructions and necessary safety measures

The following list of basic safety instructions, in combination with further engine documentation like user manual and working instructions, should ensure a safe handling of the engine. Due to variations between specific plants, this list does not claim to be complete and may vary with regard to project-specific requirements.

7.1.1 General

There are risks at the interfaces of the engine, which have to be eliminated or minimised in the context of integrating the engine into the plant system. Responsible for this is the legal person which is responsible for the integration of the engine.

Following prerequisites need to be fulfilled:

- Layout, calculation, design and execution of the plant have to be state of the art.
- All relevant classification rules, regulations and laws are considered, evaluated and are included in the system planning.
- The project-specific requirements of MAN Energy Solutions regarding the engine and its connection to the plant are implemented.
- In principle, the more stringent requirements of a specific document is applied if its relevance is given for the plant.

7.1.2 Safety equipment and measures provided by plant-side

- Proper execution of the work

  Generally, it is necessary to ensure that all work is properly done according to the task trained and qualified personnel.

  All tools and equipment must be provided to ensure adequate accesible and safe execution of works in all life cycles of the plant.

  Special attention must be paid to the execution of the electrical equipment. By selection of suitable specialised companies and personnel, it has to be ensured that a faulty feeding of media, electric voltage and electric currents will be avoided.
- Fire protection

  A fire protection concept for the plant needs to be executed. All from safety considerations resulting necessary measures must be implemented. The specific remaining risks, e.g. the escape of flammable media from leaking connections, must be considered.

  Generally, any ignition sources, such as smoking or open fire in the maintenance and protection area of the engine is prohibited.

  Smoke detection systems and fire alarm systems have to be installed and in operation.
- Electrical safety

  Standards and legislations for electrical safety have to be followed. Suitable measures must be taken to avoid electrical short circuit, lethal electric shocks and plant specific topics as static charging of the piping through the media flow itself.

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- Noise and vibration protection

  The noise emission of the engine must be considered early in the planning and design phase. A soundproofing or noise encapsulation could be necessary. The foundation must be suitable to withstand the engine vibration and torque fluctuations. The engine vibration may also have an impact on installations in the surrounding of the engine, as galleries for maintenance next to the engine. Vibrations act on the human body and may dependent on strength, frequency and duration harm health.
- Thermal hazards

  In workspaces and traffic areas hot surfaces must be isolated or covered, so that the surface temperatures comply with the limits by standards or legislations.
- Composition of the ground

  The ground, workspace, transport/traffic routes and storage areas have to be designed according to the physical and chemical characteristics of the excipients and supplies used in the plant.

  Safe work for maintenance and operational staff must always be possible.
- Adequate lighting

  Light sources for an adequate and sufficient lighting must be provided by plant-side. The current guidelines should be followed (100 Lux is recommended, see also DIN EN 1679-1).
- Working platforms/scaffolds

  For work on the engine working platforms/scaffolds must be provided and further safety precautions must be taken into consideration. Among other things, it must be possible to work secured by safety belts. Corresponding lifting points/devices have to be provided.
- Setting up storage areas

  Throughout the plant, suitable storage areas have to be determined for stabling of components and tools.

  It is important to ensure stability, carrying capacity and accessibility. The quality structure of the ground has to be considered (slip resistance, resistance against residual liquids of the stored components, consideration of the transport and traffic routes).
- Engine room ventilation

  An effective ventilation system has to be provided in the engine room to avoid endangering by contact or by inhalation of fluids, gases, vapours and dusts which could have harmful, toxic, corrosive and/or acid effects.

  The engine room ventilation must ensure a maximum engine room temperature, with following boundary conditions:

  – Maximum air temperature in the area of the engine and its components ≤ 45°C.

  – Maximum air temperature at least 5 K below the flash point of any liquids, that is present within the engine room.
- Venting of crankcase and turbocharger

  With crankcase ventilation the gases/vapours originating from crankcase and turbocharger are not ignitable. For multi-engine plants, each engine has to be ventilated separately. The engine ventilation of different engines must not be connected.

  In case of an installed suction system, it has to be ensured that it will not be stopped until at least 20 minutes after engine shutdown.
- Intake air filtering

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In case air intake is realised through piping and not by means of the turbocharger´s intake silencer, appropriate measures for air filtering must be provided. It must be ensured that particles exceeding 5 µm will be restrained by an air filtration system.

- Quality of the intake air

  It has to be ensured that combustible media will not be sucked in by the engine.

  Intake air quality according to the section Specification of intake air (combustion air), Page 156 has to be guaranteed.

- Emergency stop system

  The emergency stop system requires special care during planning, realisation, commissioning and testing at site to avoid dangerous operating conditions. The assessment of the effects on other system components caused by an emergency stop of the engine must be carried out by plant-side.

- Fail-safe 24 V power supply

  Because engine control, alarm system and safety system are connected to a 24 V power supply this part of the plant has to be designed fail-safe to ensure a regular engine operation.

- Hazards by rotating parts/shafts

  Contact with rotating parts must be excluded by plant-side (e.g. free shaft end, flywheel, coupling).

- Safeguarding of the surrounding area of the flywheel

  The entire area of the flywheel has to be safeguarded by plant-side.

  Special care must be taken, inter alia, to prevent from: Ejection of parts, contact with moving machine parts and falling into the flywheel area.

- Securing of the engine´s turning gear

  The turning gear has to be equipped with an optical and acoustic warning device. When the turning gear is first activated, there has to be a certain delay between the emission of the warning device's signals and the start of the turning gear. The gear wheel of the turning gear has to be covered. The turning gear should be equipped with a remote control, allowing optimal positioning of the operator, overlooking the entire hazard area (a cable of approximately 20 m length is recommended). Unintentional engagement or start of the turning gear must be prevented reliably.

  It has to be prescribed in the form of a working instruction that:

  – The turning gear has to be operated by at least two persons.

  – The work area must be secured against unauthorised entry.

  – Only trained personnel is permissible to operate the turning gear.

- Securing of the starting air pipe

  To secure against unintentional restarting of the engine during maintenance work, a disconnection and depressurisation of the engine´s starting air system must be possible. A lockable starting air stop valve must be provided in the starting air pipe to the engine.

- Securing of the turbocharger rotor

  To secure against unintentional turning of the turbocharger rotor while maintenance work, it must be possible to prevent draught in the exhaust gas duct and, if necessary, to secure the rotor against rotation.

- Consideration of the blow-off zone of the crankcase cover´s relief valves

During crankcase explosions, the resulting hot gases will be blown out of the crankcase through the relief valves. This must be considered in the overall planning.

- Installation of flexible connections

  For installation of flexible connections follow strictly the information given in the planning and final documentation and the manufacturer manual.

  Flexible connections may be sensitive to corrosive media. For cleaning only adequate cleaning agents must be used (see manufacturer manual). Substances containing chlorine or other halogens are generally not permissible.

  Flexible connections have to be checked regularly and replaced after any damage or lifetime given in manufacturer manual.

- Connection of exhaust port of the turbocharger to the exhaust gas system of the plant

  The connection between the exhaust port of the turbocharger and the exhaust gas system of the plant has to be executed gas tight and must be equipped with a fire proof insulation.

  The surface temperature of the fire insulation must not exceed 220°C.

  In workspaces and traffic areas, a suitable contact protection has to be provided whose surface temperature must not exceed 60°C.

  The connection has to be equipped with compensators for longitudinal expansion and axis displacement in consideration of the occurring vibrations (the flange of the turbocharger reaches temperatures of up to 450°C).

- Media systems

  The stated media system pressures must be complied. It must be possible to close off each plant-side media system from the engine and to depressurise these closed off pipings at the engine. Safety devices in case of system over pressure must be provided.

- Drainable supplies and excipients

  Supply system and excipient system must be drainable and must be secured against unintentional recommissioning (EN 1037). Sufficient ventilation at the filling, emptying and ventilation points must be ensured. The residual quantities which must be emptied have to be collected and disposed of properly.

- Spray guard has to be ensured for liquids possibly leaking from the flanges of the plant´s piping system. The emerging media must be drained off and collected safely.

- Charge air blow-off (if applied)

  The piping must be executed by plant-side and must be suitably isolated. In workspaces and traffic areas, a suitable contact protection has to be provided whose surface temperature must not exceed 60°C.

  The compressed air is blown-off either outside the vessel or into the engine room. In both cases, installing a silencer after blow-off valve is recommended. If the blow-off valve is located upstream of the charge air cooler, air temperature can rise up to 200°C. It is recommended to blow-off hot air outside the plant.

- Signs

  – Following figure shows exemplarily the risks in the area of a combustion engine. This may vary slightly for the specific engine.

    This warning sign has to be mounted clearly visibly at the engine as well as at all entrances to the engine room.

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Figure 89: Warning sign E11.48991-1108

- Prohibited area signs.

  Depending on the application, it is possible that specific operating ranges of the engine must be prohibited.

  In these cases, the signs will be delivered together with the engine, which have to be mounted clearly visibly on places at the engine which allow intervention of the engine operation.

- Optical and acoustic warning device

  Communication in the engine room may be impaired by noise. Acoustic warning signals might not be heard. Therefore it is necessary to check where at the plant optical warning signals (e.g. flash lamp) should be provided.

  In any case, optical and acoustic warning devices are necessary while using the turning gear and while starting/stopping the engine.

7.2 Programme for Factory Acceptance Test (FAT)

	Test points	Factory Acceptance Test (FAT)			
		Pre- Tests		Demonstration tests	
Diesel engines	100 %	-		60min*	
	110 %	-		M	
	85% (nominal continuous cruise power)**	-		M	
	Minimum speed at full constant torque - (mechanical pump drive only)	-		M	
	75%	M		-	
	50%	M		-	
	25%	M		-	
	Idle*** (only engines driving generators)	M		-	
Dual Fuel (DF-) engines		Gas mode	Diesel mode	Gas mode	Diesel mode
	100%	-	-	60min*	60min*
	110%	-	-	-	M
	85% (nominal continuous cruise power)**	-	-	M	M
	75%	M	M	-	-
	50%	M	M	-	-
	25%	M	M	-	-
	Idle*** (only engines driving generators)	-	M	-	-

* 2 readings have to be done at an interval of 30 min. On DF-engines only one reading in Diesel and one in Gas-mode.

** Replaces the 90% load point of classification rules.

M = Minimum 15 minutes and steady-state conditions reached (acc. Instruction conducting a measurement of MAN-ES)

Idle*** Nominal engine speed

For all trial conditions provision should be made for time needed by the Surveyor to carry out visual inspections

Figure 90: Engine performance check – Table 1

1 Purpose

This instruction specifies tests and checks to be carried out during Factory Acceptance Tests (FAT) of marine engines manufactured by MAN ES. The following tests and checks are based on the rules and regulations of the classification societies as well as the ISO standards 3046 and 15550 in their versions at the time when this instruction is published and which have to be conducted to fulfill the requirements of a standard FAT.

2 Scope

This instruction is valid for all employees of companies and business units mentioned below, and is binding for all employees, which are affected by this instruction within the scope of their duties. The respective manager has to ensure that the employees know and observe this instruction. It is valid for marine applications of medium-, and high speed engines with a nominal speed up to 1000rpm from MAN ES and engine driving generators.

Valid for the following companies: MAN Energy Solutions SE

Valid for the following locations: Augsburg; Aurangabad; Saint-Nazaire

Valid for the following business units: SBU E

Valid for the following departments: FR-EE; RM-IN-PE; PEAA

3 Terms and definitions

Term	Definition
FAT	Factory Acceptance Test
CPP	Controllable Pitch Propeller
FPP	Fixed Pitch Propeller
IACS	International Association of Classification Societies

4 Engine testing

The complete test of a medium speed engine on a test bed requires several days. Therefore, the test is separated into two periods, the pre-test and the demonstration test. The pre-test is an internal test, which is partially to be done in presence of the classification society if required. The demonstration test is to verify the engine quality and observance of contractually agreed terms and conditions in presence of classification society and customer. For each engine, an engine specific procedure for the demonstration test has to be generated based on the tests and checks of point 4.2 of this instruction and contractual agreements with the customer. Additional test requests by the classification society have to be considered in the test procedure. Under the following points the standard scope of pre-test and demonstration test is specified.

4.1 Pre-tests (internal tests)

The pre-test is divided into tests and checks to be carried out prior to the first engine start and subsequent checks during engine operation. The main focus is to detect and fix technical issues and adjust the engine before starting the demonstration tests. Some checks of the pre-tests are required by classification rules. Before conducting these tests the corresponding surveyor of the classification society has to be informed about the pre-test date in time.

Figure 91: Engine performance check – Part 1

4.1.1 Main tests and checks before first engine start

a) check crank web deflection after alignment of the engine (results to be stated in FAT protocol)
b) flushing of all media systems (lube oil, fuel oil, water)
c) visual check of engine including cam shaft and crank shaft housing (before first engine start and subsequently during operation)
d) test of alarm and safety system. The requirements of the classification society and engine manufacturer specification (check of safety functions F0387EN) must be fulfilled. The test results must be stated in the FAT protocol.

4.1.2 Function and performance check

Limits and requirements for each test can be found in project guides, rules of classification societies and internal specifications of MAN-ES. The internal testing of engines is generally specified in the Guideline for Engine Testing of MAN ES (F0387EN). The following points represent the minimum of tests to be conducted to ensure the functionality and performance of the engine.

a. Start of tests and calculation of start air consumption in gas and diesel operation. To be done at least once per shipset for each engine type. The results have to be stated in each FAT protocol for reference.

b. Thermographic inspection (according to working instruction W0202EN - Surface Temperature Examination on Engines and Components for Marine Application) of engine insulation for confirmation of SOLAS surface temperature requirements.

c. Noise level and vibration measurements according to ISO 10816-6 and manufacturer guidelines (only to be carried out and stated in the FAT protocol if there is a contractual obligation).

d. Integration tests to be conducted on each engine, except if the tests have already been conducted on an identical engine of the same vessel or a sister vessel (same yard, same shipping company, same type of vessel). The scope of the tests has to be agreed upon with the classification society for selected cases based on the FMEA required in UR M44/M78 of IACS. For the alarm and safety system, an engine-independent test is carried out in advance and witnessed by the classification society. In the case of the FAT, only engine-related tests, such as the injection module failures, are additionally witnessed.

e. Performance Check: The engine performance is to be tested at the load points listed in table 1. Further information can be found under point 4.3 of this instruction. Performance readings must be stated in the FAT protocol.

f. Governor test (load drop): Sudden load drop from full load to zero load. Results must be stated in the FAT protocol.

g. Check of attached engine flaps and valves (blow off, blow by, waste gate, jet assist).

h. Visual check for leakages on fuel oil, lube oil and water systems of the engine (check of connecting flanges, screw connections and inspection drillings).

i. Surge test of turbocharger on new engine configurations during the turbocharger-matching process. Results not to be stated in the FAT protocol.

j. Cylinder liner inspection (only engines ≥ 32cm liner diameter) of one cylinder liner per engine by borescope. Evaluation of the cylinder liner surface according to Q10.09121-3325 “Visual Test Cylinder Liner Inspection after Running-In”. In case of additional inspections

Figure 92: Engine performance check – Part 2

(e.g. dismantling of piston) during demonstration tests the borescope inspection is omitted.)

4.2 Demonstration tests

The demonstration test is a final quality approval of the engine before its delivery in presence of the classification and the customer. The demonstration test has to be done according to the engine-specific test procedure (demonstration test), confirmed by the classification society and customer. The test procedure has to be sent to the classification society and customer one-week prior to the demonstration test at the latest. The scope of the FAT-procedure (demonstration test) is based on the following standards:

a. Switch from liquid to gas operation and back at minimum and nominal load.

b. One gas start (only on dual fuel engines with gas start functionality)

c. Performance Check: The engine performance has to be tested on the load points listed in table 1. Further information can be found under point 4.3 of this instruction.

d. Visual check of crank case, camshaft, rollers and gear drive after engine stop.

Optional tests and inspections only by request of the classification society, contractual agreement with customer or by indication of irregularities.

4.3 Engine performance check

The engine performance check has to be done on all load points listed in table 1. Engines for generator application (incl. diesel-electric dredger), diesel-mechanic dredger application with propulsion function and CPP-application have to be tested on a constant speed curve. Engines for diesel-mechanic propulsion application with fixed pitch propeller, exclusively mechanical pump drive (dredger) and water jet application have to be tested on the recommended FPP-curve of MAN-ES. Engines with ECOMAP function have to be tested on the standard full load map only. Additional mappings can be tested according to a contractual agreement with the customer. Between pre-tests and demonstration tests minor adjustments for engine optimization are allowed. These adjustments must not lead to an excess of the engine specifications in any load point and have to be stated in the FAT-protocol. The performance parameter to be measured are specified in ISO 15550. For all measurement devices the calibration tolerances of this standard are to be fulfilled and the given calibration intervals of the specific manufacturers have to be considered. The calibrations have to fulfil the requirements given by the QM-system. All performance data of the engines have to be within the specification limits (documents: quality criteria of engine) of the engine manufacturer. The performance readings have to be conducted according to the specified instructions of the engine manufacturer.

4.4 After engine operation

After finishing the test program, the engine has to be preserved according to working instruction W0176EN. The fuel delivery system of diesel-mechanic drives has to be adjusted so that overload power cannot be delivered during engine operation on board. Engines driving electrical generators have to be adjusted so that 110% rated power is possible.

Figure 93: Engine performance check – Part 3

4.5 FAT – protocol

All operations, events, findings, further measures and agreements have to be documented in one and the same engine specific FAT protocol of MAN-ES. The final FAT-protocol has to be reviewed by the surveyor of the classification society and a copy has to be handed out to the customer. The FAT protocol contains the following information:

- Cover sheet
- Signature sheet with representatives
- Operating record for all engine operation points
- Fuel oil analysis
- Line records for governor test or load jump tests
- Check of safety functions of engine and test bed before first start of the engine
- Visual inspection sheet with conducted checks and documentation of engine conditions
- Crank web deflection measurement for cold condition (check of alignment on test bed)
- Emission-relevant identification numbers, software version numbers (only on parent engines)
- Firing pressure comparison
- Starting test incl. air consumption calculation of reference engine
- Characteristic NOx emission Map (only for variable speed engines and parent engine protocols)
- Operating data sheet to estimate the engine output
- Calibration reports of fuel oil and fuel gas and torque measurement devices

5 References - applicable documents always refer to the current version unless stated otherwise.

- IACS-regulations and regulations of classification societies
- ISO 15550
- ISO 3046
- ISO 10816-6
- F0387EN Checklist for Rigging Up, Connecting, Commissioning, Performing the Test Run and Performing the Customer Acceptance Test for a Combustion Engine on the Test Bed
- W0202EN - Surface Temperature Examination on Engines and Components for Marine Application

Figure 94: Engine performance check – Part 4

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- W0176EN Preserving Internal Engine Compartments of Medium-Speed Four-Stroke Diesel Engines after Test Run
- W0221EN Sampling of Fuel Oil
- Instruction I0158 - Guideline for Conducting a Measurement at the Test Beds (only for use of EDS-System)
- Q10.09054-0005 - Fuel Oil Consumption Measurement of Diesel Engines on Test Bed
- Q10.09121-3325 - Visual Test Cylinder Liner Inspection after Running-In

6 Annexes

The annexes always refer to the current version unless not stated otherwise.

- Annex 1 example of engine performance reading

Figure 95: Engine performance check – Part 5

7.3 Engine running-in

Prerequisites

Engines require a running-in period in case one of the following conditions applies:

- When put into operation on site, if
  - after test run the pistons or bearings were dismantled for inspection or
  - the engine was partially or fully dismantled for transport.
- After fitting new drive train components, such as cylinder liners, pistons, piston rings, crankshaft bearings, big-end bearings and piston pin bearings.
- After the fitting of used bearing shells.
- After long-term low-load operation (> 500 operating hours).

Supplementary information

Operating Instructions

During the running-in procedure the unevenness of the piston-ring surfaces and cylinder contact surfaces is removed. The running-in period is completed once the first piston ring perfectly seals the combustion chamber. i.e. the first piston ring should show an evenly worn contact surface. If the engine is subjected to higher loads, prior to having been running-in, then the hot exhaust gases will pass between the piston rings and the contact surfaces of the cylinder. The oil film will be destroyed in such locations. The result is material damage (e.g. burn marks) on the contact surface of the piston rings and the cylinder liner. Later, this may result in increased engine wear and high lube oil consumption.

The time until the running-in procedure is completed is determined by the properties and quality of the surfaces of the cylinder liner, the quality of the fuel and lube oil, as well as by the load of the engine and speed. The running-in periods indicated in following figures may therefore only be regarded as approximate values.

Operating media

Liquid fuel engines

The running-in period may be carried out preferably using MGO (DMA) or MDO (DMB).

The fuel used must meet the quality standards see section Specification for engine supplies, Page 119 and the design of the fuel system.

Dual fuel engines

Dual fuel engines are run in using liquid fuel mode with the fuel intended as the pilot fuel.

Gas fuel engines

For the running-in of gas four-stroke engines it is best to use the gas which is to be used later in operation.

Lube oil

The running-in lube oil must match the quality standards, with regard to the fuel quality.

Engine running-in

Cylinder lubrication (optional)

The cylinder lubrication must be switched to "Running In" mode during completion of the running-in procedure. This is done at the control cabinet or at the control panel (under "Manual Operation"). This ensures that the cylinder lubrication is already activated over the whole load range when the engine starts. The running-in process of the piston rings and pistons benefits from the increased supply of oil. Cylinder lubrication must be returned to "Normal Mode" once the running-in period has been completed.

Checks

Inspections of the bearing temperature and crankcase must be conducted during the running-in period:

- The first inspection must take place after 10 minutes of operation at minimum speed.
- An inspection must take place after operation at full load respectively after operational output level has been reached.

The bearing temperatures (camshaft bearings, big-end and main bearings) must be determined in comparison with adjoining bearings. For this purpose an electrical sensor thermometer may be used as a measuring device.

At 85% load and at 100% load with nominal speed, the operating data (ignition pressures, exhaust gas temperatures, charge air pressures, etc.) must be measured and compared with the acceptance report.

Standard running-in programme

Dependent on the application the running-in programme can be derived from the figures in paragraph Diagram(s) of standard running-in, Page 289. During the entire running-in period, the engine output has to be within the marked output range. Critical speed ranges are thus avoided.

Running-in during commissioning on site

Most four-stroke engines are subjected to a test run at the manufacturer´s premises. As such, the engine has usually been run in. Nonetheless, after installation in the final location, another running-in period is required if the pistons or bearings were disassembled for inspection after the test run, or if the engine was partially or fully disassembled for transport.

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Running-in after fitting new drive train components

If during revision work the cylinder liners, pistons, or piston rings are replaced, a new running-in period is required. A running-in period is also required if the piston rings are replaced in only one piston. The running-in period must be conducted according to following figures or according to the associated explanations.

The cylinder liner may be re-honed according to working instructions 050.05, if it is not replaced. A transportable honing machine may be requested from one of our service and support locations.

Running-in after refitting used or new bearing shells (crankshaft, connecting rod and piston pin bearings)

When used bearing shells are reused, or when new bearing shells are installed, these bearings have to be run in. The running-in period should be 3 to 5 hours under progressive loads, applied in stages. The instructions in the preceding text segments, particularly the ones regarding the "Inspections", and following figures must be observed.

Idling or no-load operation at higher speeds for long periods should be avoided if at all possible.

Running-in after low-load operation

Continuous operation in the low-load range may result in substantial internal pollution of the engine. Residue from fuel and lube oil combustion may cause deposits on the top-land ring of the piston exposed to combustion, in the piston ring channels as well as in the inlet channels. Moreover, it is possible that the charge air and exhaust pipes, the charge air cooler, the turbocharger and the exhaust gas tank may be polluted with oil.

Since the piston rings have adapted themselves to the cylinder liner according to the running load, increased wear resulting from quick acceleration and possibly with other engine trouble (leaking piston rings, piston wear) should be expected.

Therefore, after a longer period of low-load operation (≥ 500 hours of operation) a running-in period should be performed again, depending on the power, according to following figures.

Also for instruction see section Low-load operation, Page 42.

Note:
For further information, you may contact the MAN Energy Solutions customer service or the customer service of the licensee.

Diagram of standard running-in

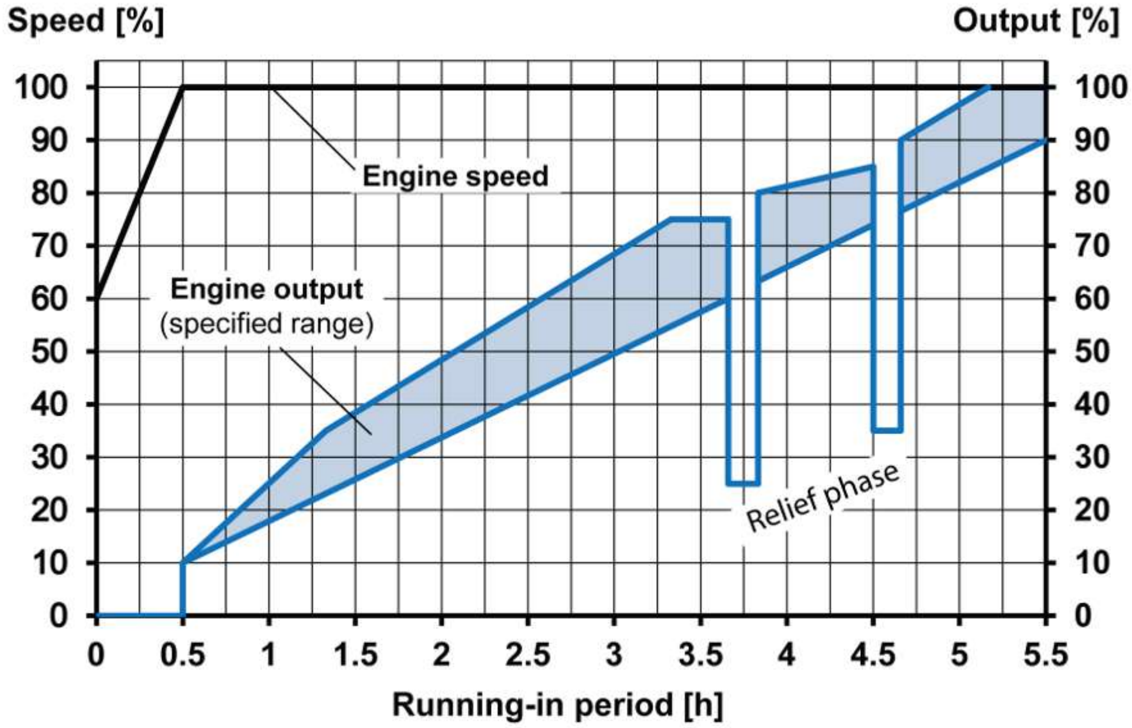

Figure 96: Standard running-in programme for engines operated with constant speed

7.4 Definitions

Auxiliary GenSet/auxiliary generator operation

A generator is driven by the engine, hereby the engine is operated at constant speed. The generator supplies the electrical power not for the main drive, but for supply systems of the vessel.

Load profile with focus between 40% and 80% load.

Engine´s certification for compliance with the NO_x limits according D2 Test cycle. See within section Engine ratings (output) for different applications, Page 27 if the engine is released for this kind of application and the corresponding available output $P_{Application}$.

Blackout

The classification societies define blackout on board ships as a loss of the main source of electrical power resulting in the main and auxiliary machinery to be out of operation and at the same time all necessary alternative energies (e.g. start air, battery electricity) for starting the engines are available.

Dead ship condition

The classification societies define dead ship condition as follows:

- The main propulsion plant, boilers and auxiliary machinery are not in operation due to the loss of the main source of electrical power.

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- In restoring propulsion, the stored energy for starting the propulsion plant, the main source of electrical power and other essential auxiliary machinery is assumed not to be available.
- It is assumed that means are available to start the emergency generators at all times. These are used to restore the propulsion.

Designation of engine sides

- Coupling side, CS

  The coupling side is the main engine output side and is the side to which the propeller, the alternator or other working machine is coupled.
- Free engine end/counter coupling side, CCS

  The free engine end is the front face of the engine opposite the coupling side.

Designation of cylinders

The cylinders are numbered in sequence, from the coupling side, 1, 2, 3 etc. In V engines, looking on the coupling side, the left hand bank of cylinders is designated A, and the right hand bank is designated B. Accordingly, the cylinders are referred to as A1-A2-A3 or B1-B2-B3, etc.

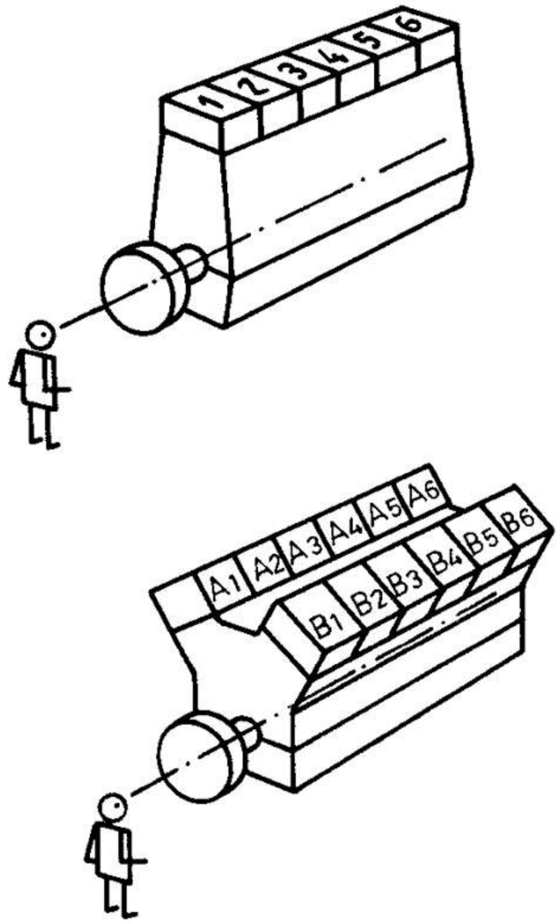

Figure 97: Designation of cylinders

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Direction of rotation

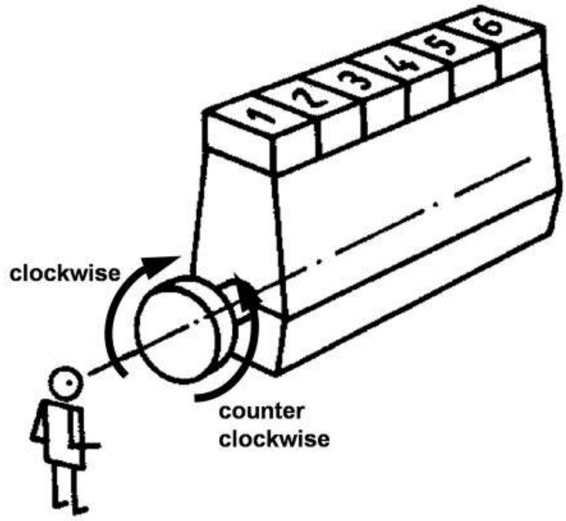

Figure 98: Designation: Direction of rotation seen from flywheel end

Electric propulsion

The generator being driven by the engine supplies electrical power to drive an electric motor. The power of the electric motor is used to drive a controllable pitch or fixed pitch propeller, pods, thrusters, etc.

Load profile with focus between 80% and 95% load.

Engine´s certification for compliance with the NO_x limits according E2 Test cycle. See within section Engine ratings (output) for different applications, Page 27 if the engine is released for this kind of application and the corresponding available output $P_{Application}$.

GenSet

The term "GenSet" is used, if engine and electrical alternator are mounted together on a common base frame and form a single piece of equipment.

Gross calorific value (GCV)

This value supposes that the water of combustion is entirely condensed and that the heat contained in the water vapor is recovered.

Idling operation

Idling/Idling operation refers to operation:

- Before the engine is coupled to the propulsion system or to the mechanical dredge pump
- Of the GenSet with open Genoswitch

A distinction is made between:

- Idling at minimum speed and
- Idling at rated speed

Mechanical propulsion with controllable pitch propeller (CPP)

A propeller with adjustable blades is driven by the engine.

The CPP´s pitch can be adjusted to absorb all the power that the engine is capable of producing at nearly any rotational speed.

Load profile with focus between 80% and 95% load.

Engine´s certification for compliance with the NO_x limits according E2 Test cycle. See within section Engine ratings (output) for different applications, Page 27 if the engine is released for this kind of application and the corresponding available output $P_{Application}$.

Mechanical propulsion with fixed pitch propeller (FPP)

A fixed pitch propeller is driven by the engine. The FPP is always working very close to the theoretical propeller curve (power input ~ n^3). A higher torque in comparison to the CPP even at low rotational speed is present.

Load profile with focus between 80% and 95% load.

Engine´s certification for compliance with the NO_x limits according E3 Test cycle. See within section Engine ratings (output) for different applications, Page 27 if the engine is released for this kind of application and the corresponding available output $P_{Application}$.

Multi-engine propulsion plant

In a multi-engine propulsion plant at least two or more engines are available for propulsion.

Net calorific value (NCV)

This value supposes that the products of combustion contain the water vapor and that the heat in the water vapor is not recovered.

No-load operation

As soon as the engine has been coupled, or a GenSet with closed Geno switch has been connected to electrical grid and no load has yet been delivered, this is named as no-load operation.

Offshore application

Offshore construction and offshore drilling place high requirements regarding the engine´s acceleration and load application behaviour. Higher requirements exist also regarding the permissible engine´s inclination.

Due to the wide range of possible requirements such as flag state regulations, fire fighting items, redundancy, inclinations and dynamic positioning modes all project requirements need to be clarified at an early stage.

Output

- ISO standard output (as specified in DIN ISO 3046-1)

  Maximum continuous rating of the engine at nominal speed under ISO conditions, provided that maintenance is carried out as specified.
- Operating-standard-output (as specified in DIN ISO 3046-1)

  Maximum continuous rating of the engine at nominal speed taking in account the kind of application and the local ambient conditions, provided that maintenance is carried out as specified. For marine applications this is stated on the type plate of the engine.
- Fuel stop power (as specified in DIN ISO 3046-1)

Fuel stop power defines the maximum rating of the engine theoretical possible, if the maximum possible fuel amount is used (blocking limit).

- Rated power (in accordance to rules of DNV)

  Maximum possible continuous power at rated speed and at defined ambient conditions, provided that maintenances carried out as specified.
- Output explanation

  Power of the engine at distinct speed and distinct torque.
- 100% output

  100% output is equal to the rated power only at rated speed. 100% output of the engine can be reached at lower speed also if the torque is increased.
- Nominal output

  = rated power.
- MCR

  Maximum continuous rating.
- ECR

  Economic continuous rating = output of the engine with the lowest fuel consumption.

Overload power (at FAT or SAT/sea trial)

Only if required by rules of classification societies, it is admitted to operate the engine at 110% of rated power for a maximum of 1 h in total as part of the FAT or SAT/sea trial and in addition a maximum of 1 h in total as part of the comissioning of the plant. Engine operation has to be done under supervision of trained MAN Energy Solutions personal.

Single-engine propulsion plant

In a single-engine propulsion plant only one single-engine is available for propulsion.

Suction dredger application (mechanical drive of pumps)

For direct drive of a suction dredger pump by the engine via gear box the engine speed is directly influenced by the load on the suction pump.

The power demand of the dredge pump needs to be adapted to the operating range of the engine, particularly while start-up operation. Load profile with focus between 80% and 100% load.

Engine´s certification for compliance with the NO_x limits according C1 Test cycle. See within section Engine ratings (output) for different applications, Page 27 if the engine is released for this kind of application and the corresponding available output $P_{Application}$.

Water jet application

A marine propulsion system that creates a jet of water that propels the vessel. The water jet propulsion is always working close to the theoretical propeller curve (power input ~ n^3). With regard to its requirements the water jet propulsion is identical to the mechanical propulsion with FPP.

Load profile with focus between 80% and 95% load.

Engine´s certification for compliance with the NO_x limits according E3 Test cycle. See within section Engine ratings (output) for different applications, Page 27 if the engine is released for this kind of application and the corresponding available output $P_{Application}$.

Weight definitions for SCR

- Handling weight (reactor only):

  This is the "net weight" of the reactor without catalysts, relevant for transport, logistics, etc.
- Operational weight (with catalysts):

  That's the weight of the reactor in operation, that is equipped with a layer of catalyst and the second layer empty – as reserve.
- Maximum weight structurally:

  This is relevant for the static planning purposes maximum weight, that is equipped with two layers catalysts.

7.5 Abbreviations

Abbreviation	Explanation
BN	Base number
CBM	Condition based maintenance
CCM	Crankcase monitoring system
CCS	Counter coupling side
CS	Coupling side
ECR	Economic continuous rating
EDS	Engine diagnostics system
GCV	Gross calorific value
GVU	Gas Valve Unit
HFO	Heavy fuel oil
HT CW	High temperature cooling water
LT CW	Low temperature cooling water
MCR	Maximum continuous rating
MDO	Marine diesel oil
MGO	Marine gas oil
MN	Methane number
NCV	Net calorific value
OMD	Oil mist detection
SaCoS	Safety and control system
SAT	Site acceptance test
SECA	Sulphur emission control area
SP	Sealed plunger

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Abbreviation	Explanation
STC	Sequential turbocharging
TAN	Total acid number
TBO	Time between overhaul
TC	Turbocharger
TC	Temperature controller
ULSHFO	Ultra low sulphur heavy fuel oil

7.6 Symbols

Note:
The symbols shown should only be seen as examples and can differ from the symbols in the diagrams.

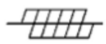
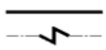
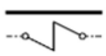
DESIGNATION	SYMBOL	CODE	DESIGNATION	SYMBOL	CODE
MAIN CIRCUIT (FLOW DIRECTION SHOWN)			FLEXIBLE PIPE CONNECTION		EH
SECONDARY CIRCUIT			EXPANSION BELLOWS (STEEL)		EB
CONTROL AIR PIPE, PULSE LINE, ELECTRICAL LINE	-------		2/2 (TWO-PORT, TWO-POSITION) DIRECTIONAL CONTROL SOLENOID-OPERATED VALVE		
CAPILLARY TUBE (WITH THERMOSTATIC REGULATORS)	—x—x—x—		3/2 (THREE-PORT, TWO-POSITION) DIRECTIONAL CONTROL VALVE		
LAGGED PIPE			GENERAL SHUT-OFF VALVE		V
STEAM HEATED PIPE (HEAVY FUEL OIL OPERATION, MAIN CIRCUIT)			GATE VALVE		GV
ELECTRICALLY HEATED PIPE (HEAVY FUEL OIL OPERATION, MAIN CIRCUIT)			STRAIGHT-WAY VALVE		V

Figure 99: Symbols used in functional and pipeline diagrams 1

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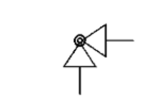
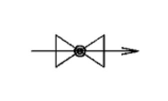
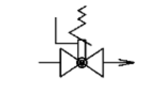
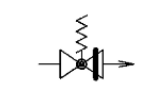
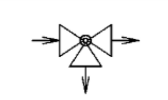
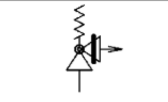
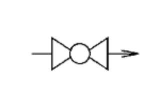
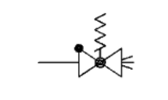
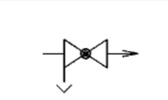
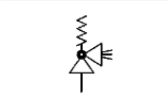
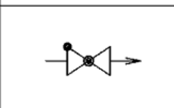
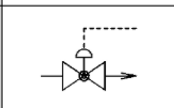
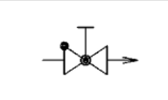
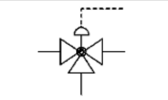
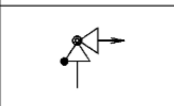
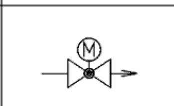
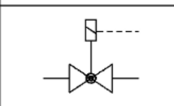
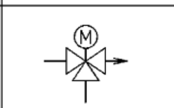
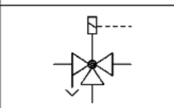
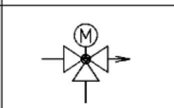
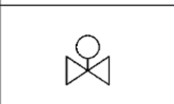
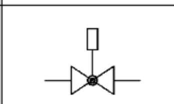
DESIGNATION	SYMBOL	CODE	DESIGNATION	SYMBOL	CODE
ANGLE VALVE		V	GENERAL SHUT-OFF VALVE, MOTOR DRIVEN		MOV
VALVE WITH MINIMUM FLOW		V	QUICK ACTING SHUT-OFF VALVE		V
GENERAL THREE-WAY VALVE		CK	SAFETY VALVE (STRAIGHT WAY)		PSV
THREE-WAY VALVE		V	SAFETY VALVE (ANGLE)		PSV
COCK		CK	BACK PRESSURE VALVE (STRAIGHT WAY)		BPV
SHUT-OFF VALVE WITH VENTILATION		V	BACK PRESSURE VALVE (ANGLE)		BPV
NON-RETURN VALVE		NRV	DIAPHRAGM VALVE (PNEUMATICALLY-OPERATED)		DV
NON-RETURN VALVE (CAN BE SHUT OFF)		NRV	DIAPHRAGM SHUTTLE VALVE		DV
ANGLE NON-RETURN VALVE		NRV	MOTORISED VALVE		MOV
SOLENOID-OPERATED VALVE		SOV	GENERAL THREE-WAY VALVE, MOTOR DRIVEN		MOV
SOLENOID-OPERATED VALVE (AUTOMATIC VENT)		SOV	MOTORISED SHUTTLE VALVE		MOV
GENERAL SHUT-OFF VALVE, GENERAL DRIVE		V	GENERAL SHUT-OFF VALVE WITH TRANSATORY MOTON VALVE		V

Figure 100: Symbols used in functional and pipeline diagrams 2

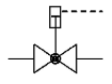
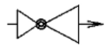
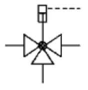
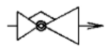
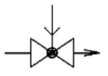
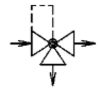
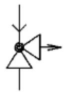
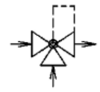
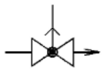
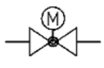
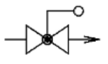
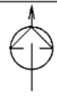
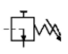
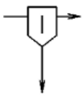
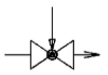
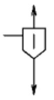
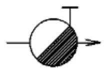
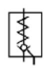
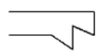
DESIGNATION	SYMBOL	CODE	DESIGNATION	SYMBOL	CODE
PISTON-OPERATED VALVE		POV	PRESSURE REDUCING VALVE		PCV
SHUTTLE VALVE WITH DRIVE PISTON		POV	PRESSURE CONTROL VALVE		PCV
SELF-CLOSING VALVE (STRAIGHT WAY)		QV	TEMPERATURE REGULATOR (SELF-ACTUATING DISTRIBUTION VALVE)		TCV
SELF-CLOSING VALVE (ANGLE)		QV	TEMPERATURE REGULATOR (SELF-ACTUIATING MIXING VALVE)		TCV
AUTOMATIC OPENING VALVE		V	TEMPERATURE CONTROL VALVE, ELECTRICALLY CONTROLLED		TCV
FLOAT VALVE		LOV	VANE HAND PUMP		P
SPRING-LOADED ADJUSTABLE PRESSURE LIMITING VALVE		PCV	WATER TRAP		TR
SAFETY VALVE		PSV	OIL TRAP		TR
FLOW-CONTROL VALVE, ADJUSTABLE			CONDENSATE TRAP, CAN BE SHUT OFF		TR
NON-RETURN VALVE, UNIDIRECTIONAL FLOW			ACCUMULATOR, GAS CYLINDER		
NON-RETURN VALVE WITH SPRING, NORMALLY CLOSED			OILER		
PILOTED NON-RETURN VALVE WITH SPRING, FLOW IN BOTH DIRECTIONS POSSIBLE DUE TO CONTROL PRESSURE			HEATING COIL (STEAM OR WATER)		H

Figure 101: Symbols used in functional and pipeline diagrams 3

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DESIGNATION	SYMBOL	CODE	DESIGNATION	SYMBOL	CODE
PLUG-IN HEATER (STEAM OR WATER)		H	SUCTION STRAINER		STR
PLUG-IN HEATER (ELECTRIC)		H	SUCTION BELL		SB
BACKFLOW PREVENTER (DISCOTYP)		NRV	FLAME TRAP		GS
NON-RETURN FLAP		NRF	VENT		
STRAINER		STR	VENT WITH FLAME TRAP		
FUNNEL (OPEN)		FU	VENT, OUTBOARD ABOVE DECK		
FUNNEL (CLOSED)		FU	VENT CAP		
OVERFLOW CHECK TANK, DISCHARGE FUNNEL		FU	Withdrawal point for fuel oil sample		

Figure 102: Symbols used in functional and pipeline diagrams 4

7.7 Preservation, packaging, storage

7.7.1 General

Introduction

Engines are internally and externally treated with preservation agent before delivery. The type of preservation and packaging must be adjusted to:

- Means of transport
- Type and period of storage

Improper storage may cause severe damage to the product.

Packaging and preservation of engine

The type of packaging depends on:

- The requirements imposed with transport and storage period
- Climatic and environmental effects
- Which preservative agents are used

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As standard, the preservation and packaging of an engine is designed for a storage period of 12 month and for sea transport.

Note:
The packaging must be protected against damage. It must only be removed when:

- A follow-up preservation is required
- The packaged material is to be used
- Shortly before operating the engine

The condition of the packaging must be checked regularly and repaired in case of damage. Especially a VCI packaging can only provide a proper corrosion protection if it is intact and completely closed.

In addition, the engine interiors are protected by vapour phase corrosion protection. Inner compartments must not be opened while transportation and storage. Otherwise, a re-preservation of the opened compartment will be required. The inner corrosion protection can remain inside the engine.

If bare metal surfaces get exposed for example, by disassembly of the coupling device, the unprotected metal must be treated with agent "f" according to the list of recommended anti-corrosion agents (https://www.man-es.com/documentation-/corrosion-protection).

This especially applies to the tie rod where the lifting device has been mounted.

In case of an installed intake air filter there is a steel plate cover or similar around the filter fleece, which has to be used during transportation and storage.

Note:
During storage and in case of a follow-up preservation the crankshaft must not be turned. If the crankshaft is turned, usually for the first time after preservation this will be done during commissioning, the preservation is partially removed. If the engine is to be stored again for a period thereafter, then adequate re-preservation is required.

Preservation and packaging of loose equipment

Unless stated otherwise in the customer specification, the preservation and packaging of loose equipment and engine parts which are dismantled for transport, must be carried out such that:

- The preservation and packaging of loose equipment and engine parts will not be damaged during transport
- The corrosion protection remains fully intact for at least 12 months when stored in a roofed dry room

Transport

Transport and packaging of the engine, loose equipment and engine parts must be coordinated.

After transportation, any damage to the corrosion protection and packaging must be rectified, and/or MAN Energy Solutions must be notified immediately.

7.7.2 Storage location and duration

Storage location

Storage location of engine

As standard, the engine is packaged and preserved for outdoor storage.

The storage location must meet the following requirements:

- Engine is stored on firm and dry ground.
- Packaging material does not absorb any moisture from the ground.
- Engine is accessible for visual checks.

Storage location of loose equipment

Loose equipment must always be stored in a roofed dry room.

The storage location must meet the following requirements:

- Parts are protected against environmental effects and the elements.
- The room must be well ventilated.
- Parts are stored on firm and dry ground.
- Packaging material does not absorb any moisture from the ground.
- Parts cannot be damaged.
- Parts are accessible for visual inspection.
- An allocation of loose equipment to the order or requisition must be possible at all times.

Note:
Packaging made of or including VCI paper or VCI film must not be opened or must be closed immediately after opening.

Storage conditions

In general the following requirements must be met:

- Minimum ambient temperature: –10°C
- Maximum ambient temperature: +60°C
- Relative humidity: < 60%

In case these conditions cannot be met, contact MAN Energy Solutions for clarification.

Storage period

The permissible storage period of 12 months must not be exceeded.

Before the maximum storage period is reached:

- Check the condition of the stored engine and loose equipment.
- Renew the preservation or install the engine or components at their intended location.

7.7.3 Follow-up preservation when preservation period is exceeded

A follow-up preservation must be performed before the maximum storage period has elapsed, i.e. generally after 12 months.

Request assistance by authorised personnel of MAN Energy Solutions.

7.7.4 Removal of corrosion protection

Packaging, corrosion protection and silica gel must only be removed from the engine immediately before commissioning the engine in its installation location.

Remove outer protective layers, any foreign body from engine or component (VCI packs, blanking covers, etc.), check engine and components for damage and corrosion, perform corrective measures, if required.

The preservation agents sprayed inside the engine do not require any special attention. They will be washed off by engine oil during subsequent engine operation.

Contact MAN Energy Solutions if you have any questions.

7.8 Engine colour

Engine standard colour according RAL colour table is RAL 7040 Window grey. Other colours on request.

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