# ENGINE SAFETY CONCEPT

## for WinGD dual-fuel engines

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Change History

**ENGINE SAFETY CONCEPT**

for WinGD dual-fuel engines

**PC-Drawing**

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| | 2.5 | VCR technology introduced |

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# Abbreviations

| Abbreviation | Full name |
|---|---|
| AMS | Alarm and Monitoring System |
| BPV | Back Pressure Valve |
| BMEP | Brake Mean Effective Pressure |
| CCM | Cylinder Control Module |
| CCU | Cylinder Control Unit |
| CMCR | Contracted Maximum Continuous Rating (Rx) |
| CSM | Combustion Stability Mode |
| DBB | Double Block and Bleed |
| DCC | Dynamic Combustion Control |
| DCM | Data Collection Monitoring |
| DENIS | Diesel Engine coNtrol & optImising Specification |
| DF | Dual-Fuel |
| DG | Design Group |
| Drw. | Drawing |
| ECR | Engine Control Room |
| ECS | Engine Control System |
| EGC | Exhaust Gas Cooler |
| ESS | Engine Safety System |
| FGSS | Fuel Gas Supply System |
| FMEA | Failure Mode and Effect Analysis |
| FRV | Flow Regulating Valve |
| FSM | Fuel Sharing Mode |
| GAV | Gas Admission Valve |
| GDS | Gas Detection System |
| GSS | Gas Supply System |
| GT | Gas Trip (forced switch to diesel mode) |
| GTU | GaTeway Unit |
| GVU | Gas Valve Unit |
| GVU-ED™ | Gas Valve Unit – Enclosed Design |
| GVU-OD™ | Gas Valve Unit – Open Design |
| HC | HydroCarbon |
| HFO | Heavy Fuel Oil |
| HMI | Human Machine Interface |
| HT | High Temperature |
| iCAT | Integrated Cylinder lubricant Auto Transfer |
| iCER | Intelligent Control by Exhaust Recycling |
| IGC Code | International Code of the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk |
| IGF Code | International code of safety for ships using gases or other low-flashpoint fuels |
| iGPR | Integrated Gas Pressure Regulation |
| IMO | International Maritime Organization |
| IOM | Input /Output Module |
| LDU | Local Display Unit |
| LEL | Lower Explosive Limit |
| LNG | Liquefied Natural Gas |
| LNG carrier | Ship carrying liquefied natural gas as cargo |
| LO | Lubricating Oil |
| LT | Low Temperature |
| MCM | Main Control Module |
| MCP | Manual Control Panel |
| MCU | Main Control Unit |
| RCS | Remote Control System |

| Abbreviation | Full name |
|---|---|
| PSV | Purging & Sealing Valve |
| SAC | Scavenge Air Cooler |
| SCR | Selective Catalytic Reaction |
| SHD | Shutdown |
| SLD | Slowdown |
| SOV | Shut-Off Valve |
| TC | Turbocharger |
| TVM | Torsional Vibration Monitoring |
| UNIC | UNIfied Controls (ECS) |
| WiCE | WinGD Integrated Control Electronics (ECS) |
| WMC | Water Mist Catcher |

# 1 Introduction

The purpose of this document is to describe the engine room arrangement and safety functions of Dual-Fuel (DF) engine applications. Only items that are specifically related to gas safety and differ from diesel engine application are handled in this document. The X-DF engine itself is classified. The present document contains only information that is necessary to understand the function and safety features of the X-DF engine.

The WinGD 2-stroke X-DF engine is a long-stroke crosshead engine which can be operated using either gas or liquid fuel. To enable this, the engine is equipped with an electronically controlled diesel fuel injection system and with electronically controlled gas and pilot fuel injection systems.

The X-DF engine is designed to operate on gas fuel at the same safety level as when using diesel fuel. The safety concept is based on early detection of problems that could lead to a hazard, followed by immediate actions to prevent the situation from becoming dangerous. Depending on the machinery configuration and the detected problem type, the Engine Safety System (ESS) can initiate the alarm, trip to diesel mode and induce slowdown or shutdown of the X-DF engine.

All systems must be built in accordance with the requirements of both the IMO and the classification society. Accordingly, the content of this document is aligned with rules and regulations from IMO's IGC and IGF codes and the classification society. A Failure Mode and Effect Analysis (FMEA) has been performed. The FMEA document itself is WinGD intellectual property and, therefore, cannot be disclosed to any third party.

The X-DF engines onboard seagoing vessels use the cargo LNG or LNG stored in a separate / additional gas fuel tank in gaseous phase as their primary fuel. This document covers the gas fuel related matters, i.e. the systems that are different from or additional to a standard diesel engine. The standard diesel systems and the diesel operation safety are not described here.

The scope of the document encompasses the systems to be installed in the engine room up to the manual shut-off valve outside the engine room, which are needed to operate the X-DF engine in gas mode.

Documentation referred to in the text, such as arrangement drawings, flow sheets, calculations etc. are listed in the Reference section at the end of this document.

The special features and safety arrangements of X-DF engine installations must be included in the ship operational documentation, and the crew must be trained accordingly.

# 2 Description of the X-DF engine and related systems

The purpose of this chapter is to describe the WinGD 2-stroke X-DF engine general operating principle and components related to gas operation. Components and functions of X-DF engine auxiliary systems related to gas operation and gas safety are also described in this chapter.

## 2.1 The lean burn concept – Operating principle in gas mode

In gas mode, the X-DF engine runs as a lean burn engine where the ignition is initiated by injecting a small amount of pilot diesel oil, giving a high-energy ignition source for the main fuel charge (gas-air mixture) in the cylinder (Figure 2-1).

With the lean fuel mixture, it is possible to achieve excellent engine characteristics including output, efficiency and emissions. A lean air-fuel mixture is also utilised to avoid pre-ignition, knocking or excessively fast combustion. However, at high loads the misfiring limit is nearing the knocking limit, which means that the available operating window is narrowed (Figure 2-2).

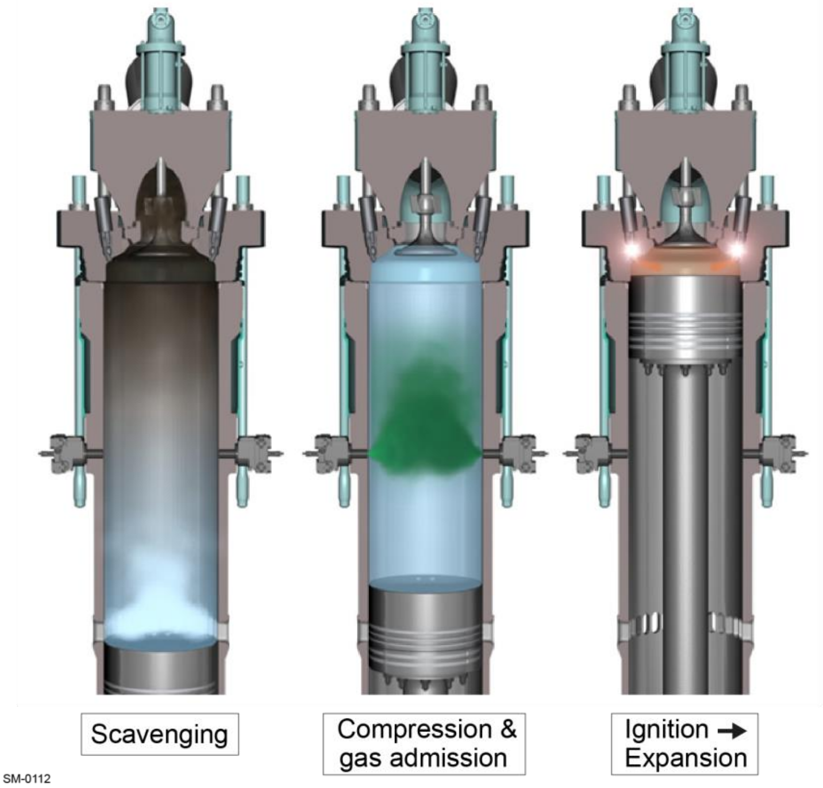

Figure 2-1 Lean burn with pilot ignition

However, by controlling the combustion process, individually in each cylinder, the optimal operating window and performance can be maintained for all conditions. The X-DF engine facilitates individual cylinder combustion control, which makes it possible to obtain optimal operating performance at conditions where gas fuel quality, ambient temperature etc. vary.

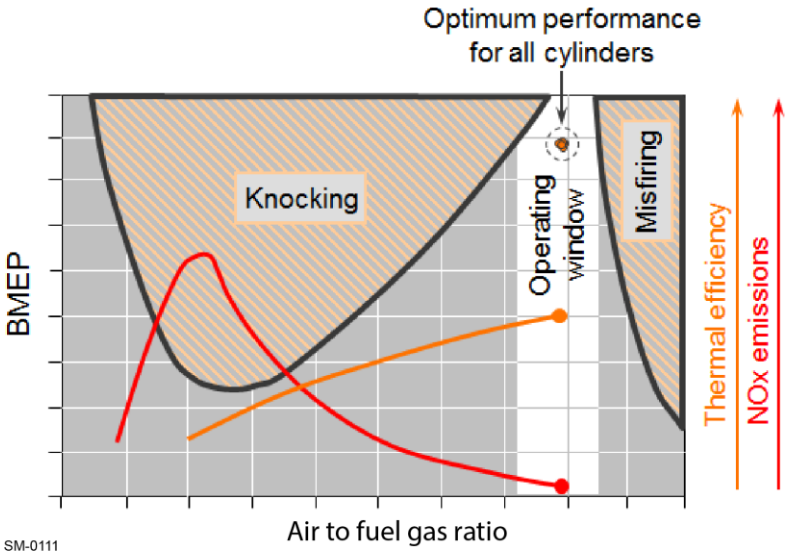

Figure 2-2: Lean burn operation window

### 2.1.1 Combustion check principle

The engine is equipped with a misfiring and knock detection system which monitors individual cylinders during gas operation. This ensures that the Engine Control System (ECS) immediately trips to diesel mode if the number of consecutive misfires exceeds the threshold or heavy knocking is detected. The system is active when gas fuel is used, including transfers, and can therefore immediately detect a non-igniting cylinder.

### 2.1.2 Dynamic combustion control (for the X-DF engines without iCER)

The Dynamic Combustion Control (DCC) function allows the engine to reach full power in gas mode during difficult conditions. Such conditions can include, for example, hot ambient suction and use of gas fuel with a low methane number. If critical combustion pressures are reached, the main fuel injectors start injecting a small amount of liquid fuel, while concurrently reducing the amount of gas fuel admission. Since the liquid fuel backup system is always on standby with MGO or MDO, the DCC starts on these fuel types. During DCC operation, a changeover to HFO is possible. In order to stop the DCC operation, a changeover back to MGO or MDO is required, and the engine must be operated with these fuel types until the fuel system is flushed.

### 2.1.3 Intelligent control by exhaust recycling (for the X-DF2.0 technology engines)

The Intelligent Control by Exhaust Recycling (iCER) function allows the engine to operate with a higher compression ratio, which increases the fuel efficiency, while reducing its environmental impact. The application of the iCER system reduces the reactivity of the mixture by substituting part of the oxygen with cooled exhaust gas. The iCER system consists of a low-pressure exhaust gas recirculation path including an efficient Exhaust Gas Cooler (EGC) and an optional micro economiser (see Figure 2-3). Due to the clean gas fuel combustion, there is neglectable contamination to the cooling water.

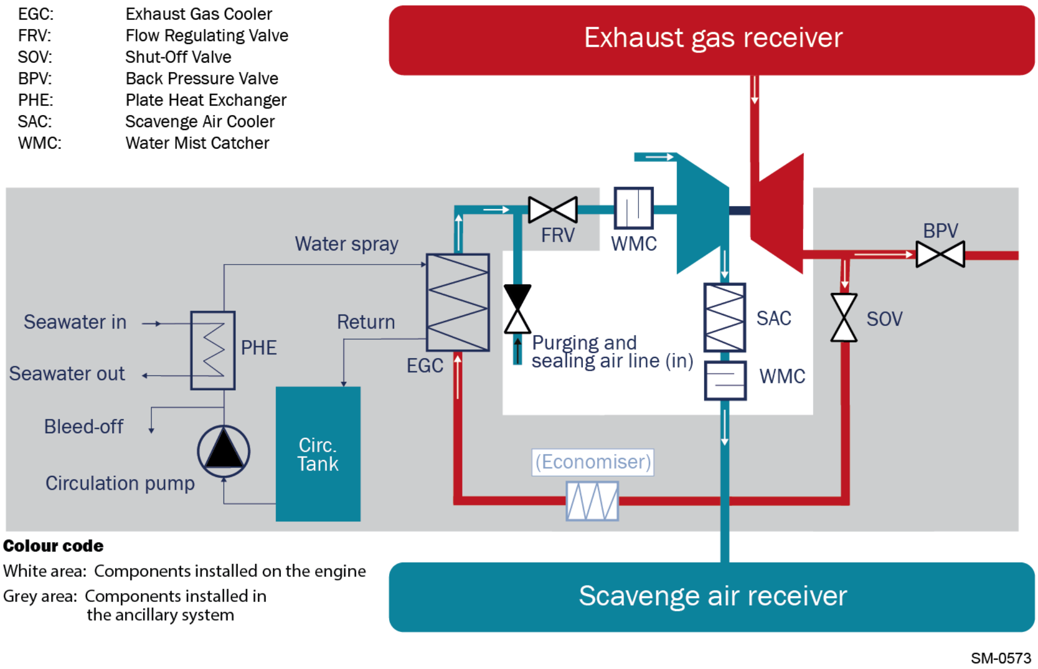

Figure 2-3: iCER system

The extended operating window of the X-DF engines with the iCER system is shown in Figure 2-4. The gas fuel reactivity depends on the exhaust gas recirculation ratio. By applying exhaust gas recirculation, the reactivity of the pre-mixed gas fuel is reduced. As a result, the ignition delay is increased, while the combustion speed is reduced. An increased resistance to auto-ignition and the reduced combustion speed provides the possibility to control the combustion phasing. This works even at high loads as it reduces the firing pressure. Therefore, an increase of the geometric compression ratio becomes possible which increases the thermal efficiency both in gas mode and diesel mode.

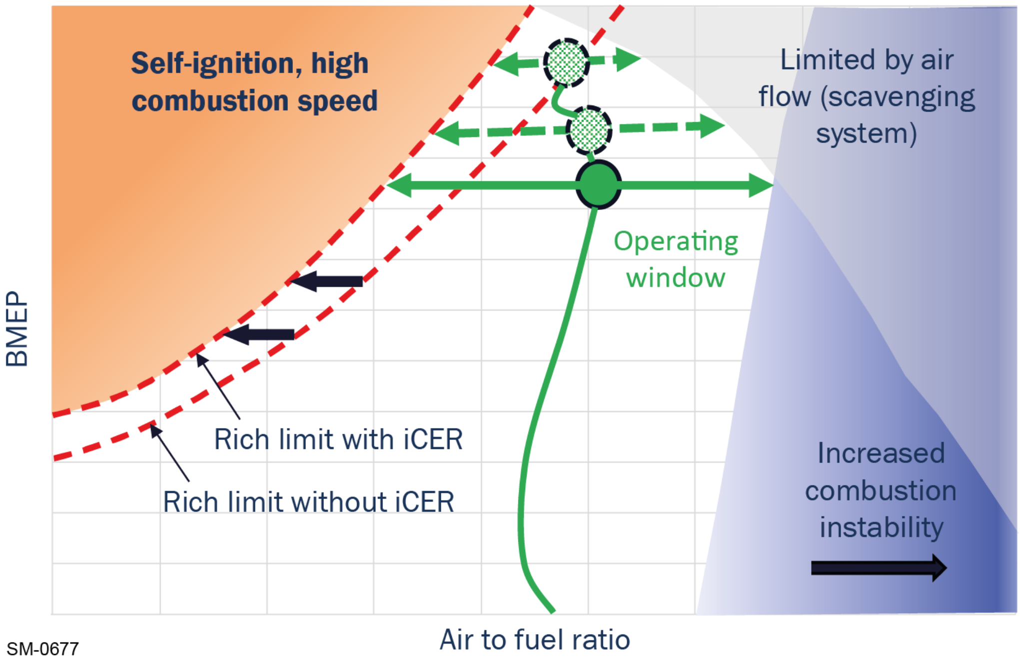

Figure 2-4: X-DF operating window with iCER

## 2.2 Fuel gas system

### 2.2.1 General description

The fuel gas system consists of the external Fuel Gas Supply System (FGSS), the gas fuel pressure control (GVU or iGPR) and engine internal fuel gas system. The fuel gas systems vary to some extent depending on X-DF engine type and specific ship installation, but the main principles regarding structure, operation and safety are the same.

### 2.2.2 Engine internal fuel gas system

The main components of the engine internal fuel gas supply system are vent valves on the engine, shut-off valves, fuel gas supply pipes and gas admission valves.

### 2.2.3 Gas admission valve

The gas admission valves are controlled by the ECS to regulate the engine speed and power by controlling the amount of gas fuel fed to each cylinder. The valves are situated so that gas fuel is fed into the cylinder liner (located directly at the cylinder liner below the mid-stroke). The gas fuel is mixed with combustion air only in the cylinder liner (Figure 2-5). The gas admission timing is set so that the cylinder is scavenged without unburned gas fuel escaping directly from the inlet to the exhaust gas system.

The gas admission valve is an electro-hydraulically actuated valve. The valve is closed by a spring when no servo oil pressure is available. A stroke sensor mounted on the gas admission valve provides feedback to either the Cylinder Control Module (CCM) or the Cylinder Control Unit (CCU) of each individual cycle. As such, the ECS can immediately trigger a gas trip in case a valve shows delayed closing or is stuck open for some reason and performs corrections of gas admission timing and duration. A sealing oil system prevents gas fuel from flowing into the servo oil system and ensures lubrication of the valve spindle.

The gas admission valve features a single-walled housing, which is pressure tested after manufacturing.

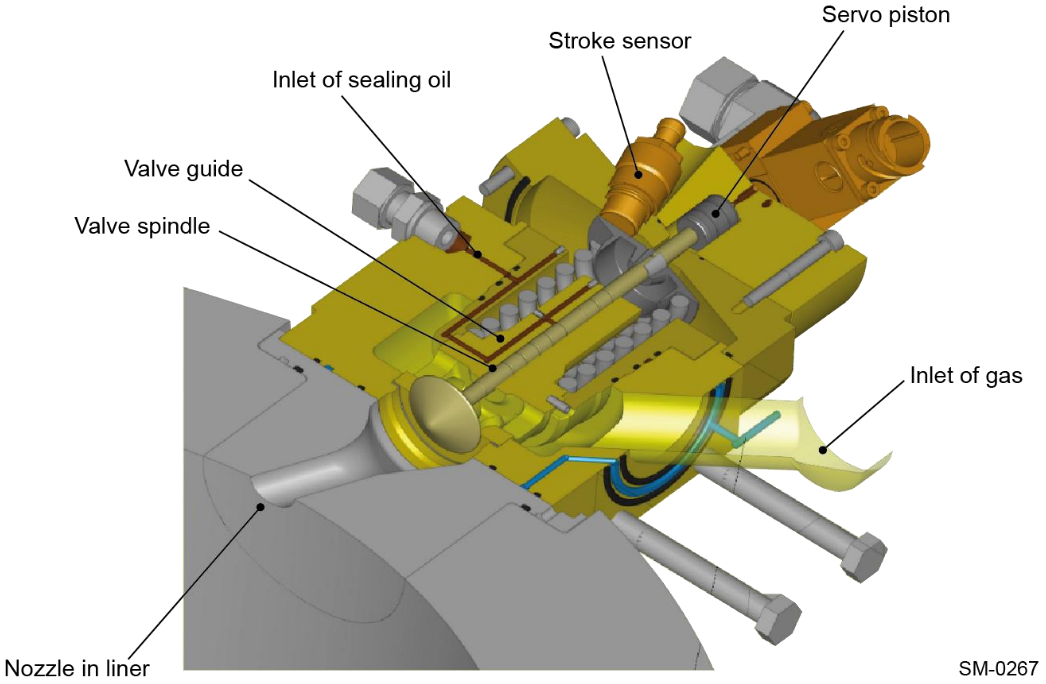

Figure 2-5: Gas admission valve

### 2.2.4 Fuel gas supply pipes

A double-walled manifold pipe supplies the gas fuel to the engine (see Figure 2-6). This pipe runs on either side of the engine, branching with individual and flexible feed pipes towards the gas admission valves. Two shut-off valves are located upstream from the admission valves and provide isolation and protection for the engine (see Figure 2-7).

Within the double-walled manifold, the inner pipe contains the gas fuel, while the outer space, called the annular space, is ventilated by air. Further information with a detailed description of the ventilation system is provided in section 3.4.3.

The air inlet to the annular space is arranged on the engine as a pipe connection. If requested by the classification society, a pipe must be added to this pipe connection to take the ventilation air from the gas-safe area outside of the engine room.

The venting of the inner fuel gas pipe is described in section 3.4.2.

All fuel gas pipes on the engine are depressurised, when not running in gas mode. Before any maintenance work is carried out, the system must be purged with inert gas (typically nitrogen).

All pipes are pressure tested after assembling, and tightness of the fuel gas system is constantly monitored with the double-walled piping concept (where a possible gas fuel leakage is detected by the gas fuel concentration sensor in the annular space of the piping).

### 2.2.5 Shut-off and vent valves

Shut-off and vent valves are placed in the main fuel gas line on the engine (see Figure 2-7). The shut-off valves isolate the engine from the fuel gas supply. This ensures that no gas fuel is delivered to the engine. The vent valves on the engine can quickly release the gas fuel pressure in the engine fuel gas pipes to ensure a gas fuel pressure-free engine as soon as the gas operation is stopped. Every section of fuel gas piping can be depressurised to allow maintenance.

The type of valves must be correctly selected to ensure that if they are deactived, the shut-off valves are closed and the vent valves are opened. The deactivation of the valves can occur, for example, due to a loss of power or a failure of control air. The correctly selected valves ensure an immediate gas fuel supply cut off and depressurisation of the fuel gas pipes.

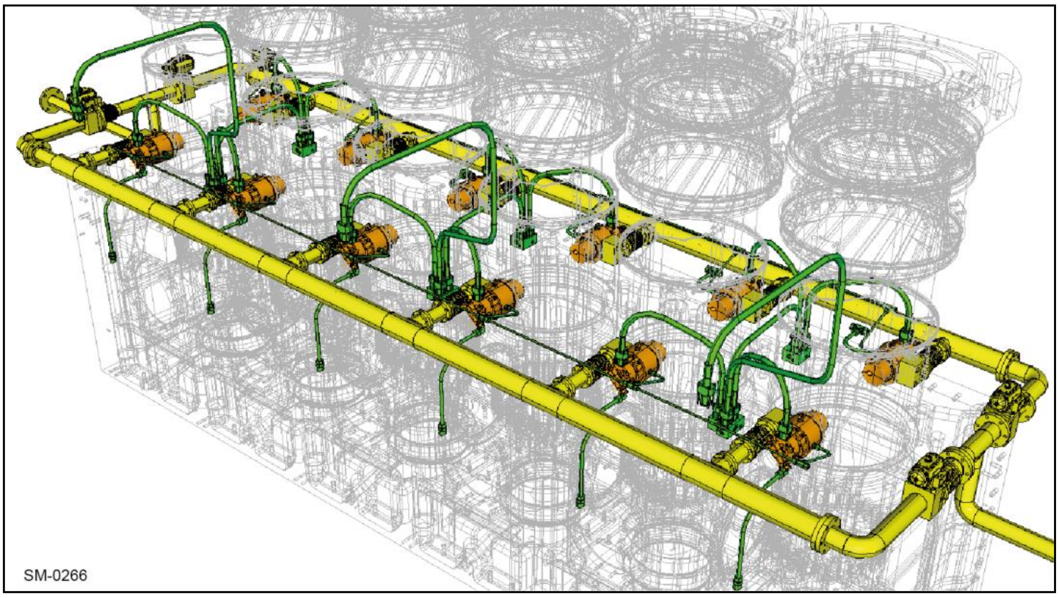

Figure 2-6: Example of double-walled fuel gas distribution piping on WinGD 6RT-flex50DF

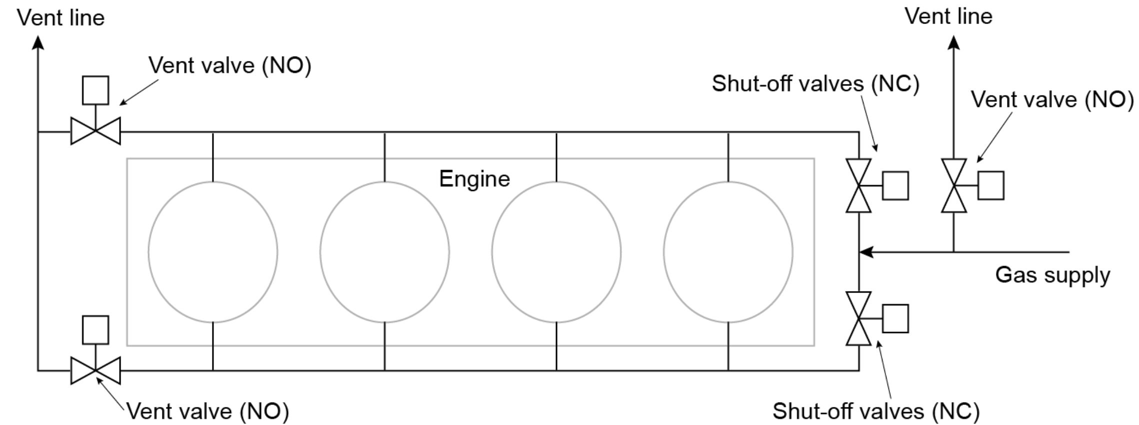

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Figure 2-7: Piping design of fuel gas supply pipe to engine

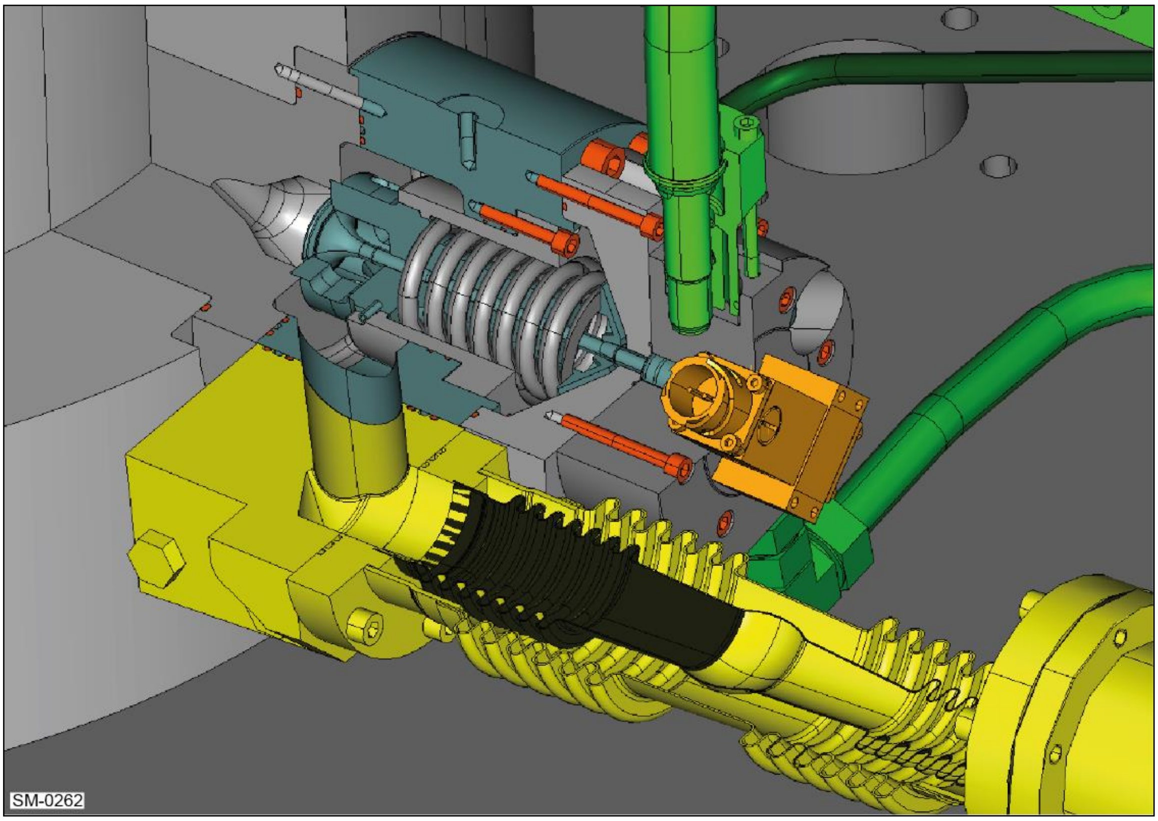


Figure 2-8: Double-walled fuel gas piping around gas admission valve and gas manifold

### 2.2.6 Gas Valve Unit and external fuel gas supply system

The gas fuel pressure is either controlled by an external Gas Valve Unit (GVU) or an Integrated (fuel) Gas Pressure Regulation (iGPR). This section describes the option of the execution with the GVU.

#### 2.2.6.1 General description of external fuel gas supply system

The external fuel gas supply system upstream from the GVU consists of fuel gas supply piping and pressurised gas fuel supply. Only some general notes about the gas fuel supply piping and the master gas fuel engine valve are given in this document.

**Fuel gas supply piping**
If fuel gas supply piping between the gas fuel storage area and the engine room is extended through other enclosed spaces, the piping must be double-walled or enclosed in a ventilated duct. The duct is equipped with gas detection. Through underpressure detection, the flow rate is monitored.

**Master gas fuel engine valve**
The master gas fuel engine valve, situated before the gas fuel pressure control, is open under gas mode condition and used to shut off the gas fuel supply to the engine room. This valve is controlled by the ESS. The master gas fuel engine valve can be closed from the X-DF engine room, engine control room and wheelhouse.The master gas fuel engine valve must close automatically in response to detected failures and as required by class rules.

A manual shut-off valve must be placed upstream from the master gas fuel engine valve. Alternatively, the master gas fuel engine valve can be designed with manual override function.

#### 2.2.6.2 General description of the Wärtsilä Gas Valve Unit (GVU)

**Introduction**
WinGD 2-stroke X-DF engines require precise regulation of gas fuel pressure with a timely response to changing load conditions.The Wärtsilä Gas Valve Unit (GVU) encompasses all performance and safety requirements associated with 2-stroke X-DF engine applications. There are two versions of the GVU available:

- GVU-ED™ (Enclosed Design): The enclosed design GVU incorporates a continuously vented, gas-tight enclosure and double-walled piping, which allows it to be installed within engine rooms without rendering them a gas hazardous area. The GVU-ED™ is sized according to engine bore size and cylinder configuration.
- GVU-OD™ (Open Design): The open design GVU is a simpler and more cost-efficient version without enclosure or double-walled piping. However, a ventilated space (gas valve room) outside of the engine room is required. The GVU-OD™ is sized according to engine bore size and cylinder configuration.

**Main functions of the GVU**

- Safety barrier between the FGSS and engine
  - Safety barrier is ensured by having Double Block and Bleed (DBB) valves.
- Fuel gas pressure regulation
  - The fuel gas pressure is regulated according to the engine load.
  - The signal for the fuel gas pressure requirement originates from the ECS.
- Leak test sequence
  - The sequence is performed before the engine transfers to gas operation.

  - It confirms that the GVU valves are working properly and that no internal leakages are detected.
- Purging with inert gas and venting
  - Purging and venting sequences are included in the GVU automation.
  - Safety is ensured during normal operation and in the event of system disturbance.
- Fuel gas temperature monitoring
  - The temperature of the fuel gas supplied by the FGSS is monitored at the GVU inlet. If the conditions for the natural gas are outside of the operational conditions, then a gas trip is triggered.

Figure 2-9: GVU Human Machine Interface

The complete GVU functionality is controlled by the built-in (GVU-ED™) or remote (GVU-OD™) control system. The control system is based on the Wärtsilä UNIC hardware.

Based on the signals from the control system logic, the solenoids control the valves. Furthermore, a full-color Human Machine Interface (HMI) panel (Figure 2-9) is mounted on the control cabinet, from where the following parameters can be monitored:

- current status of the GVU
- valve positions and readings from the sensors
- alarm history
- possible active alarms.

The GVU is Factory Acceptance Tested with the control system, consequently ensuring a high quality and trouble-free commissioning.

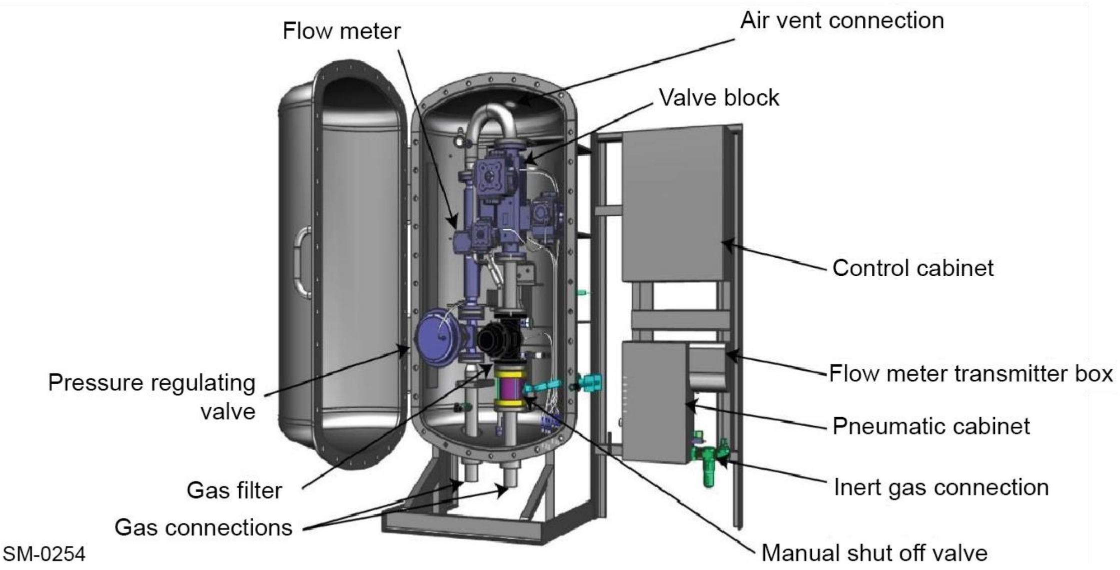
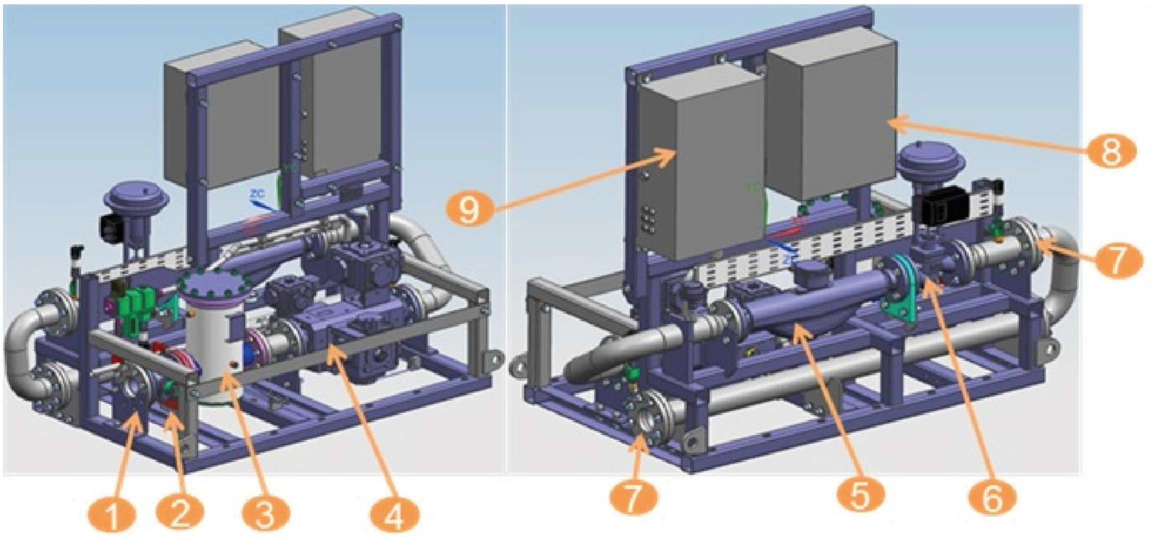


Figure 2-10: GVU-ED™ components overview



1 Gas Inlet
2 Manual valve
3 Gas Valve
4 Valve block
5 Flow meter
6 Pressure regulating valve
7 Gas outlet
8 Junction box
9 Solenoid valve cabinet

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Figure 2-11: GVU-OD™ components overview

### 2.2.6.3 The GVU installation aspects

**The GVU-ED™**

The GVU-ED™ includes an incorporated gas-tight enclosure around the process components (Figure 2-10). Due to the enclosure design, the same principles as for double-walled piping apply. The enclosure forms a gas-tight, second barrier against any unforeseen gas leakages. Hence, the GVU-ED™ as such is part of the larger ventilated double-walled piping system. The piping and components are coated on the outside in accordance with marine specific colour schemes. Since the gas fuel related equipment is contained within the unit, the Wärtsilä GVU-ED™ is installed next to the engine, and similarly as other auxiliary equipment (Figure 3-1). In order to ensure sufficient response of the gas fuel pressure regulation, the length of the pipe between the GVU and the engine must not be more than 30 m.

The air vent of the GVU-ED™ enclosure connects to an extraction fan, inducing forced air ventilation. The extraction fan is sized to exchange the volume of the annular space of the connected double-walled piping at a minimum rate of 30 times per hour. The extraction fan must maintain a constant underpressure in the double-walled piping and this is constantly monitored. If the extraction fan fails or is no longer providing the required underpressure, a pressure transmitter is located inside the annular space and connected to the GVU-ED™ control box and triggers gas trip to diesel mode. Consequently, the gas fuel pressure in the fuel gas pipe between the GVU and engine is released. In the event of overpressure detection, this gas pipe is also purged with inert gas (see section 3.4.2). The outlet of the air vent must be discharging to a well ventilated area outside of the engine room.

The ventilation of the GVU-ED™ must be independent of all other ventilation systems.

For any concentration of gas fuel, the annular space of the double-walled piping and the GVU enclosure are constantly monitored by at least two gas detectors (Figure 3-1).

At least one gas detector must be installed in order to monitor the double-walled piping from around the engine until the GVU enclosure; this should be as close as possible to the GVU. At least one other gas detector must be installed to monitor the GVU enclosure.

In the event of gas detection (i.e. if the class LEL is exceeded), a gas trip (to diesel mode) is triggered by the ESS, and the fuel gas piping is vented and purged with inert gas (see section 3.4.2).

**The GVU-OD™**

If a single-walled fuel gas pipe passes through a room below the deck, the room becomes a gas hazardous area. To fulfil safety requirements in an installation utilizing the GVU-OD (Figure 2-11), a completely separate and gas-tight room must be dedicated exclusively for the GVU. Refer to the Wärtsilä GVU-OD™ room safety concept guidance as the room must meet these requirements.

The GVU control panel must be installed in a different room than the GVU-OD™, as it does not fulfil requirements for hazardous areas, Hazard Zone 1 (refer to 3.6 for hazardous areas definition).

### 2.2.6.4 Fuel gas pipe purging

Purging is the process of removing natural gas from the fuel gas piping by substituting it with an inert gas, e.g. nitrogen. The GVU purging sequence ensures that after detection of a gas leak, no natural gas can escape to the engine room. Therefore, eliminating potential risks.

In the event of gas detection within the annular space of the double-walled gas piping or the GVU enclosure (GVU-ED™), a gas trip is triggered by the ESS. As an additional safety measure, the gas piping downstream from the GVU and on the engine, is automatically vented and purged with inert gas. For this purpose, the GVU is equipped with a purging valve ('$N_2$ Engine' in Figure 2-12), which introduces pressurised inert gas into the fuel gas piping. The inert gas flows through the open vent valves on the engine, replacing any remaining natural gas in the system. This timed sequence is calibrated during commissioning to exchange the fuel gas piping volume at least three times.

Before maintenance work is commenced on the engine and/or the GVU, it is required to purge the piping. This ensures no natural gas leaks into the engine room.

This is a manual process, initiated by operators as needed. For the piping on engine side, the sequence is the same as the one described above. For the purposes of the GVU and its upstream pipe purging, an additional purging valve ('N2 GVU' in Figure 2-12) is located before the GVU to supply the pressurised inert gas in the system. Vent valves, an integral part of the GVU valve block, allow inert gas to vent, eventually replacing any remaining natural gas in the GVU and its upstream pipe. The purging sequence can be found in the WinGD Operation Manual.

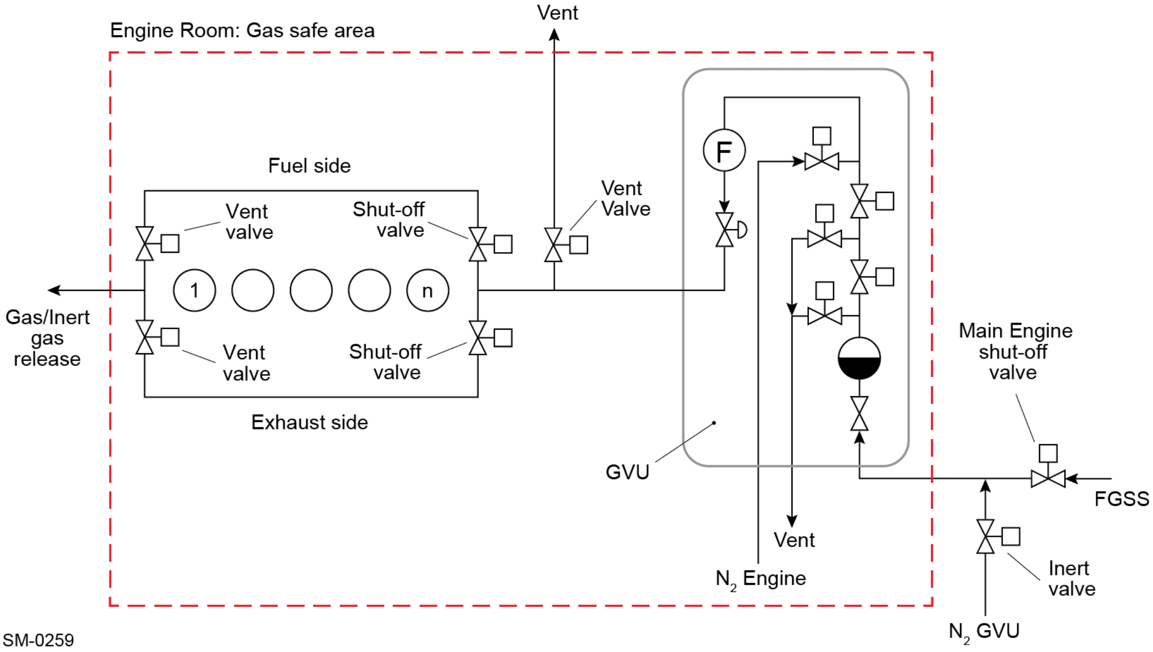

Figure 2-12: GVU process component diagram

## 2.2.7 The iGPR and external fuel gas supply system

The gas fuel pressure is either controlled by an external GVU or an Integrated Gas Pressure Regulation (iGPR). This section describes the option of the execution with the the iGPR.

### 2.2.7.1 General description of external fuel gas supply system

The external fuel gas supply system upstream from the iGPR consists of fuel gas supply piping and pressurised gas fuel supply. Only some general notes about the fuel gas supply piping and the master gas fuel engine valve are given in this document.

#### Fuel gas supply piping

If the fuel gas supply piping between the gas storage area and engine room is extended through other enclosed spaces, the piping must be double-walled or enclosed in a ventilated duct. The duct is equipped with gas detection. Through underpressure detection, the flow rate is monitored.

#### Master gas fuel engine valve

The master gas fuel engine valve, situated before the gas fuel pressure control, is open during gas operation condition and used to shut off the fuel gas supply to the engine room. This valve is controlled by the ESS. The master gas fuel engine valve can be closed from the X-DF engine room, engine control room and wheelhouse. The master fuel gas engine valve must close automatically in response to detected failures and as required by class rules.

**Control of gas supply**

The fuel gas supply is controlled by double block and vent valves (bleeding function), which are activated by the iGPR control system. The type of valves must be correctly selected to ensure that if they are deactived, the double block shut-off valves are closed and the vent valves are opened. The deactivation of the valves can occur, for example, due to a loss of power or a failure of control air. The correctly selected valves ensure an immediate gas fuel supply cut off and depressurisation of the fuel gas pipes.

### 2.2.7.2 General description of the Integrated Gas (Fuel) Pressure Regulation (iGPR)

**Introduction**

WinGD 2-stroke X-DF engines require precise regulation of the gas fuel pressure with a timely response to changing load conditions. For this purpose, WinGD has developed the Integrated Gas (Fuel) Pressure Regulation (iGPR), which encompasses all performance and safety requirements associated with 2-stroke X-DF engine applications. In contrast to the GVU, the components of the iGPR are mounted on the engine.

**Main functions of the iGPR**

- Safety barrier between the FGSS and engine
  - Safety barrier is ensured by having Double Block and Bleed (DBB) valves.
- Gas fuel pressure regulation
  - The gas fuel pressure is regulated according to the engine load.
  - The signal for the gas fuel pressure requirement originates from the ECS.
- Leak test sequence
  - The sequence is performed before the engine transfers to gas operation.
  - It confirms that the iGPR valves are working properly and that no internal leakages are detected.
- Purging with inert gas and venting
  - Purging and venting sequences are included in the iGPR automation.
  - Safety is ensured during normal operation and in the event of system disturbance.
- Gas fuel temperature monitoring
  - The temperature of the gas fuel supplied by FGSS is monitored at the iGPR inlet. If the conditions for the natural gas are outside of the operationa conditions, then a gas trip is triggered.

The complete iGPR functionality is controlled by dedicated iGPR control boxes. The control system is based on the Wärtsilä UNIC hardware~~.~~

Based on the signals from the control system logic, the solenoids control the valves. Furthermore, a full-color HMI panel is mounted on the control cabinet, from where the following parameters can be monitored:

- current status of the gas fuel pressure control
- valve positions and readings from the sensors
- alarm history
- possible active alarms.

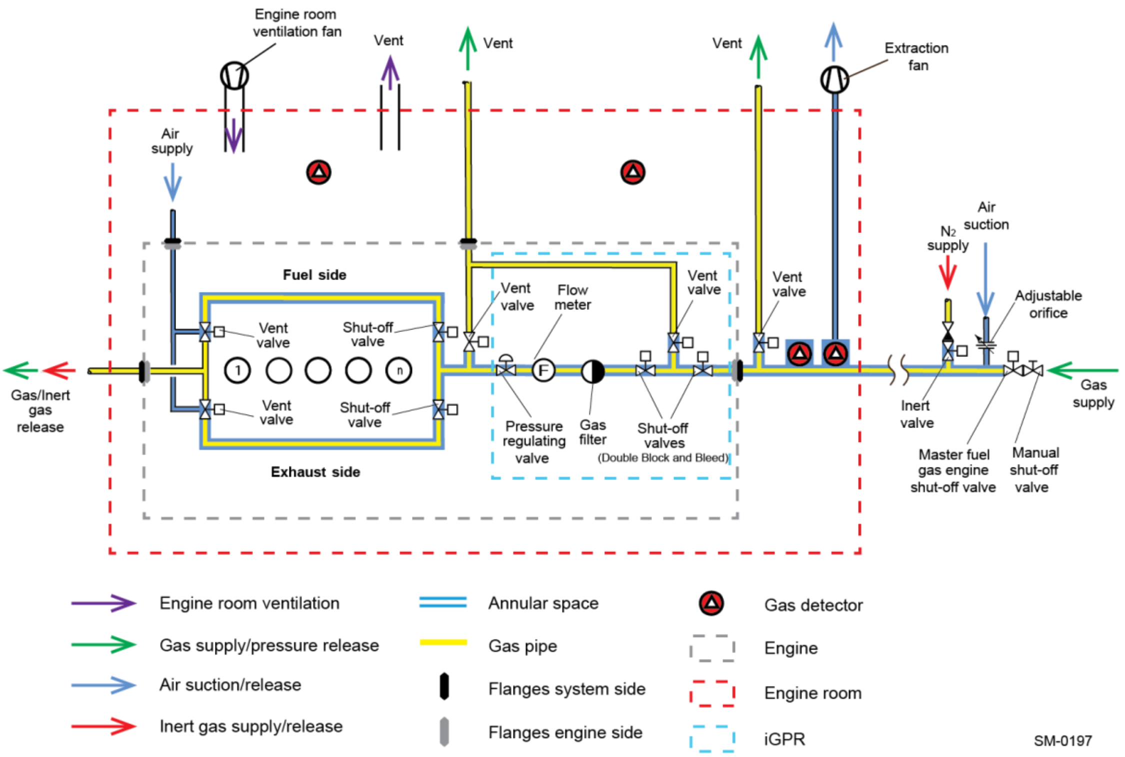

Figure 2-13: Typical sketch of the iGPR layout

### 2.2.7.3 The iGPR installation aspects

The air vent of the double-walled piping connects to an extraction fan, inducing a forced air ventilation system. The extraction fan is sized to exchange the volume of the annular space of the connected double-walled piping at a minimum rate of 30 times per hour. The extraction fan must maintain a constant underpressure in the double-walled piping. This is constantly monitored. If the extraction fan fails, a flow switch which is located inside the annular space sends a signal to the ESS and triggers a gas trip to diesel mode, beginning the event sequence and releasing the gas fuel from the pipes, as well as purging of the pipes (see section 2.2.7.4). In addition, the underpressure is constantly monitored by a pressure sensor in the iGPR and is connected to the iGPR control system.

The air ventilation outlet must be discharged to a well-ventilated area outside of the engine room. The ventilation of the double-walled piping must be independent of all other ventilation systems. For any concentration of gas fuel, the annular space of the double-walled piping is constantly monitored by gas detectors (Figure 2-13). In the event of gas detection (i.e. if the class LEL is exceeded), a gas trip (to diesel mode) is triggered by the ESS, and the fuel gas piping is vented and purged with inert gas (see section 3.4.2 and section 2.2.7.4).

### 2.2.7.4 Purging

Purging is the process of removing natural gas from the fuel gas piping by substituting it with an inert gas, e.g. nitrogen. The purging sequence, as illustrated below in Figure 2-14, ensures that after detection of a gas fuel leak, no natural gas can escape to the engine room. Therefore, eliminating potential risks.

For example, in the event of gas detection within the annular space of the double-walled fuel gas piping or the engine room, a gas trip with purging is triggered by the ESS. Consequently, fuel gas piping downstream from the master gas fuel engine valve is automatically vented and purged with inert gas.

For this purpose, pressurised inert gas is supplied through the inert valve on the ship side and into the fuel gas piping. The inert gas purges the entire system as it flows through the piping, the iGPR and the already open vent valves on the engine fuel gas distribution piping, replacing any remaining natural gas in the system.

During this process, the vent valves between the master gas fuel engine inlet and the engine fuel gas distribution pipe are closed. The volume of the total fuel gas piping must be exchanged at least three times. Before maintenance work is started on either the engine or the iGPR, the corresponding fuel gas piping must be purged, ensuring that no natural gas leaks into the engine room. This is a manual process only and it needs to be initiated by operators.

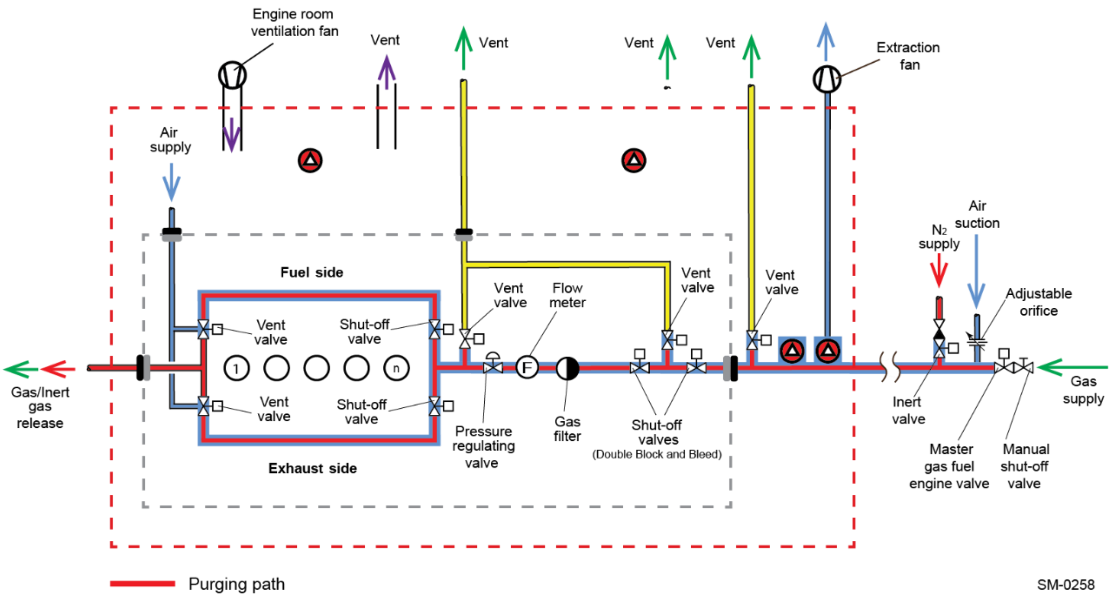

Figure 2-14: Purging from the inert valve on the ship side

## 2.3 Pilot fuel oil system

The main components of the pilot fuel oil systems are the pump unit, common rail pipe, supply pipes and injection valves (see Figure 2-15).

The pump unit raises the pilot diesel oil pressure to the required level. It consists of an electrically driven radial piston pump (with a built-in overpressure bypass valve), fuel filters and a flow control valve. The pump unit is located on the engine.

Pressurised pilot fuel is delivered from the pump unit into a common rail pipe. From the pump to the injectors, the piping consists of the high-pressure, double-walled type. Any leakage is collected from the annular space of the double-walled pipe and led to a collector with a leakage sensor. The common rail piping delivers pilot fuel to each injection valve and acts as a pressure accumulator against pressure pulses.

The X-DF engine uses pilot injectors with built-in solenoid valves. The injectors are electronically controlled by the ECS system allowing exact timing and duration of the injection process. To have the best ignition and combustion stability, the pilot injection valves are combined with pre-chambers. These pre-chambers are directly water-cooled by the HT cooling water from the cylinder cover. Furthermore, the injectors are cooled by the system oil.

The pilot fuel injection is also activated during diesel operation to prevent excessive deposit formation on the injector tips and in the pre-chambers. The injected fuel amount is however minimised.

Under any operation mode with the exception of diesel mode, the pilot fuel system is constantly monitored to ensure the gas fuel in the cylinder is properly ignited.

The monitoring includes the pilot fuel pressure level with two redundant measurement signals as well as the electrical circuit needed for activation of the pilot injectors.

The installation of two pilot injectors per cylinder increases the availability of a reliable ignition source. If the pilot fuel pressure is found to be too low or the electrical wiring has an open loop or short-circuit, the ECS does not allow the transfer to gas or fuel sharing mode.

An additional safety measure during transfer and gas operating mode is the detection of misfiring, using a redundant detection system. If the number of consecutive misfires exceeds the threshold, the engine automatically trips to diesel mode and restore to a safe mode of operation (see Figure 5-1).

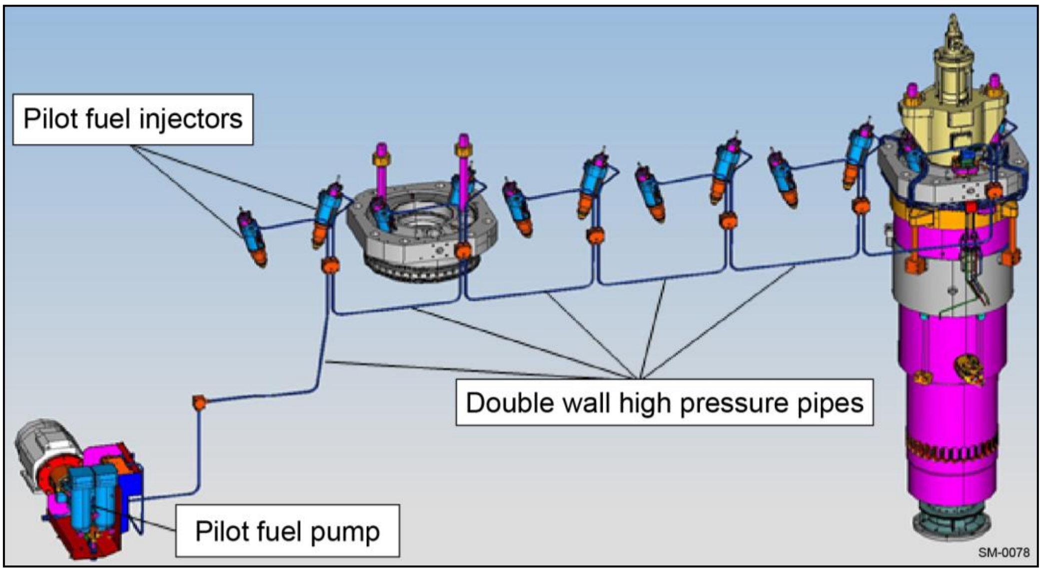

Figure 2-15: Pilot fuel high-pressure system

## 2.4 Exhaust gas system

### 2.4.1 Exhaust gas system description

The exhaust gas can contain some unburned gas fuel due to malfunction. The design of the exhaust gas system must ensure that gas fuel cannot accumulate anywhere in the system. Precautions must be taken to prevent an exhaust gas explosion damaging equipment and personnel in close vicinity.

#### 2.4.1.1 External exhaust gas system

The external exhaust gas system consists of a compensator and of piping downstream of the turbocharger.

In the exhaust gas system design the following main features must be considered:

- According to class requirements, piping and components must be designed in such a way that gas fuel cannot accumulate in the exhaust gas system, especially in the installed silencer and exhaust gas boiler.
- In general, according to the general rules the exhaust gas system must be designed to withstand a potential explosion, which can be achieved by applying explosion relief devices. However, WinGD has demonstrated that there is no exhaust gas explosion risk. Accordingly, the explosion relief devices are not required, if approved by the involved classification society. If the explosion relief devices are installed, the following installation requirements apply:

  – The number and placement of the explosion relief devices must be calculated, e.g. with a computer simulation. Any assumptions of the scenario simulation are to be justified. For example, for a single main engine the explosion relief devices either must include a duct leading the exhaust gas to the outside or must be made of the self-closing type.
  – The explosion relief devices must be in such a way that the hot combustion gases erupting from them do not cause a significant health hazard at the point of release. In case of eruption the gas concentration is detected by the engine room detector.
  – Explosion relief devices installed within the engine room area must be of the self-closing type.
  – All explosion relief devices must be equipped with flame arrestors.
- All explosion relief devices must be equipped with flame arrestors, if required.
- Any bellows to be used in the exhaust gas system must be approved by the classification society.
- The exhaust gas duct of the X-DF engine must not be connected to the exhaust gas duct of any other equipment.

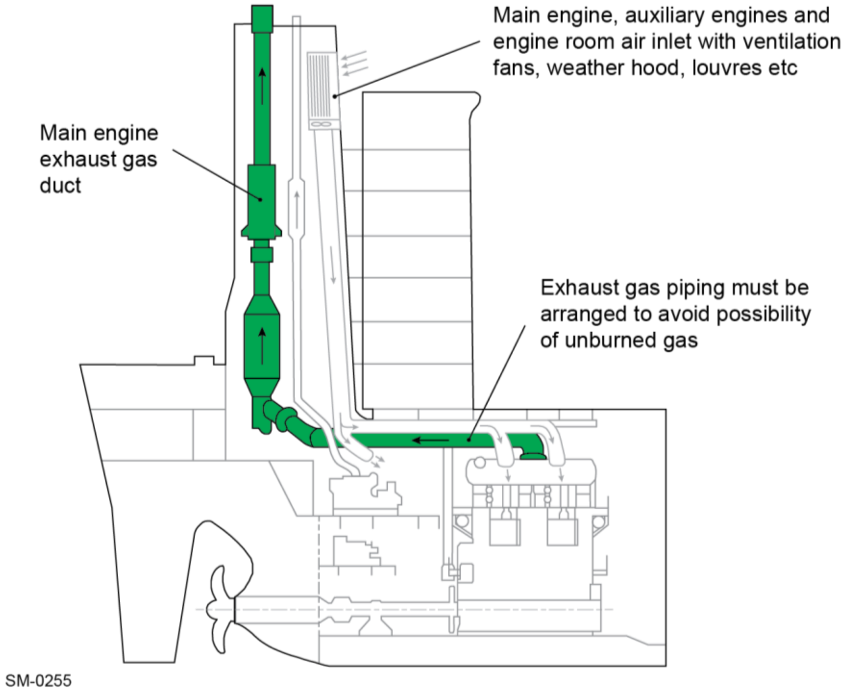

Figure 2-16: External exhaust gas system

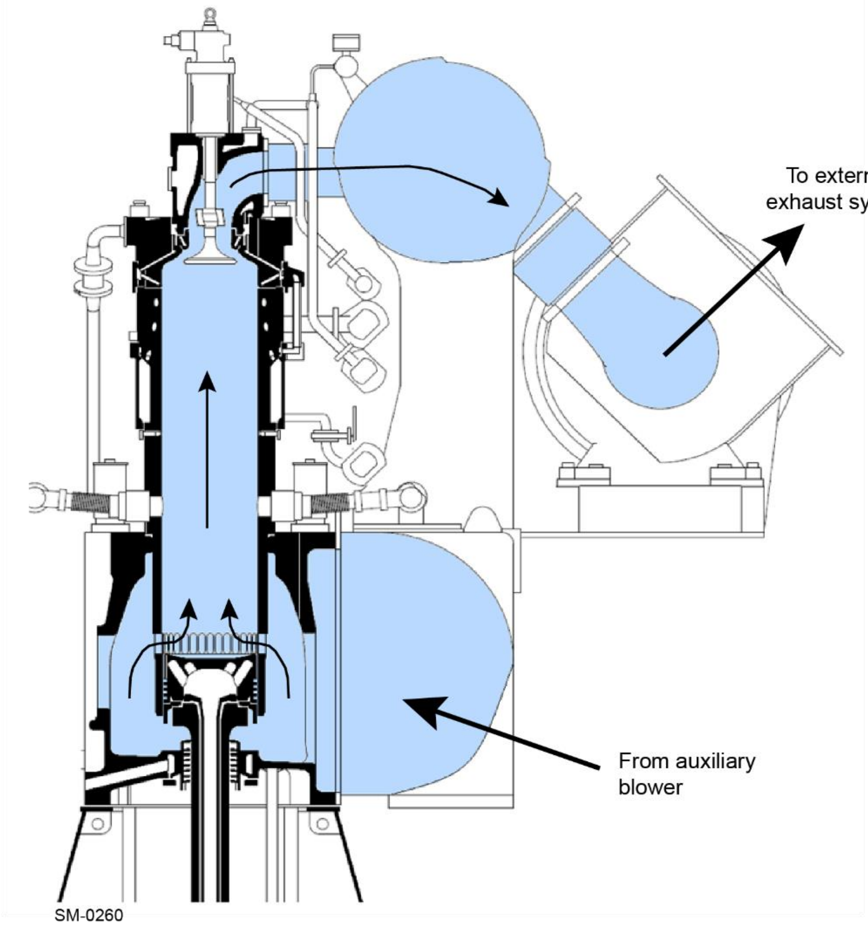

Figure 2-17: Exhaust gas ventilation

### 2.4.1.2 Engine exhaust gas system

The engine exhaust gas system consists of pipe sections connected to the manifold with flexible bellows. These stainless-steel bellows are critical components with respect to internal overpressure in the exhaust gas system. Both the exhaust gas manifold and the flexible bellows are designed to withstand a possible explosion without bursting.

WinGD sees no reason for concern regarding the ongoing operational functionality of a turbocharger if an explosion has occured in the exhaust gas system before. However, for specific questions, please address the turbocharger manufacture.

### 2.4.1.3 Safety measures for preventing a potential explosion in the exhaust gas system

In addition to the safety of the exhaust gas system design described above, precautions on the engine side must be taken. For example, during engine operation, explosive exhaust gas could be created by misfiring. Consequently, the engine combustion process must be continuously monitored, controlled and adjusted. Under the circumstance that the number of consecutive misfires exceeds the threshold, the engine automatically trips to diesel mode.

An emergency engine stop, a non-cancellable shutdown or blackout (power-off of the ECS) during operation in gas or fuel sharing mode can lead to unburned gas fuel in the engine and the exhaust gas system. Therefore, engine ventilation and exhaust gas system ventilation is automatically requested before the engine restart and a prolonged starting on air is applied.

#### 2.4.1.4 Exhaust gas ventilation procedure

1. The ventilation sequence is requested automatically by the ESS or ECS and needs to be confirmed manually by the operator.
2. After confirmation, the ventilation is performed automatically by the ECS.
3. The sequence can be cancelled at any time by the operator in case of an urgent need of engine start.
4. After the ventilation request a prolonged engine start is performed.

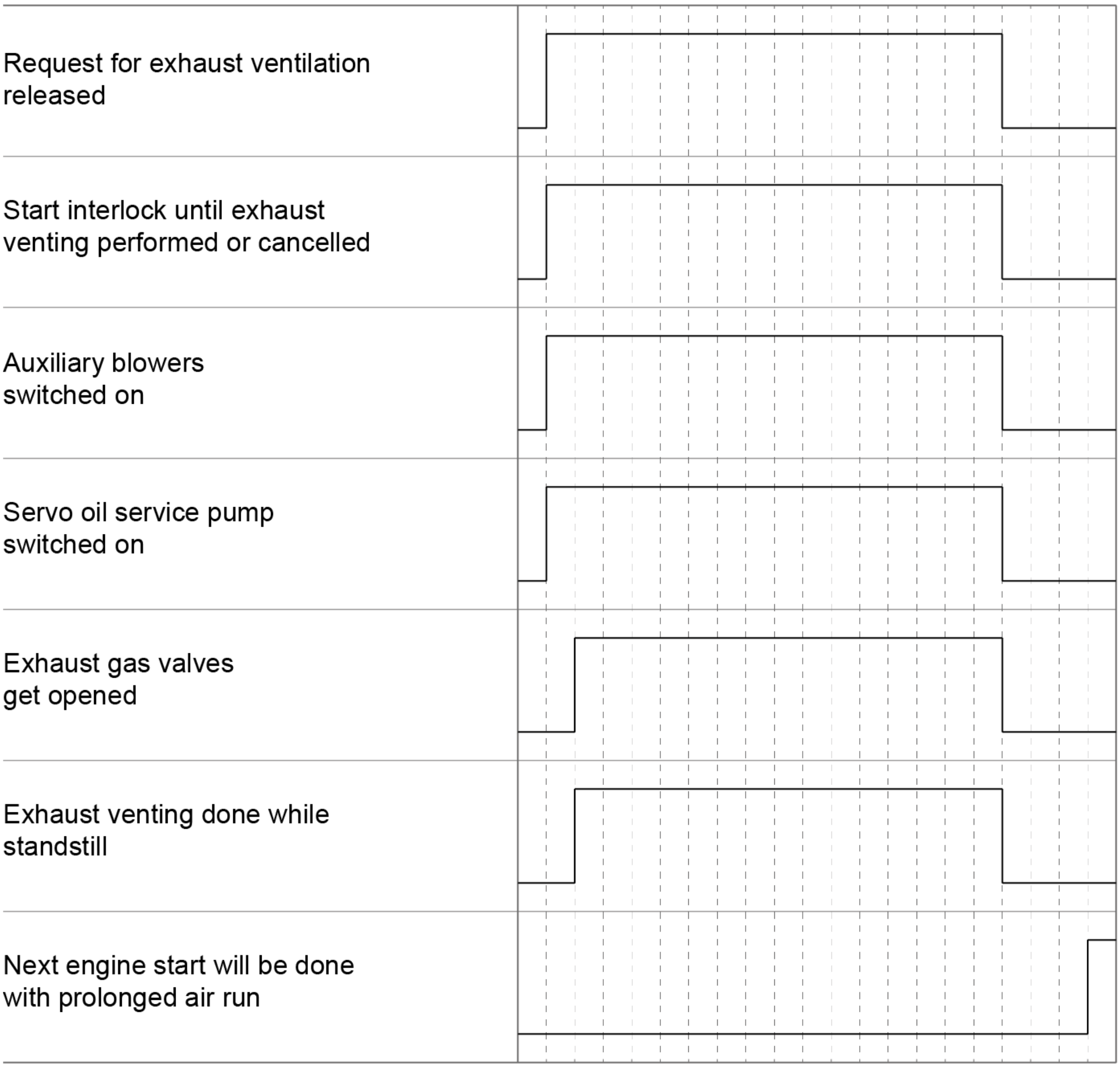

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Figure 2-18: Exhaust gas ventilation procedure event sequence

### 2.4.1.5 Exhaust gas system with optional Selective Catalytic Reduction (SCR) installation

An SCR system can be installed to achieve IMO Tier III compliance while operating in diesel mode[1]. The SCR system includes the urea dosing and compressed air auxiliary equipment, while the detailed arrangement can vary: Low-Pressure (LP) and High-Pressure (HP) SCR arrangements are available.

Low-pressure SCR

In the exhaust gas channel, the LP SCR system is arranged with the SCR reactor located at the low-pressure side of the turbocharger. Butterfly valves are installed to isolate the reactor whenever the SCR system is bypassed. Different layout solutions are available (see Figure 2-19, Figure 2-20, and Figure 2-21 for the detailed layouts).

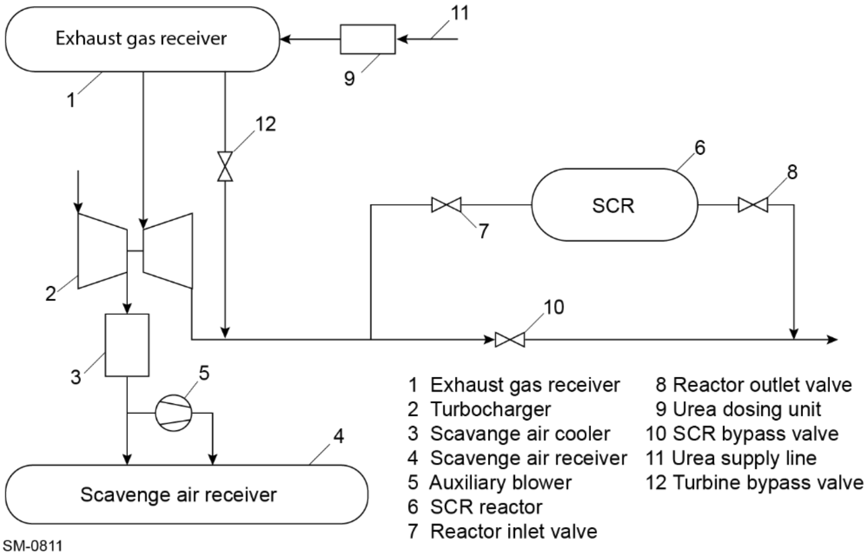

Figure 2-19: LP SCR with direct urea injection

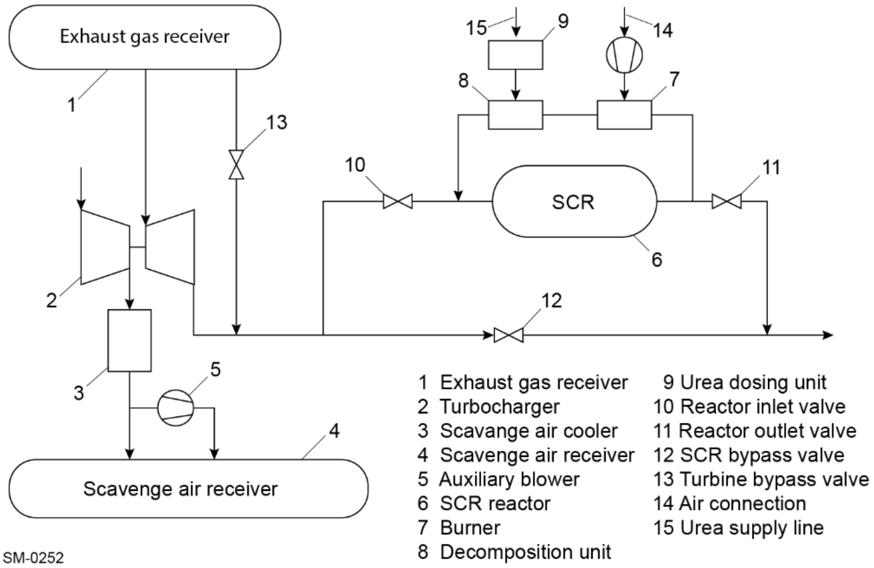

Figure 2-20: LP SCR with indirect urea injection (temperature controlled)

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[1] Not available for Fuel Sharing Mode (FSM) and Combustion Stability Mode (CSM)

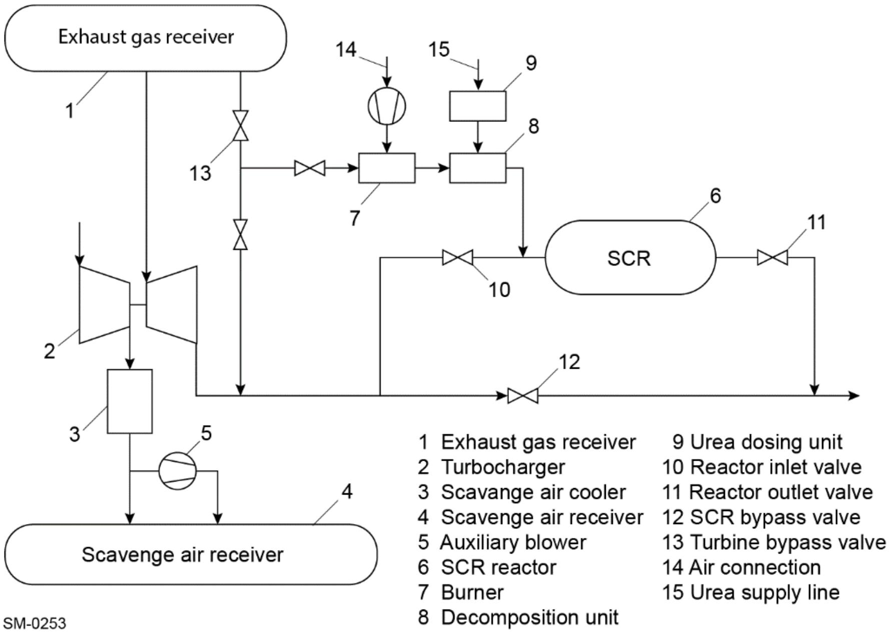

Figure 2-21: LP SCR with indirect urea injection (bypass rate controlled)

### High-pressure SCR

The HP SCR is arranged with the SCR reactor positioned on the high-pressure side, between the engine exhaust gas manifold and the turbocharger. Two shut-off valves are installed at the inlet and outlet of the SCR reactor with an additional bypass valve installed to isolate and assist with bypassing the SCR system. Refer to Figure 2-22 for the detailed layout.

The exhaust gas system with SCR installation must meet the requirements for overpressure and withstand a potential explosion. As such, the components and piping of the SCR system must be designed and comply with the same principles as stated for non-SCR installations. Furthermore, the installed shut-off valves are designed to withstand the potential pressures in case of an exhaust gas explosion.

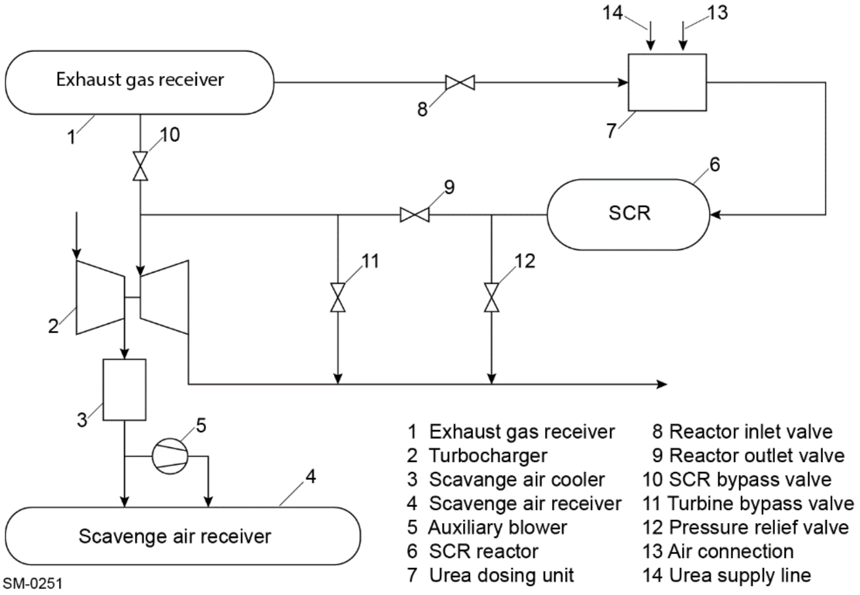

Figure 2-22: HP SCR

Note: SCR can only be used in diesel mode. Whenever gas fuel is used (in gas mode or fuel sharing mode), the SCR reactor must be bypassed.

### 2.4.2 Scavenge air system control

To ensure optimal performance of the engine, it is essential to have a correct air-fuel ratio during the varying operating conditions. WinGD X-DF engines use a proportional exhaust gas waste gate valve to adjust the air-fuel ratio. The exhaust gas waste gate valve allows part of the exhaust gas to bypass the turbocharger turbine and can therefore be used to adjust the scavenge air pressure. By changing the scavenge air pressure, the air-fuel ratio is adjusted to the correct value regardless of the varying site conditions (ambient temperature, humidity, etc.)

Figure 2-23: Exhaust gas waste gate installation

## 2.5 The X-DF engine automation architecture

The ECS provides data bus connection to the Propulsion Control System (PCS) and the Alarm and Monitoring System (AMS). The AMS is usually provided by the shipyard. The leading suppliers PCSs approved by WinGD ensure complete meeting the engine requirements.

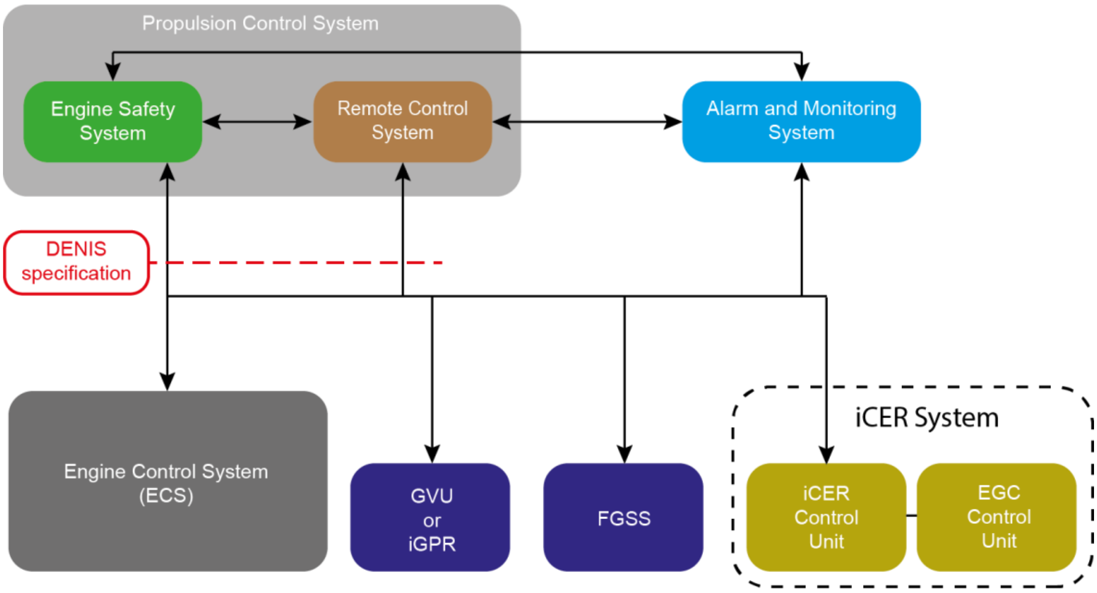

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Figure 2-24: Engine automation architecture

### 2.5.1 Signal flow diagram between the engine control system and external systems

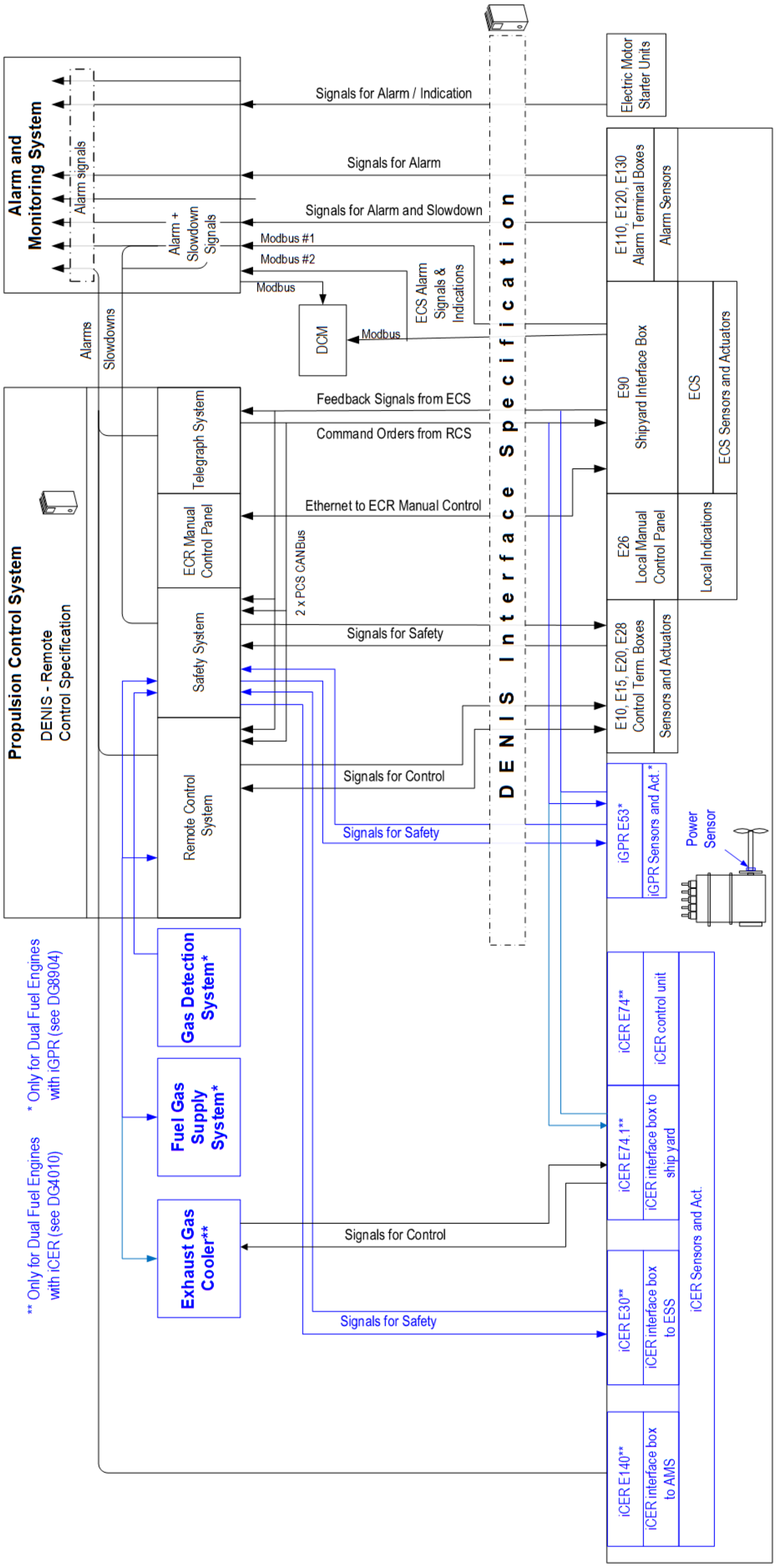

Figure 2-25: Signal flow diagram between the ECS and external systems

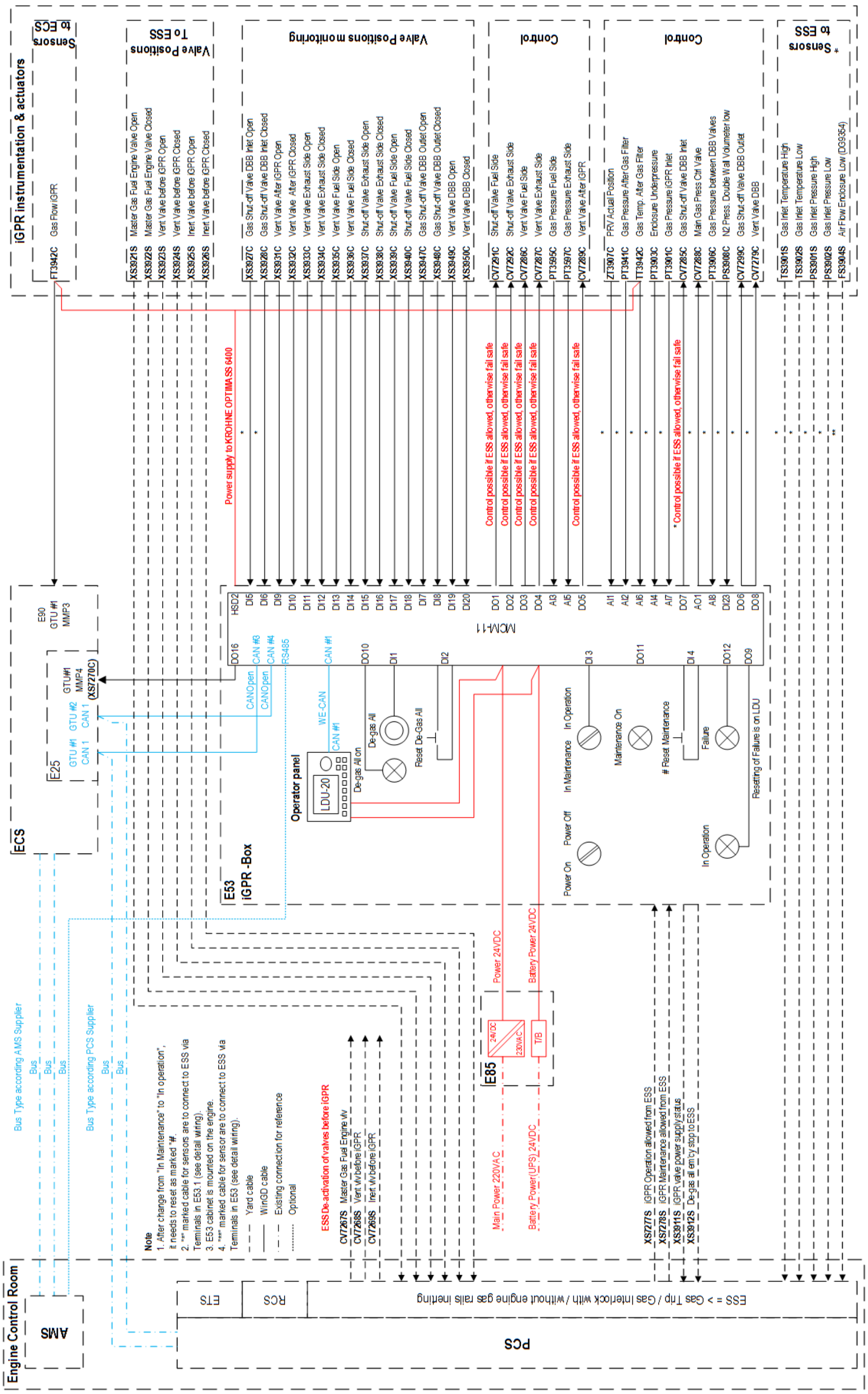

Figure 2-26: Typical signal flow diagram between the ECS and external system, e.g. for iGPR

The gas operation related signals and the related failure action are listed in the tables of section 0. Communication to the external systems is described in the signal lists.

### 2.5.2 Fuel operating modes

The engine is designed for continuous service on gas fuel with fuel oil as a back-up fuel. Depending on the selected option, different operating modes are available within specific engine power ranges (see

Figure 2-27 and Figure 2-28).

The following list includes the operating modes of X-DF engines without iCER:

- gas mode
- diesel mode
- if contracted, fuel sharing mode Tier III.

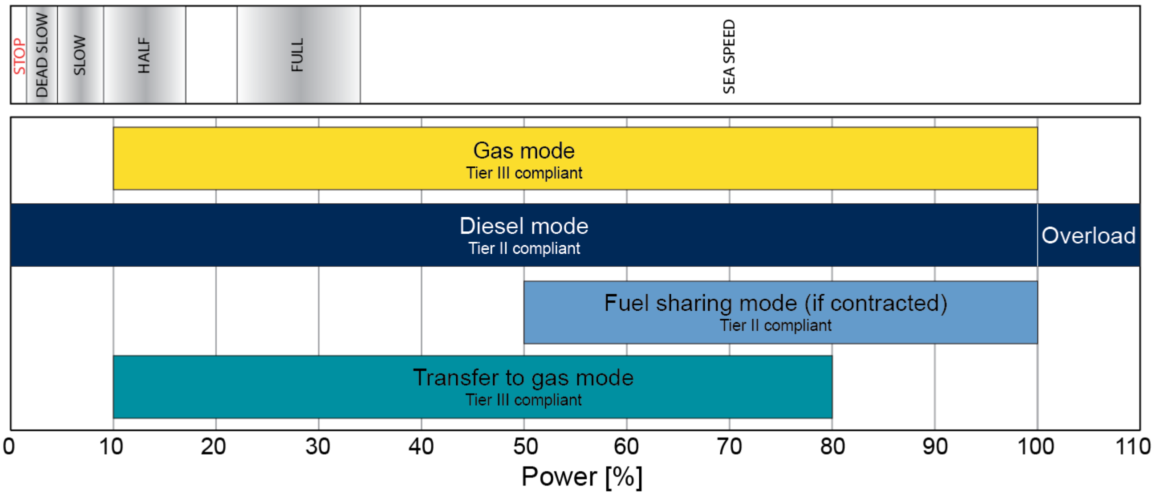

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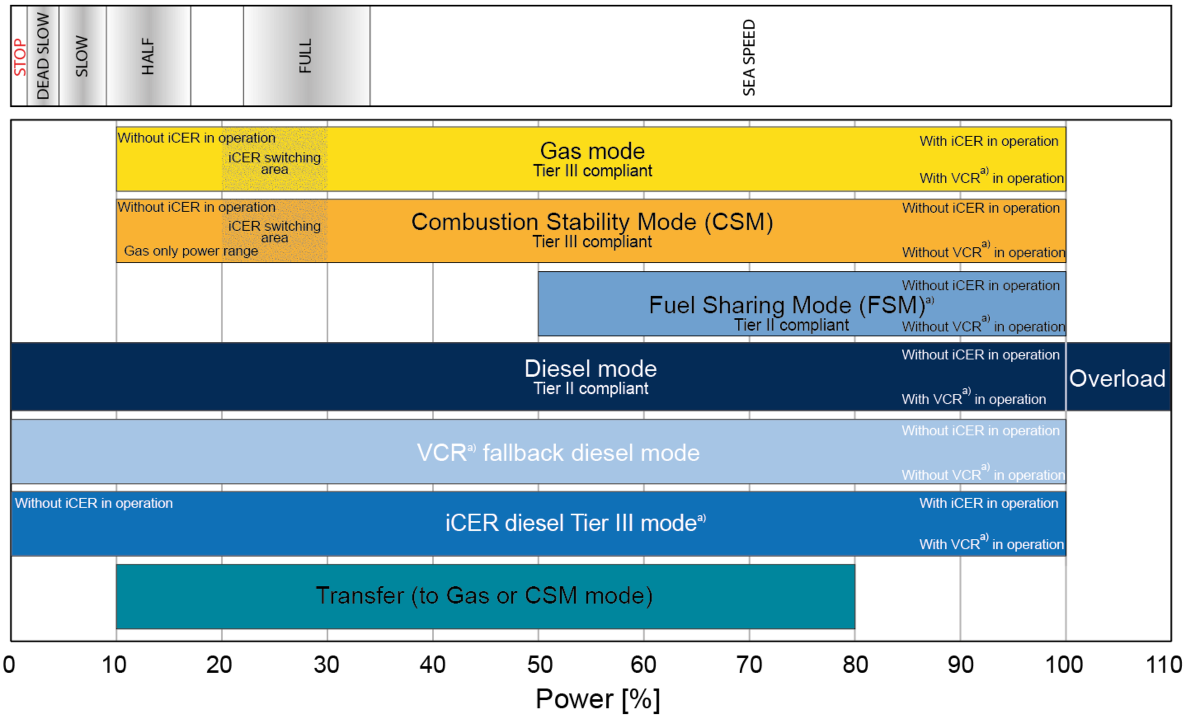
Figure 2-27: Operating modes of X-DF engines without iCER

The following list includes the operating modes of X-DF2.0 engines:

- gas mode (with the iCER system in operation and VCR[1] in operation))
- Combustion Stability Mode (CSM)
- diesel mode (with VCR[1] in operation)
- if contracted, Fuel Sharing Mode[1] (FSM)
- if contracted, iCER diesel Tier III mode[1] (with the iCER system and VCR[1] in operation).



a) It is an available option in addition to the chosen engine configuration, and not included in the standartd configuration. It needs to be contracted.

Figure 2-28: Operating modes of X-DF2.0 engines Tier III

Changeover between the operating modes:

- transfer (automatically active for changeover to, or between, modes with gas operation)
- gas trip (immediate action, always available while a mode with gas operation is selected).

In diesel mode, the X-DF engine operates the same as a conventional diesel engine. The pilot fuel injection remains active at minimised injection amount (MGO or MDO).

Diesel mode with iCER is without gas fuel and has no relevance to the Safety Concept. There is no gas fuel supplied to the X-DF engine, as in the case of the standard diesel mode without the iCER.

In gas mode, the X-DF engine operates as described in section 2.1.

The fuel sharing mode is an optional feature that allows increased fuel flexibility. In this mode, the X-DF engine operates on a variable ratio of liquid and gas fuel, which is simultaneously combusted in the cylinders. Gas fuel is admitted by the gas admission valves as per normal gas operation. However, an additional portion of liquid fuel is injected through the main fuel injection system. If contracted, Fuel sharing mode is available above 50% Contracted Maximum Continuous Rating (CMCR) engine power and with a liquid-to-gas fuel ratio of up to 50%. The ratio of liquid-to-gas fuel is requested by the remote control system. The total amount of both fuels is controlled by the speed governor, following the same principles as during a gradual transfer from diesel mode to gas mode.

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[1] It is an available option in addition to the chosen engine configuration, and not included in the standard configuration. It needs to be contracted.

Since fuel sharing operation involves gas as a fuel, the same general safety principles apply as when running in gas mode.

Engine start and reversing are always performed in diesel mode.

For X-DF2.0 engines, in gas mode with active iCER, the engine operates as described in section 2.1.3. The Combustion Stability Mode (CSM) can be selected as an operating mode, which does not use the iCER system. The CSM can be active above 10% CMCR power.

Starting from 10%CMCR power, only gas fuel is applied. Starting in a range of 20% to 30% CMCR power, a part of the gas fuel is replaced with liquid fuel to ensure stable combustion. In CSM, the X-DF2.0 engine operates on a predefined ratio of gas to liquid fuel. Gas fuel is admitted by the gas admission valves as per normal gas mode. However, an additional portion of liquid fuel is injected through the main liquid fuel injection system. The total amount of both fuels is controlled by the speed governor, following the same principles as during a gradual transfer from diesel mode to gas mode.

Since engine operation in CSM involves gas as a fuel, the same general safety principles apply as when running in gas mode.

Engine start and reversing are always performed in diesel mode.

An engine equipped with VCR has the same operating modes as an X-DF2.0 engine without VCR.

In the unexpected case of a VCR failure, the engine can continue to operate in diesel mode. In such an event, the piston rod is pushed to the initial (low) position, which means a low CR. The ‘fail-safe design’ ensures that in any failure case, the full propulsion power of the vessels remains available.

Manual transfers between the operating modes and automatic gas trips to diesel mode are described in section 2.5.3 and illustrated in Figure 2-29, Figure 2-30, and Figure 2-31.

If an SCR system is installed, it can only be operated in diesel mode. During gas and/or fuel sharing mode the SCR system is bypassed. Consequently, Tier III compliance cannot be achieved when gas or fuel sharing mode is in operation.

### 2.5.3 The X-DF engine fuel mode transfers and trips

The changeover between operating modes can be categorised in two ways. If the changeover introduces or continues to use gas fuel, it is called a ‘transfer’. If the changeover between operating modes stops the use of gas fuel, therefore defaulting to diesel mode, then the changeover is called a ‘gas trip’ (or just a ‘trip’). Often a gas trip is associated with automatic initiation as part of a system safety procedure, but it can also be intentially initiated by the operator. In comparison to a gas trip, the transfer between operating modes can only happen from operator initiation.

A gas trip always stops the gas fuel operation, and results in diesel mode. The gas trip is completed within half a revolution of the engine and can occur at any engine power and any operating mode where gas fuel is in use. This includes any point of transfer between operating modes. While the engine runs in gas mode, the liquid fuel backup system is always on standby with MGO or MDO. This is different from modes that share fuel, Fuel Sharing Mode (FSM) or Combustion Stability Mode (CSM) above a range of 20% to 30% CMCR engine power, which is backed up by the selected fuel type.

In comparison to a gas trip, a ‘transfer’ between operating modes can only happen from operator initiation.

A transfer includes a changeover between fuel sharing and gas mode (maintaining the use of gas fuel). Also, a transfer can include a changeover from diesel mode to either gas mode or a mode that shares fuel (CSM or FSM), which introduces gas fuel (see Figure 2-29 and Figure 2-31). When introducing gas fuel, the transfer is a gradual changeover as a system safety test must be successfully completed before gas operation can start. If FSM is not contracted, a direct transfer from gas mode to CSM is not available (see Figure 2-30).

A transfer from diesel mode to gas mode is prohibited (and therefore disabled) when the engine is running on HFO. Before changing to gas mode, the engine must stop using HFO and operate with MGO or MDO until the fuel system is fully flushed of HFO. This prevents HFO clogging.

A transfer to a mode which shares gas and liquid fuel is only possible when no gas operation interlock is active and the engine is running at approximately above 26% CMCR engine power for CSM or approximately above 50% CMCR engine power for FSM. The transfer to and the operation within this mode is possible with HFO, MDO and MGO. When the engine power is reduced below the mode operating range, an alarm message is released. If the engine power is not increased within the required time period, a gas trip is initiated.

An engine equipped with VCR has the same operating modes as an X-DF2.0 engine without VCR.

In addition, the VCR[1] fallback diesel mode which is an emergency mode used in the event of a VCR[1] failure. If a VCR[1] failure occurs while the engine is running in gas mode, diesel mode or in iCER diesel Tier III mode[1], an engine trip to the VCR fallback diesel mode[1] is automatically initiated. From the VCR fallback diesel mode[1] a transfer to CSM or FSM [1] can be manually initiated (see Figure 2-30). Similar to the WinGD diesel engines, changing the fuel input from HFO to either MGO or MDO and vice versa can be done at any time (assuming, HFO is permitted in the operating mode) without interruption of the engine operation. The fuel oil changeovers are managed by external systems. Before changing to iCER diesel Tier III mode[1], the engine must be in diesel mode and fully flushed with MGO (with maximum 0.10% m/m sulphur). The iCER system must be ready for operation. It only operates above approximately 20% CMCR engine power.

When the engine operates in diesel mode or in gas mode, upon activation of VCR control all pistons are gradually lifted up until the final elongation of the piston is reached. By the elongation of the piston rods, the compression ratio (CR) increases. With increased compression ratio, fuel savings can be realised.

In gas mode, with increased compression ratio, fuel savings can be realised only if the following conditions are met.

- The engine operates within operational range of VCR.
- At all piston rods the difference between the position set point and current position is within tolerance.
- The VCR system is ready for operation (no major failure of VCR system is active).

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[1] It is an available option in addition to the chosen engine configuration, and not included in the standard configuration. It needs to be contracted.

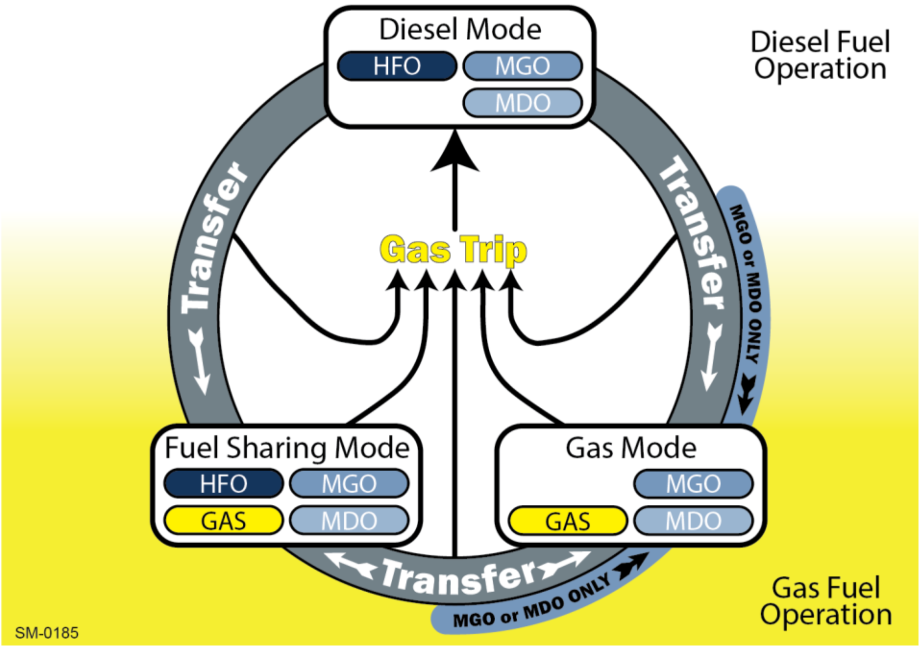


Figure 2-29: Overview of fuel transfers for X-DF engines without iCER

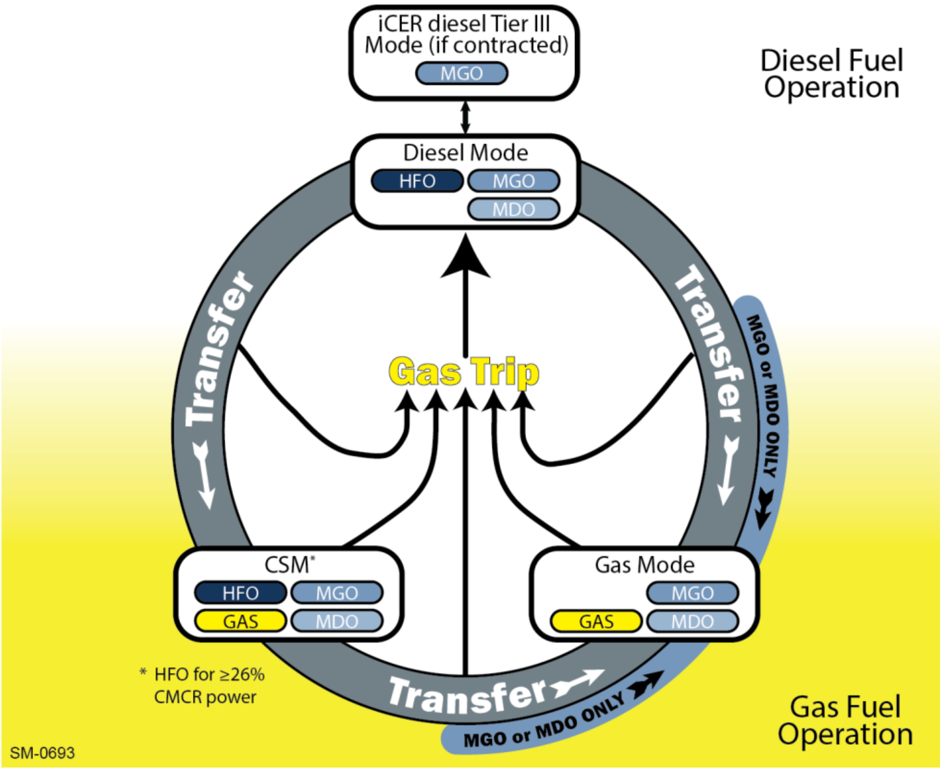
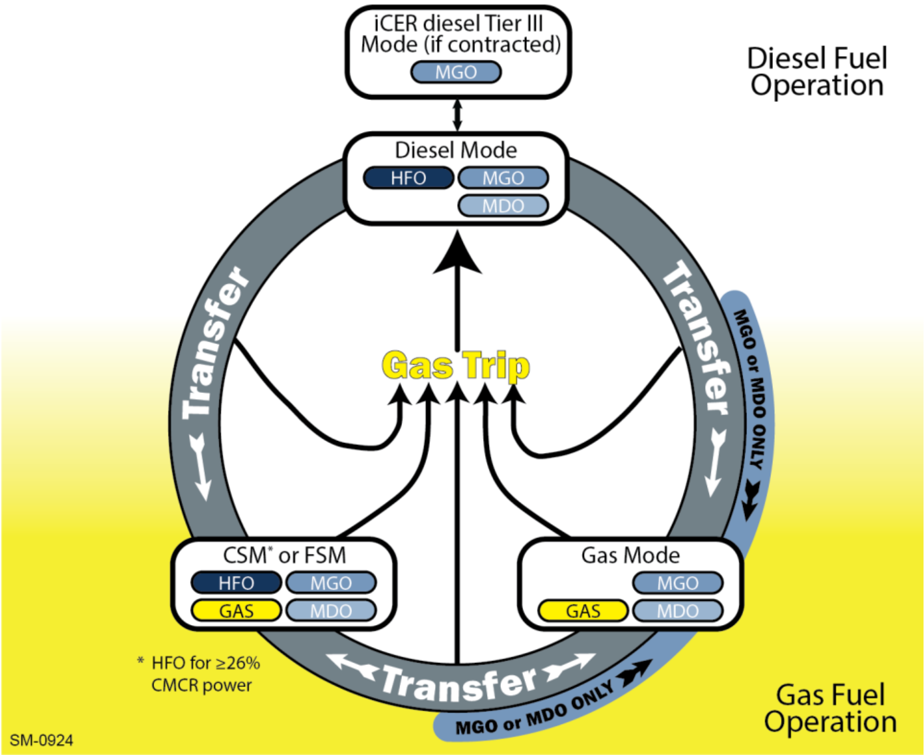
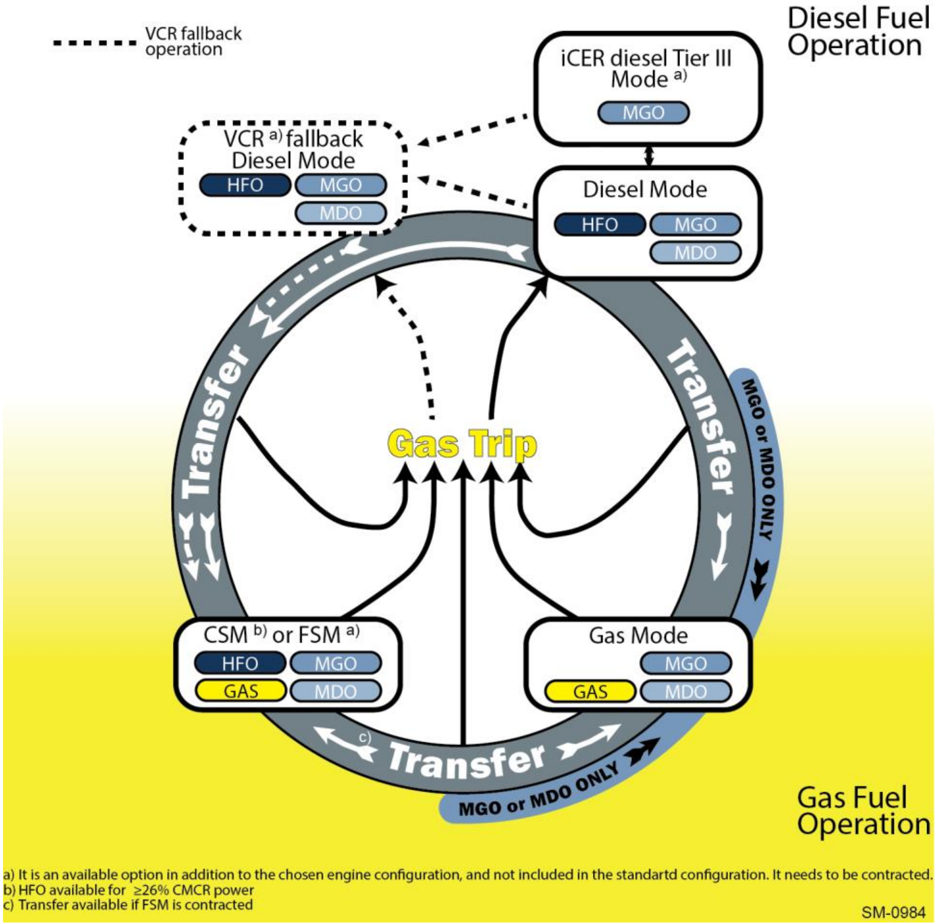


Figure 2-30: Overview of fuel transfers for X-DF2.0 engines where FSM is not contracted



* HFO for ≥26% CMCR power

Figure 2-31: Overview of fuel transfers for X-DF2.0 engines with FSM contracted

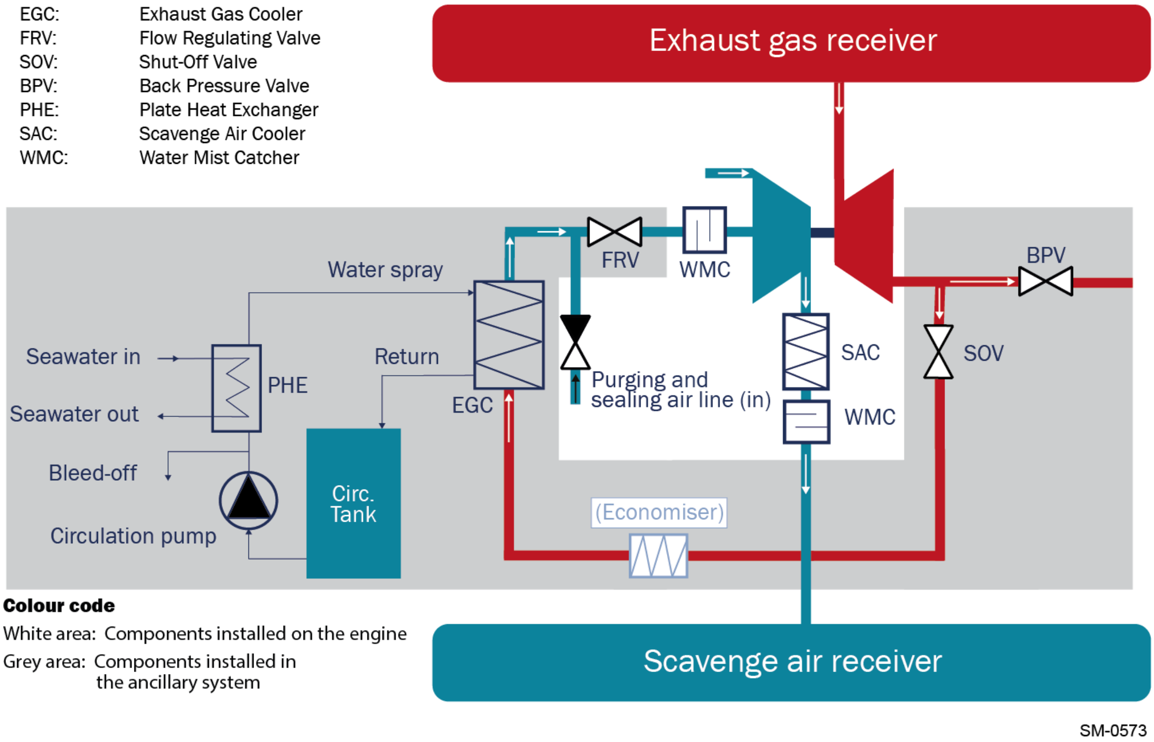


a) It is an available option in addition to the chosen engine configuration, and not included in the standartd configuration. It needs to be contracted.
b) HFO available for ≥26% CMCR power
c) Transfer available if FSM is contracted

Figure 2-32: Overview of fuel transfers for X-DF2.0 engines with VCR technology option

Note:

- Before the operator can request a transfer back to gas or fuel sharing mode, the cause of the gas trip must be investigated, the problem resolved, and the alarm reset.
- Any relative failures or conditions (see section 0) stop the recirlucation of the exhaust gas and deactivate the iCER system. When the iCER system is deactivated, the setting of each of the valves are as listed below (this is to prevent exhaust gas flow through the iCER system):
  - BPV – Open (to release back pressure from the iCER)
  - SOV – Closed (to stop entre of exhaust into the iCER)
  - FRV – Closed (to stop entre of exhaust into the iCER).
- The iCER system comes in different plant layouts which are shown in Figure 2-33, Figure 2-34, Figure 2-35, and Figure 2-36.



| | |
|---|---|
| EGC: | Exhaust Gas Cooler |
| FRV: | Flow Regulating Valve |
| SOV: | Shut-Off Valve |
| BPV: | Back Pressure Valve |
| PHE: | Plate Heat Exchanger |
| SAC: | Scavenge Air Cooler |
| WMC: | Water Mist Catcher |

**Colour code**
White area: Components installed on the engine
Grey area: Components installed in the ancillary system

Figure 2-33: The iCER system (off-engine option) with one turbocharger and the exhaust gas return pipe routed to the turbocharger connection from above

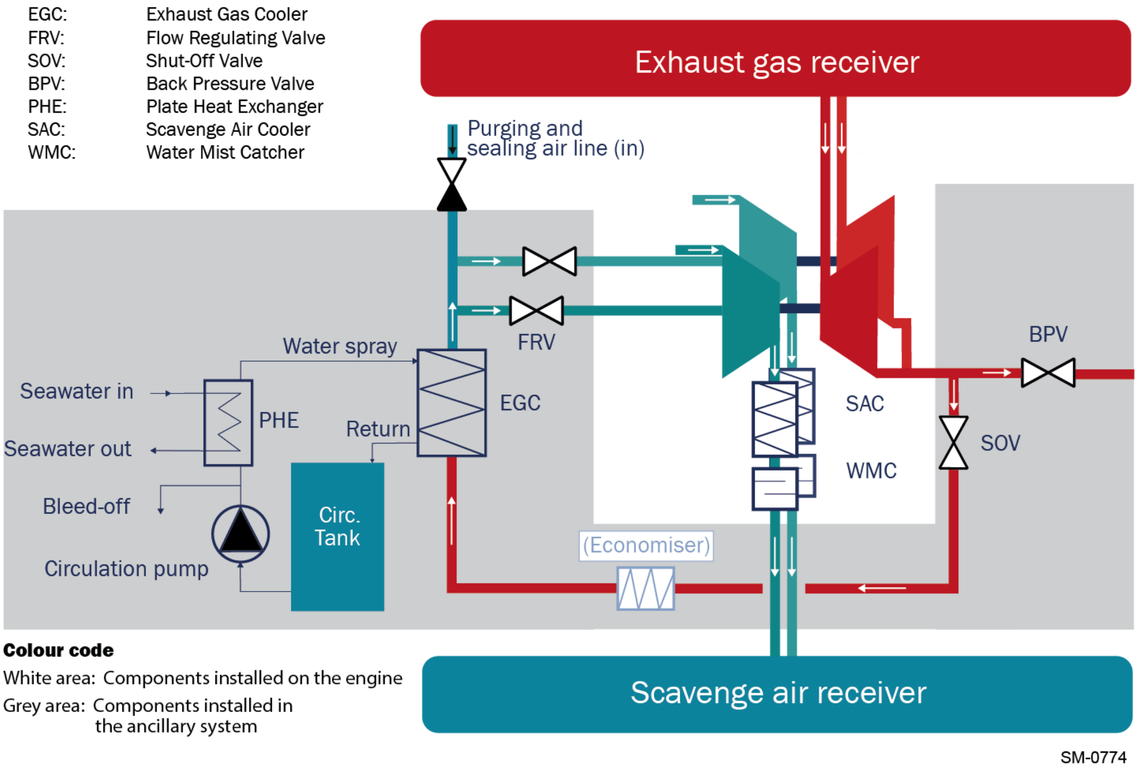


Figure 2-34: The iCER system (off-engine option) with two turbocharger and the exhaust gas return pipe routed to the turbocharger connection from below

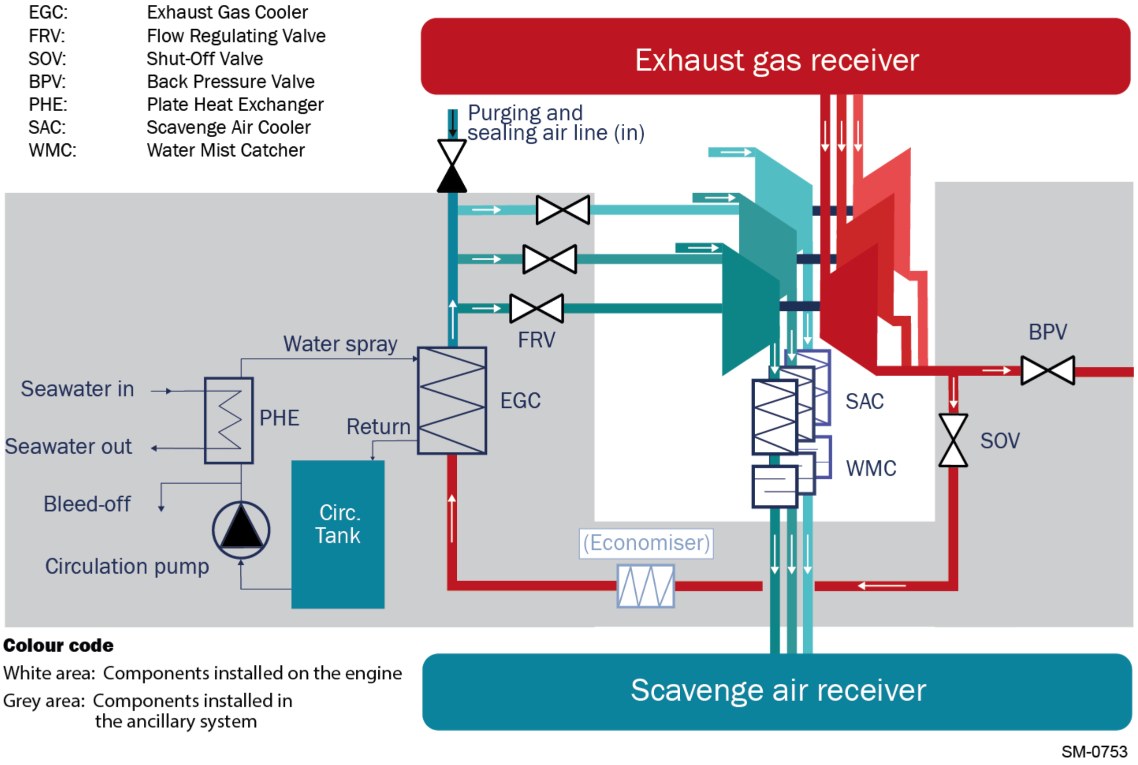
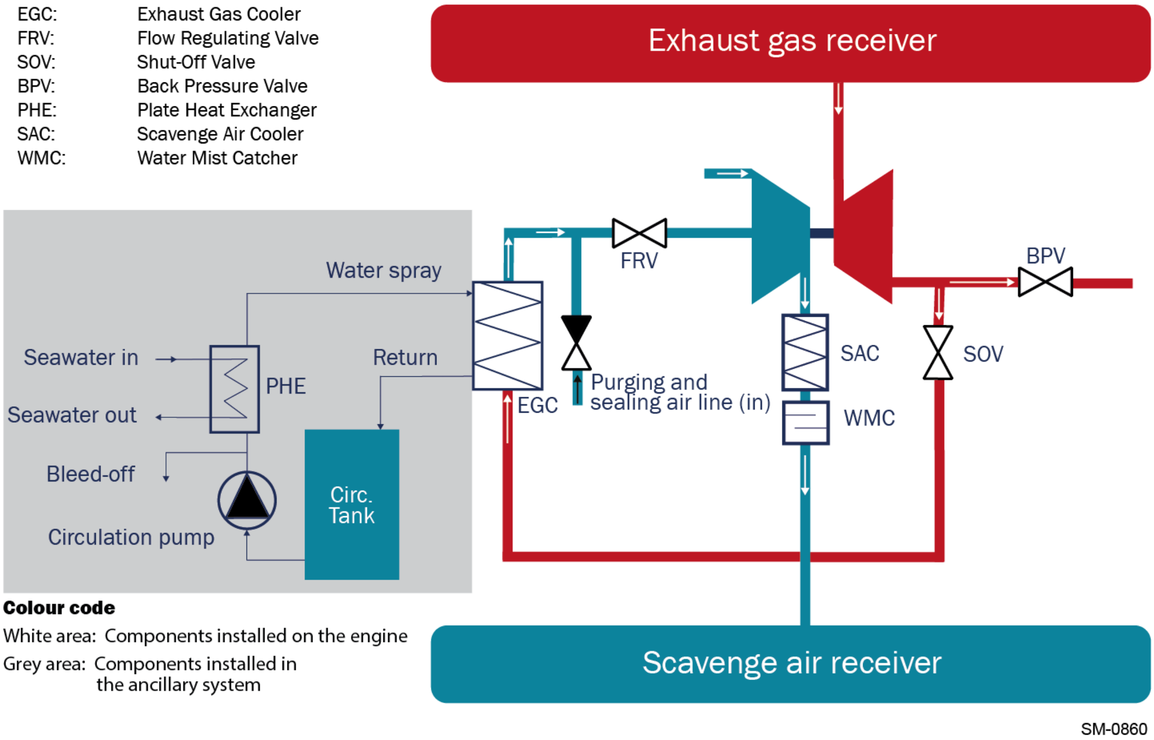


Figure 2-35: The iCER system (off-engine option) with three turbochargers and the exhaust gas return pipe return pipe routed to the turbocharger connection from below



| | |
|---|---|
| EGC: | Exhaust Gas Cooler |
| FRV: | Flow Regulating Valve |
| SOV: | Shut-Off Valve |
| BPV: | Back Pressure Valve |
| PHE: | Plate Heat Exchanger |
| SAC: | Scavenge Air Cooler |
| WMC: | Water Mist Catcher |

**Colour code**

White area: Components installed on the engine

Grey area: Components installed in the ancillary system

Figure 2-36: iCER on-engine system with one turbocharger

## 2.5.4 The X-DF engine internal operating modes

The ECS has several internal states which are called internal modes:

- start mode
- run mode
- stop mode
- slowdown mode
- emergency stop mode
- shutdown mode.

The present document focuses on description of the X-DF engine internal modes when engine is running on gas fuel. Some information on internal modes in diesel mode is also given here. This information is necessary to understand the gas safety features, e.g. in a transfer or blackout situation.

### 2.5.4.1 Engine starting

Engine can only be started in diesel mode. No start block can be active to perform an engine start. Engine start can only be attempted when engine is stopped and ready for start.

Prolonged starting sequence, when the engine is turned minimum 1 revolution by air, is applied after regular stop in gas mode and after ventilation request. This is to ensure that all cylinders are free of gas fuel before the fuel injection is activated.

### 2.5.4.2 Engine running

Engine running in diesel mode is entered after start mode. Engine is running when speed is above a preset speed limit, and no stop, shutdown or emergency stop is active. Gas mode is activated if transfer from diesel mode to gas mode is successfully performed.

Engine run mode can be interrupted by the following internal modes:

- stop mode
- slowdown mode
- shutdown mode
- emergency stop mode.

Gas mode can be interrupted in case of gas trip.

### 2.5.4.3 Engine stop from gas operation

In case of a normal stop request in gas mode, i.e. the engine speed is above minimum speed for gas operation, the engine control system changes its internal mode into stop mode. Immediately after the engine stop signal is activated in gas mode, gas shut-off and venting is performed (the gas fuel is depressurised and vented). The gas admission is de-activated. Pilot fuel injectors are operating longer than the gas admission valves to ensure that all gas fuel in the cylinder liners is burned. Stop sequence is presented in the following graph.

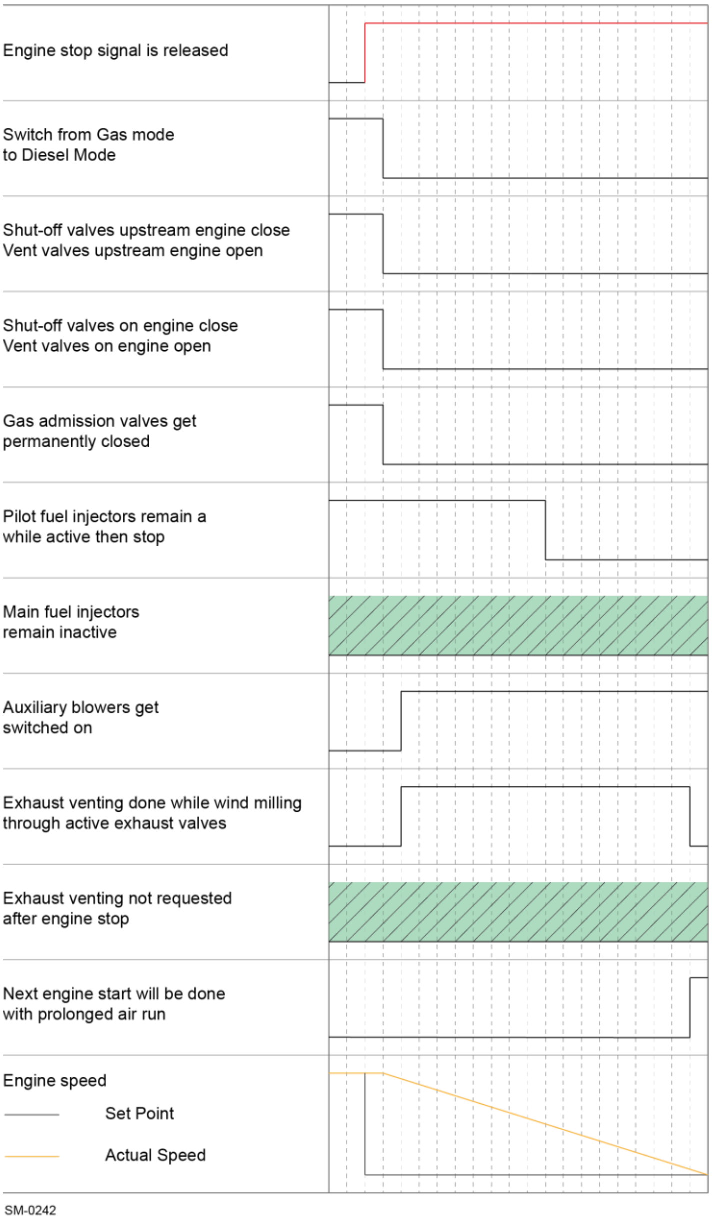


Figure 2-37: Gas mode event sequence. Engine stop

### 2.5.4.4 Engine shutdown from gas operation

Shutdown mode is initiated automatically as response to measurement signals. In case of cancellable shutdown, the operating mode is changed to diesel mode and the engine continues running as long as the SHD signal does not become active (operator can cancel SHD and continue running in diesel mode). Exhaust gas ventilation is not required in this situation.

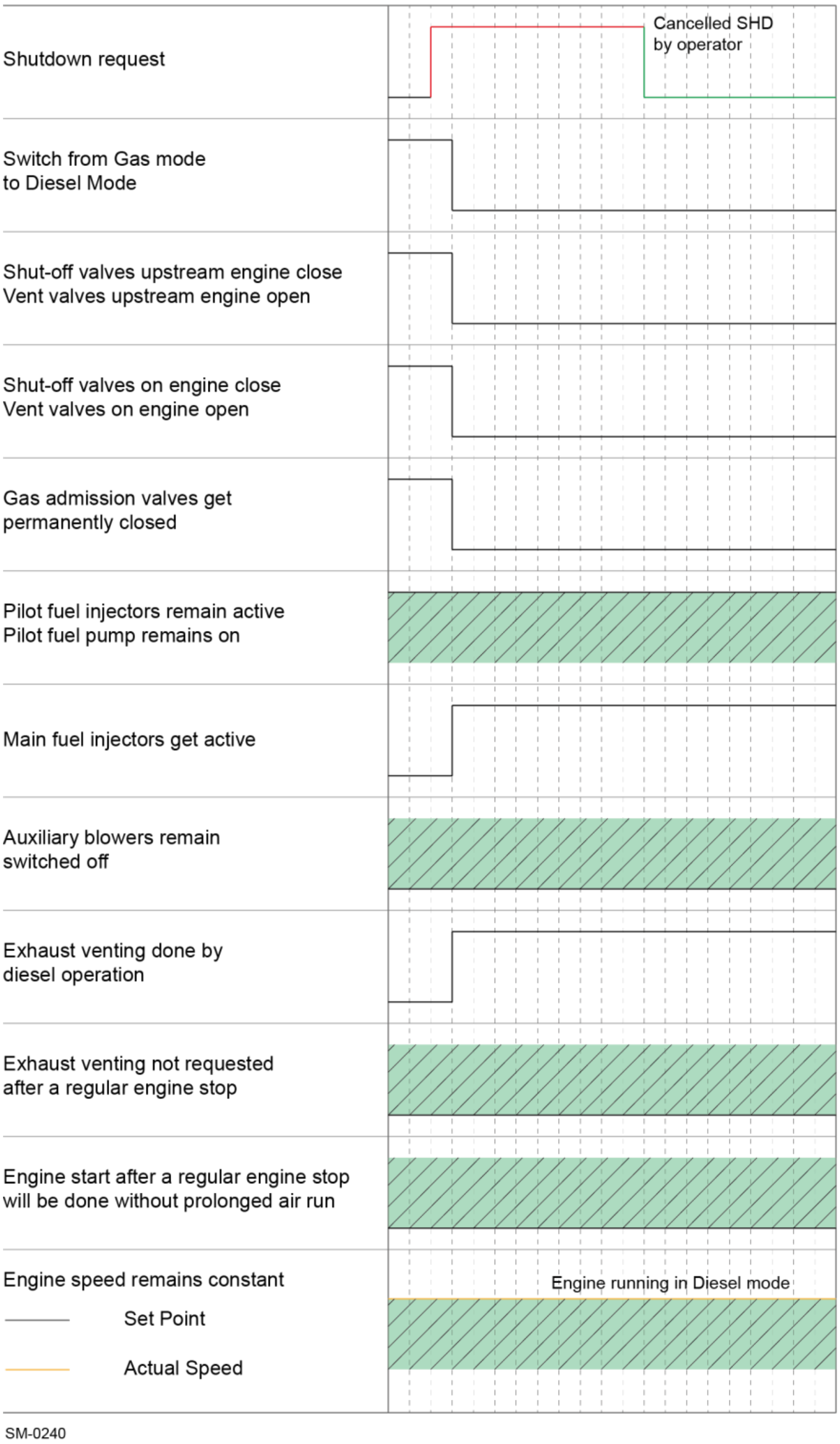


Figure 2-38: Gas mode event sequence. Cancellable shutdown

If non-cancellable shutdown occurs from gas or fuel sharing mode (i.e. engine overspeed or critical failure), exhaust gas ventilation is required. Defined shutdown failure states are given in the Marine Installation Manual (MIM). Shutdown mode must be reset by the operator and the root cause for shutdown must be investigated and corrected before re-start.

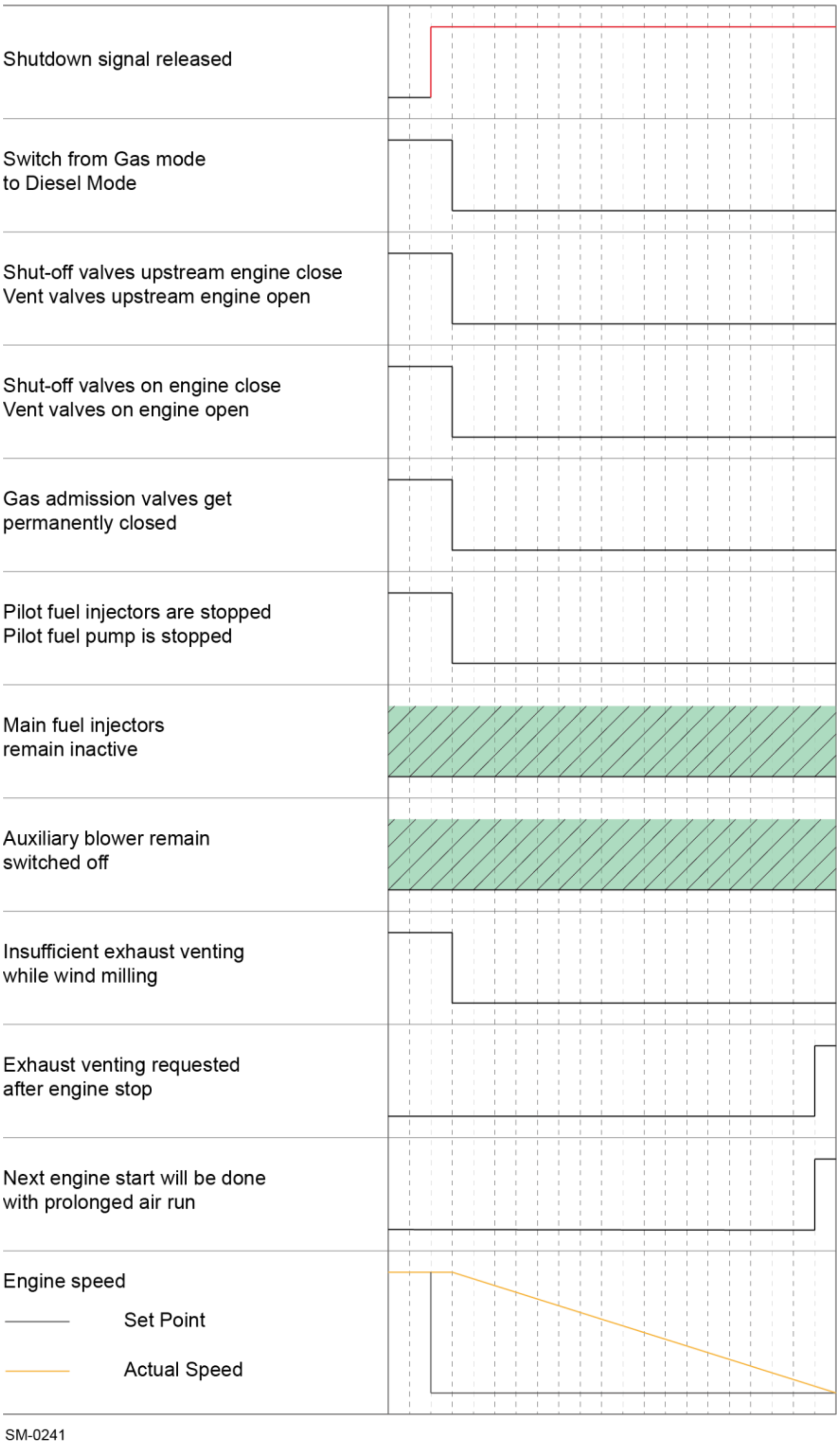


Figure 2-39: Gas mode event sequence. Non-cancellable shutdown and emergency stop

### Emergency stop from gas operation

Emergency stop mode is activated manually by pressing the emergency stop push-button. Emergency stop is the fastest way to manually shut down the engine. To return to normal operation the push-button must be pulled out and alarms acknowledged.

The emergency stop sequence is identical to the non-cancellable shutdown sequence and shown in Figure 2-39.

### Transfer from diesel mode to gas mode

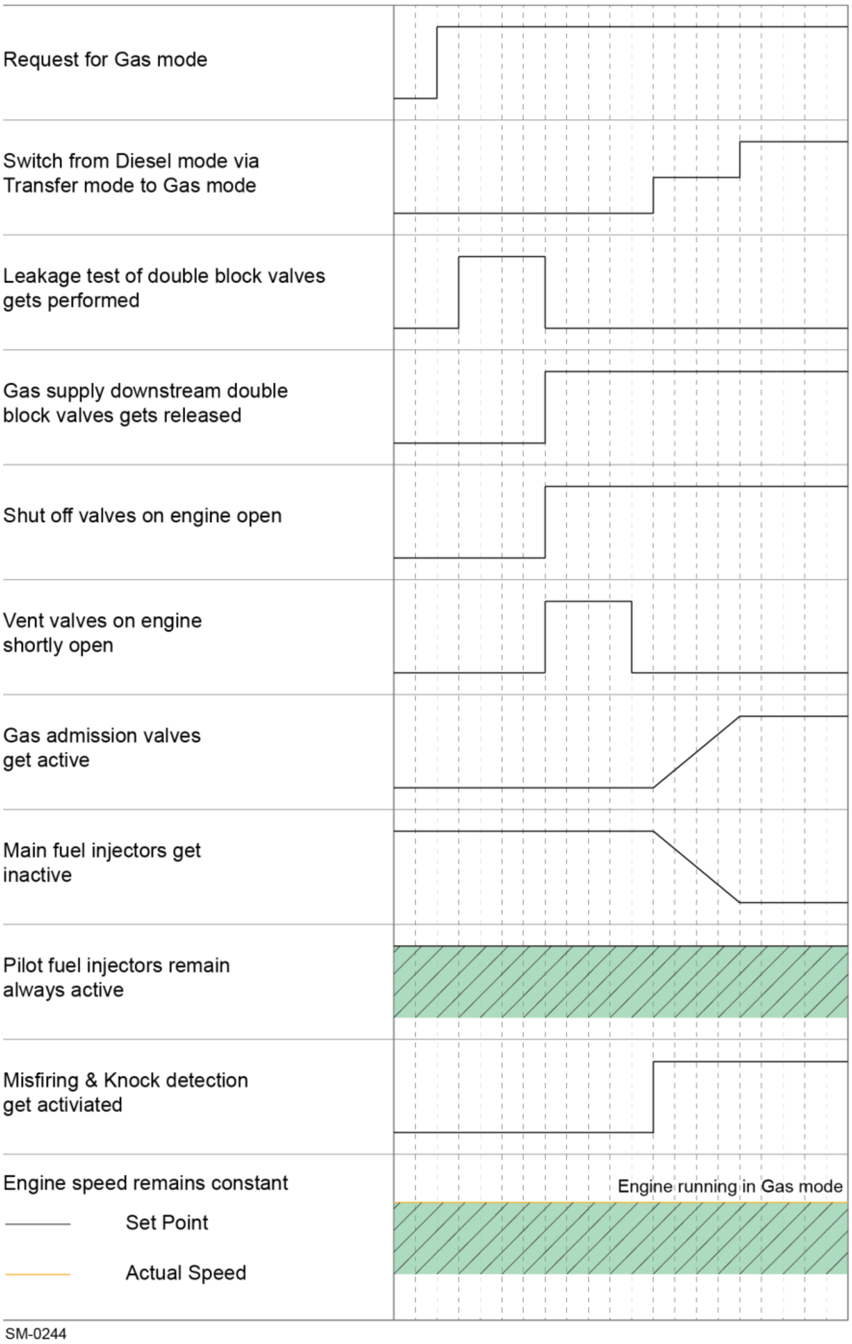


Figure 2-40: Gas mode event sequence. Transfer from diesel mode to gas mode

### Transfer from gas mode to diesel mode (gas trip)

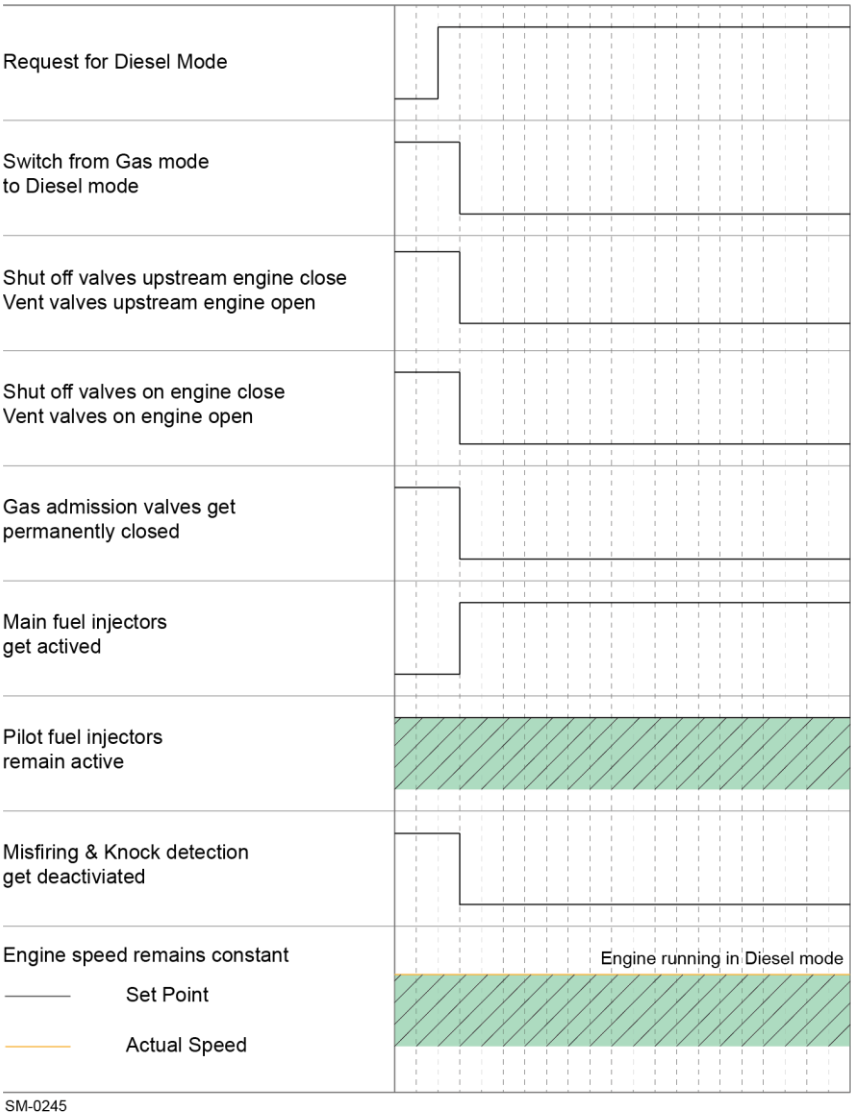


Figure 2-41: Gas mode event sequence. Transfer from gas mode to diesel mode

# 3 Arrangement and safety of machinery spaces

Engine room design, arrangement and location, as well as equipment and systems installed varies depending on specific ship installation, but the main principles concerning gas safety and redundancy must follow the minimum requirements stated in this chapter.

## 3.1 Engine room arrangement

With double-walled fuel gas pipe configuration, the engine room is considered a gas safe area according to IGC Code 1.3.17.10, 1.3.18 and IGF.

Permanent gas detectors are installed in the engine room.

There are no special requirements as to the location of auxiliary systems in the room. The automatic gas fuel shut-off valve must be installed outside the engine room.

External fuel gas piping to the engine room led through enclosed spaces need to be equipped with ventilation and gas detection as per IMO regulation.

## 3.2 Safety of electrical equipment in engine room

Engine rooms of X-DF engines on seagoing vessels are considered gas-safe according to IGC and IGF codes. Therefore, electrical equipment inside the engine room does not need to be certified ex-proof apparatus. For further information on sensors in hazardous areas, see section 0.

## 3.3 Ventilation of engine room

Engine room ventilation must be forced (IGC code 16.2.1 and IGF code). This means, no difference in comparison to normal engine room ventilation via engine room ventilation fans. The engine can suck combustion air directly from outside with a dedicated duct (option). Ventilation should be particularly effective in the vicinity of all electrical equipment and prevent the formation of ‘dead spaces’ in accordance with IGC Code regulations.

## 3.4 Breathing / venting arrangement of certain X-DF engine systems

### 3.4.1 General description

In the hazardous areas, as shown in Figure 3-2, small volumes of gas fuel can require venting to a gase-safe area outside of the engine room, and away from any sources of ignition. A gas hazard zone includes any area around the location of a vent outlet. These outlets can be located in the funnel, provided that the distance to any source of ignition (such as the exhaust gas outlet of the engines, oil-fired boiler, incinerator, gas combustion unit, inert gas generator, etc.) is at least the minimum distance required by the rules of the classification society in charge of the installation.

Vent outlets and vent pipe discharges that can contain gas fuel need to be located away from vent inlets. As an alternative to venting the gas fuel to the outside, into the atmosphere, the gas fuel can instead also be directed to an incinerator. However, such arrangements must be accepted by the classification society case-specifically.

All breathing and vent pipes that can contain gas fuel must be built continuously sloping upwards, so that there is no possibility of gas fuel accumulating inside the piping.

These pipes have an open end at atmospheric pressure. Under all normal operation conditions, there is no pressured gas fuel concentration in these pipes. Consequently, the probability of any leakage of natural gas from these pipes is very low, especially in any significant concentration of pressured gas fuel, and therefore these pipes can be single-walled pipes.

### 3.4.2 Gas pipe venting

At the end of gas operation, when the engine stops or changes to diesel mode, the fuel gas piping on the engine is depressurised. If the gas fuel pressure on the engine side is too high during transient operation, the vent valves are opened for very short periods to reduce the gas fuel pressure. Before transfer from diesel mode to gas or fuel sharing mode, the engine fuel gas supply pipes are filled with natural gas (flushing).

At the end of operation in gas mode and/or if the gas fuel pressure on the engine side is too high, gas fuel and/or inert gas is released through the vent valves to a gas-safe area ouside of the engine room. The driving end and free end vent lines of one engine can be combined to one common pipe, provided that the common pipe diameter is increased accordingly. However, vent lines from the fuel gas supply manifold of different engines must not be interconnected to a common outlet.

The ends of vent pipes must be equipped with flame arresters.

### 3.4.3 Ventilation of fuel gas supply piping annular space

#### 3.4.3.1 If the GVU is installed:

Layout
For the annular space ventilation layout, please refer to section 2.2.4.

Actions upon ventilation failure of double-walled fuel gas supply piping
The negative ventilation air pressure in the annular space is monitored by the GVU-ED™. A possible loss of negative pressure (Δp) causes a gas shutdown to the GVU enclosure, and the GVU control system automatically triggers a trip to diesel mode.

#### 3.4.3.2 If the iGPR is installed

Layout
For the annular space ventilation layout, please refer to section 2.2.7.

Actions upon ventilation failure of double-walled fuel gas supply piping
The negative ventilation air pressure in the annular space is monitored by the ECS (the analogue pressure sensor) and the ESS monitors the air flow in (of the double-walled pipe). A possible loss of negative pressure (Δp) or air flow automatically triggers a trip to diesel mode.

### 3.4.4 Cooling water system venting

The 2-stroke crosshead engine has a High-Temperature (HT) and a Low-Temperature (LT) cooling water system. In case of component failure (such as a crack in either the liner, the exhaust gas valve cage or the pilot fuel pre-chamber), the HT cooling water system can be contaminated with gas fuel. This gas fuel could end up in the cooling water expansion tank. Therefore, the cooling water expansion tank must be a closed type.

Ventilation of the HT expansion tank is affected by a vent pipe which leads to a safe place outside of the engine room. This prevents any gas fuel release into the funnel or engine room. Some classification societies can also require a HydroCarbon (HC) sensor in the HT expansion tank. For the LT cooling water system, it is not required, because the water does not have direct contact with the gas fuel.

If a combined HT and LT cooling water system is installed and/or if gas fuel-driven auxilaries are connected to the LT circuit, the LT expansion tank must have the same arrangement as the HT expansion tank.

Any instrumentation installed in the cooling water expansion tank must be certified as an ex-proof apparatus.

## 3.5 Gas detection in the X-DF engine room, the fuel gas supply system and the X-DF engine

### 3.5.1 If the GVU is installed

Gas detectors must be installed at the following locations:

- on the ship side, in the GVU air ventilation outlet (extraction fan) line, for detecting any leakage of the fuel gas pipes and fuel gas equipment in the double-walled pipe installation and the GVU (in the shipyard’s scope of supply)
- in the annular space of the fuel gas supply line between the GVU and engine gas inlet
- on the engine side, located at the piston underside and just before the gas monitoring outlet connection, a gas detector must be installed for detecting any leakage of the gas fuel in this area (in the engine builder’s scope of supply).

According to IGF and IGC codes the following sensors are required:

- In case if a GVU-ED™ is installed, the engine room requires a minimum of two separate HC gas detectors (see Figure 3-1):
  - one gas detector above the engine
  - one gas detector above the GVU.
- If a GVU-OD™ is installed, minimum one HC gas detector must be installed in the engine room.

However, any additional requirements by classification society, IGF and IGC codes, must be followed. In individual cases, deviations from the above precautions for detection of gas leakages can be approved by the classification society, based on prior acceptance from the responsible flag state.

All gas detector signals are connected to the external Gas Detection System (GDS), except for the gas detector located at the piston underside, which is directly connected to the ECS. Depending on the ship arrangement and requirements of IMO and classification society, the central alarm can be in one or more of the following locations:

- bridge
- cargo control room (LNG carrier)
- engine control room.

The gas detectors need to be approved by the classification society. If the detected gas fuel concentration has increased above the class specified limit, an audible and a visible alarm is initiated in the rooms. The GDS must be tested and calibrated according to the maintenance schedule and procedure as advised by the manufacturer or classification society.

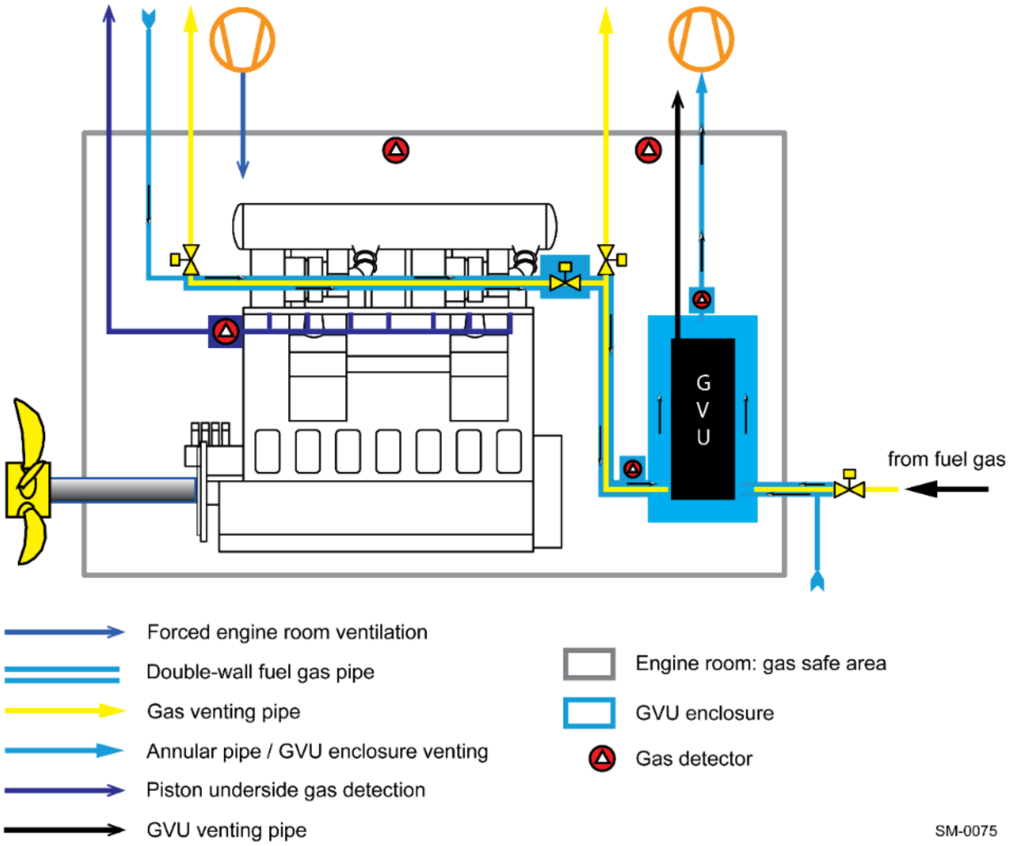


Figure 3-1: Example of gas detector position in the engine room, the gas supply system and the engine with GVU

The piston underside gas detection is ensured by a gas detector which is installed in the piston underside air sampling line. The gas detector is directly connected to the ECS. The whole piston underside gas detection arrangement, including the gas detector, is delivered by the engine maker. If gas fuel is detected in the piston underside area, the engine automatically trips to diesel mode.

The number and position of additional gas detectors in the shipyard's scope of supply must be defined according to the classification society, IGF Code and IGC Code (see Figure 3-1). All spaces and volumes, where gas fuel could accumulate, must be monitored, including the HT expansion tank.

If gas fuel is detected by the external GDS, the engine automatically trips to diesel mode and the pipes between the GVU and engine is purged with inert gas. Further measures on the vessel must be taken as defined by the shipyard and classification society.

### 3.5.2 If the iGPR is installed

Gas detectors must be installed at the following locations:

- At a maximum distance of 2 m from the engine fuel gas inlet (in the shipyard's scope of supply)
- In case if the gas detector with maximum 2 m distance to the engine fuel gas inlet cannot be integrated in the T-piece to the extraction fan, then an additional gas detector must be installed in the extraction line (in the shipyard's scope of supply)
- On the engine side, located at the piston underside and just before the gas monitoring outlet connection, a gas detector needs to be installed for detecting any leakage of the gas fuel in this area (in the engine builder's scope of supply)

A minimum of two separate HC gas detectors are required above the engine:

- One gas detector above the engine (in the shipyard's scope of supply)
- One gas detector above the iGPR (in the shipyard's scope of supply)

However, any additional requirements by the classification society, IGF and IGC codes, must be followed. In individual cases, deviations from the above precautions for detection of gas leakages can be approved by the classification society.

All gas detector signals are connected to the external GDS, except for the gas detector located at the piston underside, which is directly connected to the ECS. Depending on the ship arrangement and requirements of the IMO and classification society, the central alarm can be in one or more of the following locations:

- bridge
- cargo control room (LNG carrier)
- engine control room.

The gas detectors need to be approved by the classification society. If the detected gas fuel concentration has increased above the class specified limit, an audible and a visible alarm is initiated in the rooms. The GDS must be tested and calibrated according to the maintenance schedule and procedure as advised by the manufacturer or classification society.

The piston underside gas detection is ensured by a gas detector which is installed in the piston underside air sampling line. The gas detector is directly connected to the ECS. The piston underside gas detection arrangement including the gas detector is delivered by the engine maker. If gas fuel is detected in the piston underside area, the engine automatically trips to diesel mode. The number and position of additional gas detectors in the shipyard's scope of supply must be defined according to the classification society, IGF Code and IGC Code (see Figure 2-13). All spaces and volumes, where gas fuel could accumulate, must be monitored, including the HT expansion tank.

In case of gas detection by the external GDS, the engine automatically trips to diesel mode and the entire system is purged with inert gas. This includes the piping in between the master gas fuel engine valve and the engine fuel gas rail pipe. Then the inert gas is released through the open vent valves. Further measures on the vessel must be taken as defined by shipyard and classification society. In case of gas detection, any required additional procedures need to be defined by the shipyard and classification society.

### 3.5.3 Gas detection in the crankcase, sumps, scavenge spaces and cooling system vents

Although the IGC code 16.7.3.3 states that the crankcase, sumps, scavenge spaces and cooling system vents must be provided with gas detectors, this is not fully applicable to the WinGD X-DF engines.

Currently, the IGC code does not specify separate requirements for different engine designs (i.e. trunk piston or crosshead engines) nor for different cycles (i.e. 2- and 4-stroke, Diesel and Otto cycle). However, the IGF code 10.3.1.2 does recognise the difference between engine types and it states that the evaluation varies "for engines where the space below the piston is in direct communication with the crankcase …". Consequently, the classes have accepted, through analysis and assessment, that the architectural features of the X-DF engines provide the equivalent requirement for IGC code 16.7.3.3 and an equivalent level of safety. For these reasons, upon the prior acceptance of the responsible flag state, the absence of a gas detector in the crankcase is acceptable.

The WinGD standard design includes venting of the sumps and cooling system vents to a safe area outside of the engine room. Therefore, gas detectors in the above systems are only referred to as optional. The final above system layout(s) depend(s) on the acceptance of the responsible flag state and/or the classification society to achieve IGC compliance.

For all relevant information regarding 'Mandatory' and 'Optional' requirements for gas detector installation, please refer to the *'Gas Fuel System'* MIDS package which is available on the WinGD webpage www.wingd.com/.

Finally, the gas detectors must be installed in compliance with the requirements of the responsible classification society and/or flag state.

## 3.6 Definition of hazardous areas

Protection and certification requirements for components used in explosion hazardous areas are defined based on explosion hazard zones in which they are used. Definitions of hazardous areas according to IEC 60092-502:1999 (used as reference in IGC and IGF Codes) are:

- Hazard Zone 0 (Z0): area in which an explosive gas fuel atmosphere is present continuously or is present for long periods
- Hazard Zone 1 (Z1): area in which an explosive gas fuel atmosphere is likely to occur in normal operation
- Hazard Zone 2 (Z2): area in which an explosive gas fuel atmosphere is not likely to occur in normal operation and, if it does occur, is likely to do so only infrequently and will exist for a short period only.

The engine room and engine crankcase are considered as gas-safe, non-hazardous areas and, therefore, do not refer to the above hazard zone definitions.

The following figures (Figure 3-2, Figure 3-3, and Figure 3-4) show explosion hazard zones:

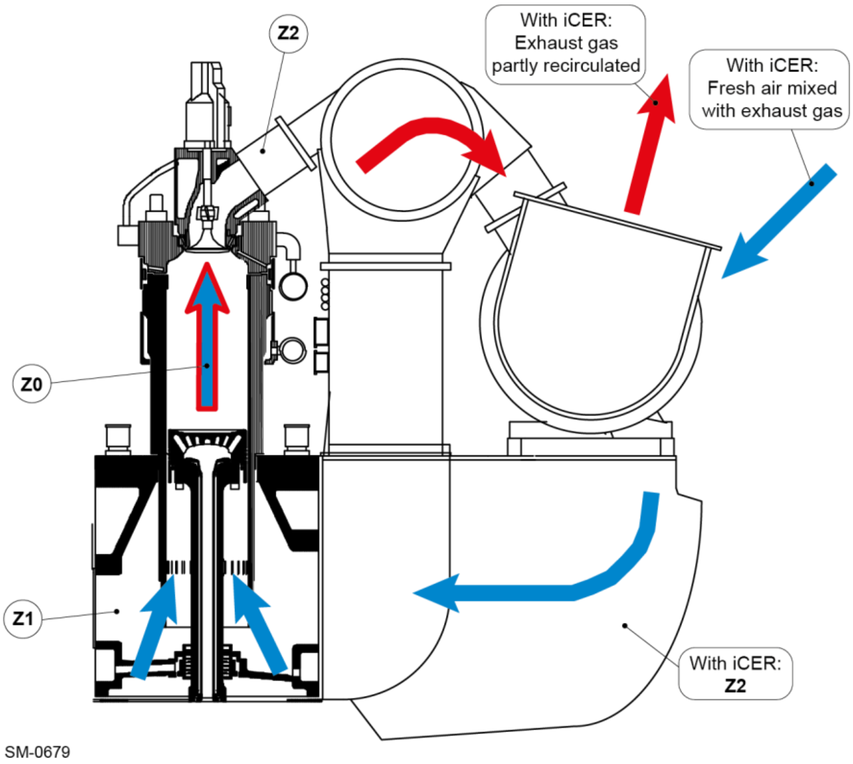


Figure 3-2: Cylinder unit and piston underside (hazard zones)

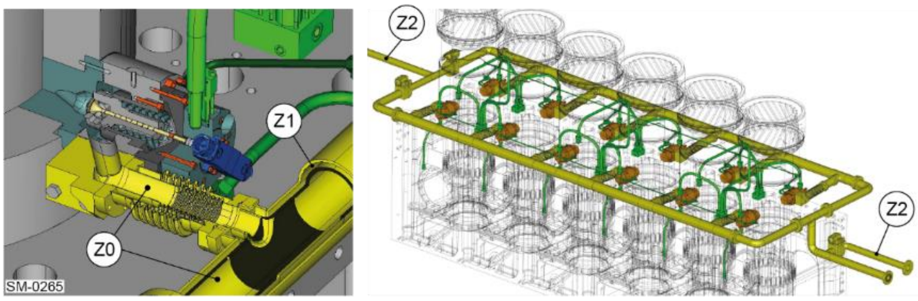


Figure 3-3: Fuel gas system (hazard zones)

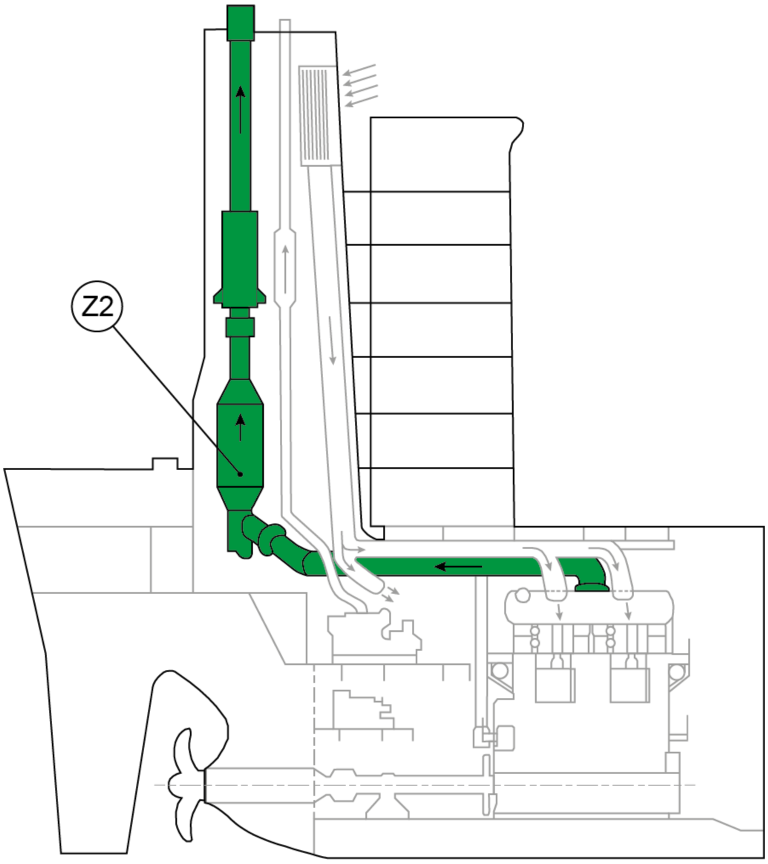


Figure 3-4: External exhaust gas system (hazard zone)

### 3.6.1 Electrical equipment in hazardous areas

### 3.6.1.1 The X-DF engine with the GVU installation

On the X-DF engine that is fed by an external GVU, only the fuel gas pipe pressure sensors PT3595C and PT3597C are installed in a way, that they measure in Hazard Zone 0 and that the electrical part is in Hazard Zone 1. The intrinsically safe sensors are connected via Zener barriers to the ECS.

### 3.6.1.2 The X-DF engine with the iGPR installation

These intrinsically safe sensors and switches of the X-DF engine and the iGPR measure in Hazard Zone 0 and the electrical part is in Hazard Zone 1:

| | |
|---|---|
| PS3901S | Gas Pressure iGPR Inlet High |
| PS3902S | Gas Pressure iGPR Inlet Low |
| PT3941C | Gas Pressure after gas filter |
| PT3595C | Gas Pressure Fuel Side |
| PT3597C | Gas Pressure Exhaust Side |
| PT3901C | Gas Pressure iGPR Inlet |
| PT3906C | Gas Pressure between DBB valves |

## 3.7 Actions to be taken in case of a fire in the engine room

The ESS provides the possibility to be connected to the fire detection system. If this possibility is selected and a fire occurs, then the ESS triggers a gas trip and start the purging procedure (section 2.2.7.4).

# 4 Twin-engine propulsion

For certain applications, the twin-engine propulsion can be applied. Specific requirements and rules of the classification society in charge must be taken into consideration, especially, but not limited to what is stated in this chapter.

## 4.1 Shaft locking device

On twin-engine operated vessels, a shaft locking device must be installed on each propeller shaft. This allows individual shaft lines to be locked during maintenance and engine shutdowns. During sailing this device prevents the stopped engine from turning by the windmilling effect. Engine start interlock and turning gear interlock are applied when the shaft is locked by the shaft locking device.

## 4.2 Exhaust gas system protection

If there is more than one gas-fuelled engine installed, each engine must have its own exhaust gas installation to avoid mixing of the exhaust gases.

## 4.3 Auxiliary systems

The auxiliary systems of each engine must be independent of each other. However, some system combinations for the Low-Temperature (LT) cooling water system and for the cylinder Lubricating Oil (LO) supply are possible according to the following descriptions.

### 4.3.1 LT cooling water system

A shared cooling water system is possible; LT cooling water supply to both engines arranged in parallel.

There is one independent stream per engine to LO cooler and High-Temperature (HT) cooling water cooler.

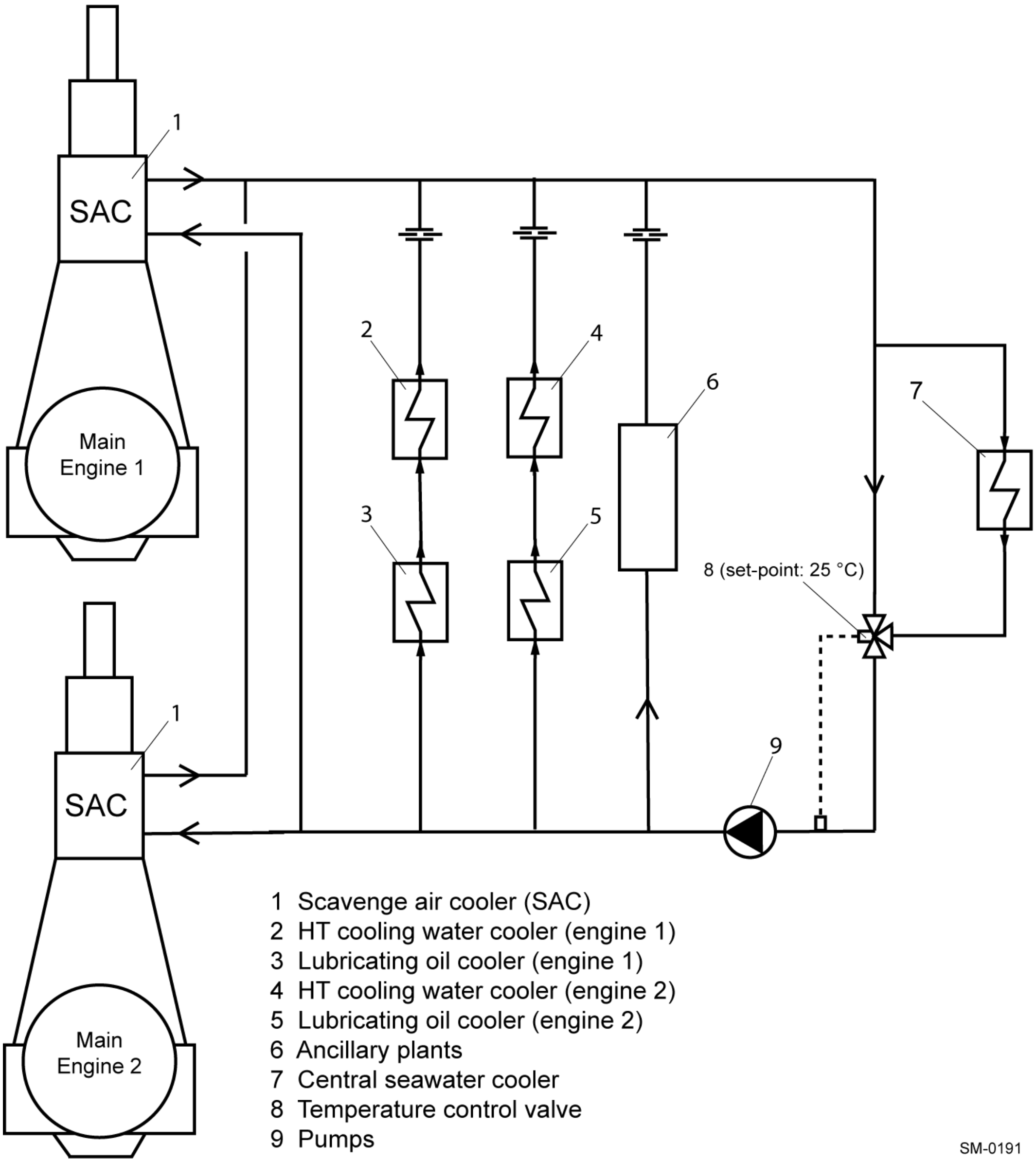


Figure 4-1: LT cooling water system layout for twin-engine installation

### 4.3.2 Cylinder LO system

Cylinder LO system has the following characteristics:

- Shared day tanks for differnet grades of LO are possible.
- A shared rising pipe is possible.
- A separate distribution to each engine is required.

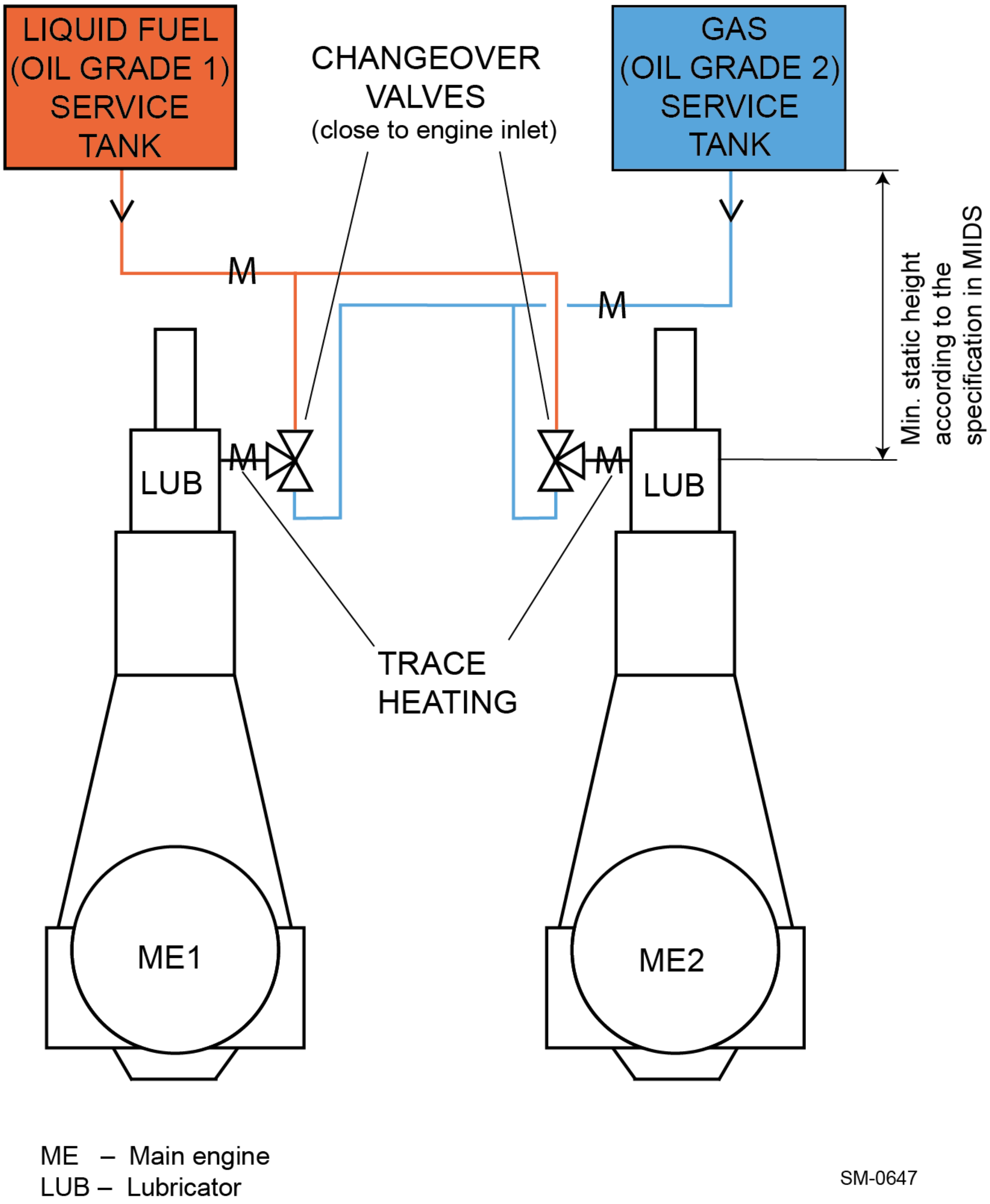


Figure 4-2: Cylinder LO system layout with iCAT for twin-engine installation

# 5 Cause and effect of safety measures

This chapter includes the causes and effects of safety measures with focus on natural gas as fuel.

## 5.1 Key safety measures:

- At any time of gas mode, the X-DF engine is able to change to diesel mode .
- An active gas trip blocks transfer from diesel mode to gas mode and fuel sharing mode.
- A shutdown or emergency stop causes an engine starting interlock in the ECS.
- If the engine is stopped while using gas fuel with emergency shutdown or non-cancellable shutdown (i.e. before re-starting the engine in diesel mode), it is necessary to perform the exhaust gas ventilation sequence using the auxiliary blowers. Due to the system design, the auxiliary blowers are divided from the piston underside with a system border, including flaps allowing only flow from the fresh air side. Therefore, the area where the auxiliary blowers are installed does not need to be classified as an area containing a gas fuel source (as defined in IGF code 13.3.3). Consequently, the auxiliary blowers for the X-DF engines without iCER do not need to be of non-sparking type.
  For the X-DF2.0 technology engines, which include the iCER, the auxiliary blowers must be of the non-sparking type, as per the definition of the international codes. Upon prior acceptance of the responsible flag state and/or classification society, the use of standard auxiliary blowers is acceptable.
- All engine control panels are equipped with an emergency gas trip button.
- The engine starts in diesel mode only.
- Gas mode and fuel sharing mode can only be used when the engine is operating in ahead direction.
- Reversing of the engine can only be done in diesel mode.
- In case of PCS failure, the engine can only be controlled from the Local Display Units (LDUs). Engine operation is only available in diesel mode.

## 5.2 Combustion control and monitoring functions

### 5.2.1 Knock detection

When knocking is detected by the knock detection system on one or more cylinders, the engine automatically trips to diesel mode.

### 5.2.2 Cylinder compression/combustion pressure balancing

When a marked deviation of compression/combustion pressures on a cylinder is detected, the ECS adjusts the exhaust gas valve timing and the amount of gas admission to that cylinder. If there is no response to the gas adjustment within a defined period, the engine automatically trips to diesel mode.

### 5.2.3 Misfiring detection

When misfiring of one or more cylinders is detected for a defined number of cycles, the engine automatically trips to diesel mode.

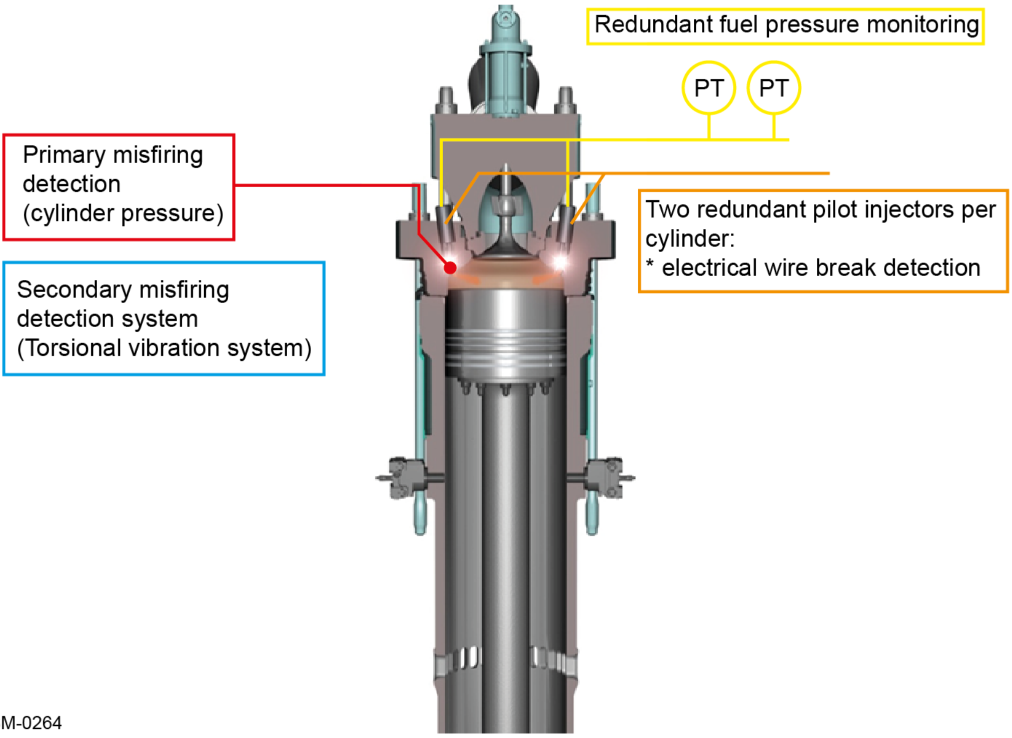


Figure 5-1: Misfiring monitoring concept

## 5.3 Cause and effect chart for engine malfunctions

The following cause and effect chart of safety measures focuses on engine operation in gas mode and fuel sharing mode and on faults affecting gas safety.

Table 5-1: Cause and effect chart in gas mode and fuel sharing mode

| Fault | Detection | Action |
|---|---|---|
| Failure without activating the request for engine load reduction | Explained in Tables 5.2 – 5.10 | GT to diesel mode |
| Failure which initiates engine load reduction – engine slowdown (SLD) in gas mode (no gas trip is activated, however, in fuel sharing mode the load reduction indirectly triggers a gas trip) | | SLD in gas mode |
| Failure which triggers a gas trip to diesel mode and engine load reduction | | GT/SLD in diesel mode |
| Failure which leads to engine shutdown (SHD) | | GT/SHD |
| Emergency stop command | Explained in Table 5-2 | GT/SHD |

## 5.4 Extract of alarm list – only the most critical alarms for gas operation included

The below monitoring tables are grouped per system (ESS, AMS, ECS, iGPR) to which the sensor and actuators are connected. Only important alarms and their related actions of those systems are mentioned, i.e. whose single failure would trigger a Gas Trip (GT), slowdown (SLD) or shutdown (SHD) by the connected system. Double failures are not noted in the following tables of this section. The definition of all alarms and ensuing actions is available in the final engine documentation (MIM and Operation Manual (OM)).

Engine safety is described as interactions between the following systems:

- Engine Safety System (ESS)
- Alarm and Monitoring System (AMS)
- Engine Control System (ECS)
- Gas Valve Unit (GVU) or Integrated Gas Pressure Regulation (iGPR)
- Gas Detection System (GDS).

The following interaction rules are applied:

**Execution of gas trip**

- Fuel gas supply
  - In case of a gas trip being triggered by the ESS, the GVU control unit, or the iGPR control unit, then the fuel gas supply is automatically stopped by the activation of the DBB valves. In addition, under the conditions of the above gas trip being triggered, the shut-off valves on the engine side are closed and the vent valves are opened by the ESS or the iGPR control unit.
  - The ECS closes the gas admission valves.
- Pilot fuel supply
  - The ECS reduces the pilot fuel amount injected.
- Main fuel supply
  - The ECS activates the main injectors and main fuel pumps.
- iCER system (if applicable)
  - The iCER system is deactivated.

**Execution of engine shutdown**

- Fuel gas supply
  - The ESS stops the gas fuel supply by the activation of the DBB valves.
  - In case of an above engine shutdown, the shut-off valves on the engine side is closed and the vent valves opened by the ESS.
  - The ECS closes the gas admission valves.
- Pilot fuel supply
  - The high-pressure pilot fuel pump is stopped by both ESS and ECS.
- Mail fuel supply
  - The ESS depressurises the main fuel rail.
  - The ECS closes the main fuel injectors and sets the fuel pump supply to zero.
- iCER system (if applicable)
  - The iCER system is deactivated. All cooling water supply pumps of the EGC are stopped.

**Execution of engine slowdown**

- Maximum speed and load is reduced. It is executed by the ECS when demanded via the Remote Control System (RCS).

Table 5-2: Sensors and signals connected to ESS. Failure monitoring and actions during operation with gas fuel

| Engine system | Failure | Actions | | | |
|---|---|---|---|---|---|
| | | ALM | SLD | SHD | GT |
| Cylinder cooling water | Cyl. Cool. Water Press. Inlet Eng. Very Low | X | | X | X |
| Main bearing oil | Main Brng. Oil Press. Supply Very Low | X | | X | X |
| Thrust bearing oil | Thrust Brng. Oil Temp. Outl. Very High | X | | X | X |
| Piston cooling oil | No Flow | X | | X | X |
| Oil mist concentration | Oil Mist Conc. in Crankcase Very High | X | X | | |
| Turbocharger oil | Turbochg. N Bearing Oil Press. Inl. Very Low | X | | X | X |
| Air spring air | Exhaust valve Air Spring Air Press. Very Low | X | | X | X |
| Engine overspeed | Engine Speed Very High | X | | X | X |
| Emergency engine stop buttons | Emergency engine stop requested | X | | X | X |
| Emergency gas trip buttons | Emergency gas trip requested | X | | | X*1 |
| Gas Detection System | Gas trip due to Very High Concentration by gas detection system | X | | | X*1 |
| Fire detection system | Gas trip due to fire detection in engine room by fire detection system | X | | | X*1 |
| Fuel gas supply system | Gas trip due to valve position failures by Fuel Gas Supply System | X | | | X*1 |
| Fuel gas supply to the iGPR | Gas fuel Pressure too high or too low | X | | | X |
| | Gas fuel Temperature too high or too low | X | | | X |
| | Air flow within annular space too low | X | | | X*1 |
| iGPR system | Gas trip by the iGPR system (see Table 5-5) | X | | | X |
| GVU system | Gas trip by the GVU system (see the supplier documentation) | X | | | X |
| iCER system (if applicable) | Gas trip by the iCER system (see Table 5-6 and Table 5-8) | X | | | X |
| Engine control system | Gas trip by ECS (see Table 5-4: Sensors and signals connected to ECS (part 1). Failure monitoring and actions during operation with gas fuelTable 5-4, Table 5-5 and Table 5-6 ) | X | | | X |

*1 In addition, these gas trips trigger a request for inerting

Table 5-3: Sensors connected to AMS. Failure monitoring and actions during operation with gas fuel

| Engine system | Failure | Actions | | | |
|---|---|---|---|---|---|
| | | ALM | SLD | SHD | GT |
| Cylinder cooling water | Cyl. Cool. Water Press. Inlet Eng. Low | X | X | | |
| | Cyl. Cool. Water Temp. Outl. Cyl. N High | X | X | | |
| Main bearing oil | Main Brng. Oil Press. Supply Low | X | X | | |
| | Main Brng. Oil Temp. Supply High | X | X | | |
| | Main Brng. Oil Temp. Outl. Brng. N High | X | X | | |
| Thrust bearing oil | Thrust Brng. Oil Temp. Outl. N High | X | X | | |
| Crank bearing oil | Crank Brng. Oil Temp. Outl. High | X | X | | |
| Crosshead bearing | Crosshead Brng. Oil Temp. Outl. N High | X | X | | |
| Oil mist concentration | Oil Mist Conc. in Crankcase High | X | | | |
| | Oil Mist Conc. Fail in Crankcase Unit | X | | | |
| Piston cooling oil | Pist. Cool. Oil Temp. Outl. Cyl N High | X | X | | |
| Turbocharger oil | Turbochg. Bearing Oil Press. Inl. Low TC n | X | X | | |
| | Turbochg. Bearing Oil Temp. Outl. High TC n | X | X | | |
| Air spring air | Air Spring Air Press. Low | X | X | | |
| | Air Spring Air Press. High | X | | | |
| | Air Spring Oil Leakage Level High (exh. v/v) | X | | | |
| Exhaust gas (at TC) | Exh. Gas Temp. before TC #N High | X | X | | |
| | Exh. Gas Temp. after TC #N High | X | X | | |
| Scavenge air | Scav. Air Temp. after Air Cooler #N Low | X | | | |
| | Scav. Air Temp. after Air Cooler #N High | X | X | | |
| | Scav. Air Temp. Pist. Underside Cyl. #N High | X | X | | |
| | Charge Air Condense Water Detection in Air Rec. High | X | X | | |
| | Charge Air Condense Water Drain Detection before Water Sep. #N High | X | X | | |
| Pilot fuel system | Pilot Fuel Filter Diff. Press. High | X | | | |

| **Engine system** | **Failure** | **Actions** | | | |
|---|---|---|---|---|---|
| | | ALM | SLD | SHD | GT |
| iCER system (if applicable) | Alarm by the iCER system (see Table 5-7) | X | | | |

The ALM Minor and ALM Major columns in Table 5-4 refer to the failure groups of the ECS. Major failures of the ECS trigger a load reduction in diesel mode SLD or engine SHD. All other failures of the ECS are tagged as minor failure, including the ones triggering a gas trip (GT).

Table 5-4: Sensors and signals connected to ECS (part 1). Failure monitoring and actions during operation with gas fuel

| **Engine system function** | **Failure** | **Actions** | | | | |
|---|---|---|---|---|---|---|
| | | **ALM Minor** | **ALM Major** | **SLD** | **SHD** | **GT** |
| UNIC-flex modules | Module Fail Diesel CCM #N | | X | X | | X |
| | Module Fail Gas CCM #N | X | | | | X |
| | Module Fail MCM | X | | | | X |
| | Module Fail IOM | X | | | | X |
| UNIC-flex internal communication | System Bus #1 Fail or #2 Fail | X | | | | |
| WiCE modules | Module Fail CCU# N | | X | X | | X |
| | Module Fail MCU#1, 2 | X | | | | X |
| | Module Fail MCU#3 (if applicable) | X | | | | |
| | Module Fail GTU #N | X | | | | X |
| | Module Fail MCP Local or ECR | X | | | | |
| WiCE internal communication | Interruption of Ethernet ring #N | X | | | | |
| Communication to ESS and RCS | Propulsion Bus #N Fail | X | | | | |
| | No connection to propulsion control system | X | | | | X |
| External gas trip | External Gas Trip | X | | | | X |
| Engine speed | Engine Speed Deviation from Reference | X | | | | |
| | Excessive Engine Speed | | X | | X | X |
| External power signal | Engine Load Measurement Fail | X | | | | |
| Load limit | Excessive Engine Load in Gas Mode | X | | | | X |
| Control air | Control Air Pressure Low | X | | | | X |
| Auxiliary Systems | Auxiliary Servo Oil Pump Fail | X | | | | |
| Servo oil pressure | Servo Oil Pressure Measuring Fail #1 or Fail #2 | X | | | | |
| | Servo Oil Pressure Measuring High Difference | X | | | | |
| | Servo Oil Pressure High | X | | | | |
| | Servo Oil Pressure Very Low | | X | X | | |
| Exhaust gas valve control | Exhaust Valve Position Measuring Fail Cyl #N | X | | | | |
| | Exhaust Valve Timing Fail Cyl #N | | X | X | | X |
| Scavenge air pressure | Scavenge Air Pressure Measuring Fail #1 or Fail #2 | X | | | | |
| | Scavenge Air Pressure Measuring High Difference | X | | | | X |
| | Scavenge Air Pressure Very High | | X | X | | X |
| | Exhaust Waste Gate wrong position | X | | | | X |
| | Auxiliary Blower #1 Fail or #2 Fail | X | | | | |
| | TC #N Speed High | X | | | | |
| | TC #N Speed Very High | | X | X | | X |
| Cylinder lubrication control | Cylinder Lubrication Oil Pressure Measuring Fail Cyl #N | | X | X | | |
| | Cylinder Lubrication Oil Injection Pressure High Cyl #N | | X | X | | |
| | Cylinder Lubrication Oil Injection Pressure Low Cyl #N | | X | X | | |
| | Wrong Cylinder Oil in Use | X | | | | |
| Cylinder balancing | Cylinder Pressure Measuring Fail Cyl #N (max load limitation) | X | | | | |
| | Cylinder Peak Pressure Very High Cyl #N | X | | | | X |
| Knock detection | Knock Sensor Fail Cyl #N | X | | | | |
| | Both Knock Detection Systems Fail Cyl #N | X | | | | X |
| | Heavy Knock Cyl #N | X | | | | X |

Table 5-5: Sensors and signals connected to ECS (part 2). Failure monitoring and actions during operation with gas fuel

| Engine system function | Failure | Actions | | | | |
|---|---|---|---|---|---|---|
| | | ALM Minor | ALM Major | SLD | SHD | GT |
| Misfiring | Misfiring Cyl #N | X | | | | X |
| | Misfiring Detection by Press. Sensor Fail Cyl #N | X | | | | |
| | Misfiring Detection by TVM Fail | X | | | | X*3 |
| Pilot fuel injection | Pilot Fuel Injector 1 Open/Short Circuit Cyl #N | X | | | | *2 |
| | Pilot Fuel Injector 2 Open/Short Circuit Cyl #N | X | | | | *2 |
| | Pilot Fuel Injector 1 and 2 Open/Short Circuit Cyl #N | X | | | | X |
| Pilot fuel oil pressure control | Pilot Fuel Pump Control Signal Failure | X | | | | X |
| | Pilot Fuel Inlet Pressure Measurement Fail | X | | | | *1 |
| | Pilot Fuel Inlet Pressure Low | X | | | | *1 |
| | Pilot Fuel Inlet Temperature Measurement Fail | X | | | | X |
| | Pilot Fuel Inlet Temperature High | X | | | | X |
| | Pilot Fuel Rail Pressure Very Low | X | | | | X |
| | Pilot Fuel Rail Pressure High | X | | | | |
| | Pilot Fuel Rail Pressure Measuring High Difference | X | | | | X |
| | Pilot Fuel Rail Pressure Measurement Fail #1 or #2 | X | | | | |
| Exhaust gas (after cylinder) | Exh. Gas Temp. after Cyl. #N High | X | | | | |
| | Exh. Gas Temp. after Cyl. #N Very High | X | X | | | |
| | ECS Exh. Gas Temp, after Cyl #N Too High | X | | | | X |
| | Exh. Gas Temp. after Cyl’s High Deviation | X | | | | |
| | Exh. Gas Temp. after Cyl’s Very High Deviation | X | X | | | |
| | ECS Exh. Gas Temp. after Cyl's #N Too High Deviation | X | | | | X |
| Gas admission valve | GAV 1 Cyl #N Stays Open | | X | X | | X*4 |
| | GAV 2 Cyl #N Stays Open | | X | X | | X*4 |
| | GAV Feedback Position Measuring Fail | X | | | | |
| | GAV 1 Cyl #N Stays Closed | X | | | | |
| | GAV 2 Cyl #N Stays Closed | X | | | | |
| Piston Underside | Gas Detection Pre-Warning | X | | | | |
| | Gas Detection | X | | | | X |
| | Gas Detection Sensor Failure | X | | | | |
| Gas sealing | Gas Admission Valves Sealing Lub. Oil Press. Low | X | | | | X |
| Gas pressure control by the GVU*5 (if installed) | Gas fuel Pressure Low or High | X | | | | X |
| | Gas fuel Pressure Setpoint Deviation High | X | | | | X |
| | Fuel gas Rails Pressure Measurement High Difference | X | | | | X |
| | Gas Pressure Fuel or Exhaust Side Measurement Fail | X | | | | |
| SCR System (if installed) | SCR Reactor not by-passed | X | | | | X*6 |
| | SCR Communication fail | X | | | | X |

*1 Gas interlock in diesel mode

*2 If one pilot fuel injector is out of order at high load, it shows only minor or none effect. At low load possibly gas trip occurs by unstable combustion. In diesel mode a gas interlock is active.

*3 The misfiring detection by TVM is based on the speed and crank angle measurement system. Only if the speed and crank angle cannot be determined, TVM cannot function.

*4 Gas trip, gas interlock and all fuel cut-out on failed cylinder unit

*5 See the documentation of the GVU (Gas Valve Unit) supplier for other alarms and gas trips

*6 Unless a redundant monitoring of SCR exhaust valves via ESS is available

Table 5-5: Sensors and actuators connected to the iGPR system. Failure monitoring and actions during operation with gas fuel

| Engine system | Failure | Actions | | | |
|---|---|---|---|---|---|
| | | ALM*1 | SLD | SHD | GT |
| iGPR (if installed) | Gas Fuel Inlet Temperature Too Low or High | X | | | X |
| | Gas Fuel Inlet Pressure Too Low or High | X | | | X |
| | iGPR Gas Pressure between Shut-Off Valves Low or High | X | | | X |
| | Gas Fuel Pressure Low or High | X | | | X |
| | Gas Fuel Pressure Set-Point Deviation High | X | | | X |
| | Fuel Gas Rails Pressure Measurement High Difference | X | | | X |
| | Pressure Regulating Valve Actual Position Wrong | X | | | X |
| | Any Shut off Valve Wrong Position | X | | | X |
| | Any Vent Valve Wrong Position | X | | | X |
| | Annular Space Underpressure too Low | X | | | X |
| | Any Criteria of Fuel Transfer to Gas Fuel not Fulfilled, e.g. Pressure Stabilization | X | | | X |
| | LDU iGPR Fail | X | | | X |
| | MCM iGPR Fail | X | | | X |
| | AC Power Supply Fail | X | | | X |
| | DC power Supply Fail | X | | | |
| | Bus Communication #1 or #2 between ECS/ESS and iGPR Fail | X | | | |
| | Gas Fuel Temperature After Gas Filter Measurement Fail | X | | | X |
| | Gas Fuel Pressure iGPR Inlet Measurement Fail | X | | | X |
| | iGPR Gas Fuel Pressure between DBB valves Measurement Fail | X | | | X |
| | Gas Fuel Pressure After Gas Filter Measurement Fail | X | | | X |
| | Gas Fuel Pressure Fuel or Exhaust Side Measurement Fail | X | | | X |
| | Fuel Gas Pressure Regulating Valve Actual Position Measurement Fail | X | | | X |
| | Annular Space Underpressure Measurement Fail | X | | | X |
| | $N_2$ Press. Double Wall Volumeter Low | X | | | X |

*1 A summary alarm is released at AMS in case of an iGPR device and control failure. The specific information is indicated on the LDU of the iGPR and optional available on a dedicated bus for customer systems.

Table 5-6: Sensors and actuators of iCER connected to the iCER control unit. Failure monitoring and actions during operation with gas fuel

| Engine system | Failure | Actions | | | |
|---|---|---|---|---|---|
| | | ALM*1 | SLD | SHD | GT*2 |
| iCER (if installed) | Any valve wrong position | X | | | X |
| | Any criteria of fuel transfer to gas fuel with exhaust gas recirculation not fulfilled, e.g. exhaust gas temperature before TC too high | X | | | X |
| | Any MCU iCER Fail | X | | | X |
| | MCP iCER Fail | X | | | |
| | Any Power Supply Unit Fail | X | | | X |
| | | X | | | |
| | Modbus Communication #1 or #2 between AMS/DCM and iCER Fail | X | | | |
| | Exhaust gas pressure after TC | X | | | X |
| | Reduced purge seal air pressure | X | | | |
| | Scavenge air temperature after scavenge air cooler before flaps | X | | | X |

*1 A summary alarm is released at the Alarm and Monitoring System (AMS) in case of an iCER component or control failure. The specific information is indicated on the Data Collection Monitoring (DCM) system and optionally available on a dedicated bus for customer systems.

*2 Combustion Stability Mode (CSM) mode, i.e. gas operation without exhaust gas recirculation, remains available

Table 5-7: Sensors and actuators of iCER connected to AMS and DCM. Failure monitoring and actions during operation with gas fuel

| Engine system | Failure | Actions | | | |
|---|---|---|---|---|---|
| | | ALM | SLD | SHD | GT*1 |
| iCER (if installed) | Drain water level high | X | | | |
| | Exhaust gas pressure before exhaust gas back pressure control valve / exhaust gas shut off valve high | X | | | |
| | Instrument air pressure low | X | | | |
| | Reduced purge/sealing air pressure low | X | | | |
| | Differential pressure over iCER high | X | | | |
| | Differential pressure over exhaust gas back pressure valve high | X | | | |
| | Differential pressure over exhaust gas back pressure valve low | X | | | |
| | Exhaust gas temperature after back pressure control valve high | X | | | |
| | Exhaust gas temperature before exhaust gas shut off valve high | X | | | |
| | Exhaust gas inlet temperature to exhaust gas cooler high | X | | | |
| | Exhaust gas temperature after exhaust gas cooler high | X | | | |
| | Exhaust gas TC suction temperature high | X | | | |
| | If applicable: iCER RUNNING | X | | | |
| | If applicable: iCER FAILURE | X | | | |

*1 Combustion Stability Mode (CSM) mode, i.e. gas mode without exhaust gas recirculation, remains available

Table 5-8: Sensors of iCER connected to ESS. Failure monitoring and actions during operation with iCER

| Engine system | Failure | Actions | | | |
|---|---|---|---|---|---|
| | | ALM*1 | SLD | SHD | GT*1 |
| iCER (if installed) | Drain water level very high | X | | | X |
| | Exhaust gas pressure before exhaust gas back pressure control valve / exhaust gas shut off valve very high | X | | | X |
| | Instrument air pressure very low | X | | | X |
| | Reduced purge/sealing air pressure very low | X | | | X |
| | Differential pressure over iCER very high | X | | | X |
| | Differential pressure over exhaust gas back pressure valve very high | X | | | X |
| | Differential pressure over exhaust gas back pressure valve very low | X | | | X |
| | Exhaust gas temperature before exhaust gas shut off valve very high | X | | | X |
| | Exhaust gas temperature after back pressure control valve high | X | | | X |
| | Exhaust gas inlet temperature to exhaust gas cooler very high | X | | | X |
| | Exhaust gas temperature after exhaust gas cooler very high | X | | | X |
| | Exhaust gas TC suction temperature very high | X | | | X |
| | Any valve wrong position | X | | | X |
| | iCER shutdown from ESS | X | | | X |
| | iCER shutdown to ESS | X | | | X |

*1 Combustion Stability Mode (CSM) mode, i.e., gas mode without exhaust gas recirculation, remains available

# 6 References

- Natural Gas – General Safety Rules
  See drawing: DAAD077500
- Engine Control Diagram - P&ID
  e.g. X62DF/72DF for design for the GVU see drawing: DAAD062059
  X52DF for design with the iGPR see drawing: DAAD097064
  X92DF for design with the iGPR see drawing: DAAD104022
- UNIC-Flex System Description 2-Stroke Dual-Fuel
  See drawing: DAAD046405
- WiCE System Description for WinGD engines
  See drawing: DAAD090055
- Electrical Design Layout for UNIC-flex
  See drawing: DAAD043775
- Electrical Design Layout for WiCE
  See drawing: DAAD095391
- Fuel Oil System
  e.g. RT-flex50DF see drawing: DAAD041620
- Diagram Fuel Gas
  e.g. RT-flex50DF see drawing: DAAD042132
- Diagram Fuel Oil
  e.g. RT-flex50DF see drawing: DAAD042133
- Fuel Gas System
  e.g. RT-flex50DF see drawing: DAAD040606
- Exhaust Gas System
  e.g. RT-flex50DF see drawing: DAAD042162
- Operational Manual “Marine”
  e.g. RT-flex50DF see drawing: DBAD114048
- Marine Installation Manual

  e.g. RT-flex50DF see drawing: DBAB646817